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Information Thieves: Using Industrial Espionage to Examine the Development of the Information Economy

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INTRODUCTION

In Boston, as the nineteenth century began, Paul Revere was an established silversmith, iron-caster, cannon-maker, and mildly disgraced Revolutionary War veteran.[1] His midnight ride of April 19th, 1775 was almost unknown, and the Henry Wadsworth Longfellow poem that propelled him into historical stardom, would not be written for another 60 years.[2] In his time, Revere was far better known for his metallurgical accomplishments than he was for his wartime activities. He had cast the first bell ever produced in Boston in 1792,[3] and was likely the only American capable of producing malleable copper bolts for use in ship-building.[4] He had supplied the bolts that were used in the construction of the USS *Constitution*,[5] and he was frequently contracted by the Navy Department to supply bolts and other metal products for new ships.

In 1801, Revere had just developed the technology of rolling sheet copper, which was used to sheathe the bottoms of ships.[6] The technology however, was not perfect, and he needed help to improve the quality of his products to compete with British imports. To accomplish this, Revere sent his son and business partner, Joseph Warren Revere, on a trip to Britain and Europe to function as one of America's earliest industrial spies. Joseph Warren went overseas with a very specific objective—to obtain information related to rolling sheet copper—but he was also a keen observer of a wide variety of British industrial practices. He carefully documented what he saw, and returned to America with a vast amount of information on sheet copper, water wheels and gear mechanisms, factory organization, and the state of British industry.

The world of industrial espionage provides a useful medium for examining the way information and knowledge are treated. Prior to the nineteenth century, the main method of industrial espionage was to seduce workers to defect and set up works in a new country.[7] The French government used this method extensively in both the eighteenth and nineteenth centuries to try to close the metallurgical technology gap between French and British manufacturers.[8] A variation on this technique was used by

Russian industrialists as well. These Russian industrialists planted young apprentices in England, who would return to Russia once they had learned their trade.[9] Both of these methods target knowledge, that is, information that is contained within a person's body. Joseph Warren, however, went to Britain to observe and document things in his journal—to return with written information.

This difference between knowledge and information is extremely important. While there is considerable overlap between these two terms when used colloquially, for the purposes of this paper they represent two distinct concepts. Knowledge refers to skills, techniques, and facts that a person has developed or acquired through his or her personal experience and training. Importantly, knowledge resides within the person who has acquired it, and nowhere else. It can be transferred from person to person, and many systems have been developed to facilitate this process, such as the apprenticeship system under which Paul Revere and his son were trained.

Information, contrarily, is what is produced when a person's knowledge is translated into a medium which resides outside of a body. In modern times this translation most often occurs with digitization of knowledge into information that can be accessed and transferred via computer networks.[10] While in Revere's time the technology of information was different, the concepts were the same. Knowledge could be turned into information through the process of writing, and it could then be reproduced and spread quickly and easily, in much the same manner as computer technology does today.

In an information economy, such as exists today,[11] information moves in a variety of ways that are not constrained by traditional barriers such as national borders, physical barriers, or geographic obstacles. Information thus moves easily between people, organizations, governments, and companies. In the twenty first century this movement mainly takes place via the internet, which is almost completely unaffected by the previously mentioned barriers. However this movement also took place in the early nineteenth century; letters, books, technical drawings, and other information travelled the globe, albeit at a slower speed than the internet allows. Once information arrives in a new location, it can transfer itself into new people without any effort or input from the person who originally created that information.

Vital to this model is the idea that information exists as its own entity, it is not merely resident in the minds of people. In the twenty first century this is easy to envision, as people are surrounded by information stored in computers on a daily basis. However, in the nineteenth century information was primarily viewed as residing within people—making it a type of knowledge. As a result, physical and political boundaries could restrict the flow of people, and therefore also the flow of knowledge. This restriction is what led to the dependence on seducing workers to acquire the information that operated inside of them. However, once information has been created from a person's knowledge, its existence is no longer linked to a specific person; it can move much more freely. This concept is what made Joseph Warren's espionage trip successful, and also why his trip is so important.

This paper will argue that Joseph Warren Revere's espionage trip to Europe represents a turning point in the way information used and in the way it moved about the world. This turning point also marks the beginning of the development of the information economy that encircles the modern world. This is in contrast to a traditional interpretation of the information economy (some sources refer to it as the information age), which is held to have developed much later than 1800. Hedieh Nashieri, for example, puts the first moves towards an information economy in the post-World War Two era, with the real changes coming in the 1980s and 1990s.[12] However as this paper will show, the origins of today's information economy can be traced much further back than is conventionally done.

There are several pre-requisites to information moving in this way. To begin with, there must be valuable information to move, and this means that there must be a number of knowledge based goods which lend themselves to the translation of knowledge into information. This information then becomes important as a separate entity from knowledge and, as a result, it becomes an item to be desired in its own right. This shift in value in turn leads to new forms of espionage aimed at securing industrial information, as opposed to knowledge. Since these forms of espionage are derived specifically from the properties of information's free movement, they strongly resemble modern industrial espionage, though with different technologies used to facilitate the information transfer.

This argument will be developed in three main parts, each of which will demonstrate that the characteristics mentioned above were present in the nineteenth century. First, we will see that many aspects of nineteenth century ship-building technologies could be represented as information (rather than as knowledge). This point is important, since without the existence of valuable information the information economy could not exist. The second section will demonstrate that the form of industrial espionage that occurred *prior* to Joseph Warren's trip operated within a knowledge, rather than information, economy—according to the assumption that knowledge was resident within people's bodies. Joseph Warren's strategies, in other words, were quite different from those used by his predecessors. Indeed, this section will also show a clear break between the earlier methods (principally those used by French industrialists), and the new techniques demonstrated by Joseph Warren. Finally, Joseph Warren's form of industrial espionage will be compared to modern espionage attempts. The similarity between the two forms will show that the methods by which information moved in the nineteenth century reflected the methods of today. This section will also demonstrate how the tactics Joseph Warren employed were used by the nineteenth century industrial spies who followed him. We will see, that Joseph Warren's trip represents a broad based turning point and not an isolated incident.

Industrial espionage has been discussed extensively, but most of this discussion deals with the last 100 years of history. The sources that do describe industrial espionage in the early nineteenth century usually focus on the textile industry, and not on areas such as naval technology or metallurgy. John R. Harris, an author who has written prolifically on both naval technology and metallurgy, advances several reasons for this narrow focus. One of these reasons is the lack of primary sources dealing with naval technology and metallurgy; a second is the inaccessibility of the sources that do exist.[13] And that is indeed the case: since much of the espionage prior to the nineteenth century relied on the movement of people rather than on written information, it can be difficult to find records of these movements.

Nonetheless, the conclusion that Harris draws as a result of this lack of technical writing, especially in several of his shorter essays, is at odds with the thesis of this paper. Once again, Harris argues that the British produced little technical writing, and therefore little information, because it was not an effective method of technology transfer.[14] Many artisans and craftsmen certainly disparaged the use of written sources to aid them in their craft,[15] and Harris continues that their lack of interest in written transfer methods meant that those methods were ineffective. Moreover, as will be discussed in the next section, this argument does apply to certain techniques and procedures; for example puddling[16] was a process that required great skill and physical technique, and was historically very difficult to transfer except by apprenticeship.[17] But, this paper will also demonstrate that as a blanket statement, Harris' argument is inadequate. While many artisans may have believed that written information was useless to them, Joseph Warren's trip (and the trips that followed his) indicate that written documents could be very useful to skilled craftsmen.

Perhaps more important, those skilled craftsmen were vitally important to the fledgling American economy, as well as to America's national security. Ironically, in the early years of the republic the American ship building industry was almost entirely reliant on the British for finished metal products with which to assemble their ships.[18] The Secretary of the Navy, Benjamin Stoddert, was keenly aware of this weakness and was eager to support Americans who could provide him with the products he had previously been forced to purchase from the British.[19] Paul Revere was one such craftsman, and though he could provide only a few pieces required for the construction of a ship, what he could provide was vital.

Chapter I – Naval Technology and Information

The discussion of naval technology in this chapter does not merely serve to set the background for Joseph Warren's activities. Rather, this chapter will show that many of the technologies that concerned Joseph Warren were knowledge goods, products where a large portion of the production cost is taken up by acquiring the knowledge of how to produce them. Furthermore, some of these goods consisted of knowledge that could be translated into information, which could then circulate freely. The presence of knowledge goods that can be turned into information is required for an information economy to exist; there must be something worth exchanging for any transfer of information to take place.

Naval ships of the eighteenth and nineteenth centuries were some of the most technologically advanced products of their time. Requiring years of effort by hundreds, if not thousands of workers, ships represented a massive investment of time, money, resources, and knowledge. Naval vessels were one of the primary ways nations displayed their technological prowess and intimidated their rivals. They also played a vital role in protecting shipping and global trade, both from hostile nations and from pirates. Ships were at the cutting edge of technology, the production of their various components was technologically challenging and extremely complex.

The *USS Constitution* provides a great example of this expenditure and complexity. When the *Constitution*, along with five other frigates, was authorized in 1794, the Federal Government secured $688,888.32 to cover the costs of construction. Only three of the frigates were ever completed, and in the end the total cost of all three was greater than 1.16 million dollars. For comparison, the entire Federal budget in 1794 was less than 7 million dollars. The construction process took over three years, and involved skilled craftsmen from throughout the new republic. Paul Revere himself was responsible for the copper bolts in the ship's hull, as well as her bell. Masts, anchors, bilge pumps, sails, ropes, cannon, rudders, and many other products were needed before the *Constitution* was launched on the

20th of September, 1797. Producing these ships was one of the most technically complex and resource intensive tasks America had ever completed.[20]

There are far too many examples of the technological features of ships of this period to cover them all in this essay. Nonetheless, it is worthwhile to address a few representative technologies—such as the manufacture of copper sheathing and the process of making bolts and spikes out of copper—in some depth. The production of cannon was also one which required a great deal of technical skill. However, not all of the knowledge required to produce these products could be treated as information. Some of the skills and techniques could not be transformed into information through the process of writing. A significant portion however, could be turned into information, and once converted, could circulate throughout the early nineteenth century world of metal-working in a way that is characteristic of information economies.

Copper Sheathing

What to put on the bottom of ships is an issue that does not get a lot of attention outside naval circles, but it was a crucially important issue for navies and private merchants in the eighteenth century. The wooden hulls of ships could be infested by the living creatures that inhabit the oceans, slowing the ships down with their bulk, and compromising the integrity of hulls by boring into the wood.[21] To combat this damage, some type of sheathing material was generally affixed to the outside of hulls below the waterline; it was designed to be removed when it became too infested and replaced with fresh sheathing. Many materials had been tried over the course of seafaring history, but by the late eighteenth century it was generally agreed that copper was the best choice.[22] Producing large sheets of copper, however, required skilled artisans using advanced technological equipment. Copper sheathing also led to a problem known as galvanic action,[23] which required additional technological innovation to resolve.

Before copper was used, a wide range of materials had been used to sheath the hulls of ships, with varying degrees of success. Engineers in ancient civilizations such as Rome had used thin sheets of lead to protect their ships from fouling,[24] and a fourth-century B.C.E. ship discovered in the Mediterranean was protected in a similar manner.[25] Lead was once again tried by the British Navy in the seventeenth century, when a new process of rolling sheets of lead was developed.[26] However, this method fell rapidly out of favor because lead had a detrimental effect on the iron fastenings used in the ships;[27] it corroded them through galvanic action just as copper would 100 years later.[28] By the eighteenth century, most European ships were using disposable sheathing made of thin sheets of wood, which was meant to be stripped off and replaced once it had become either too weak or too parasite-infested.[29] This method was cheap and easy, but ships still suffered in speed and maneuverability when the sheathing planks were filled with barnacles, worms, and plant life.

Copper's exact date of entry into the scene of naval sheathing is not clear. Michael McCarthy notes that the Chinese may have been using it as early as the seventeenth century,[30] whereas the earliest date Harris mentions is 1708, when an entrepreneur approached the Royal Navy with an idea for sheathing ships in copper.[31] What every source agrees on is that in 1761 (approximately) the frigate *Alarm* was sheathed with sheet copper.[32] It proved to be a resounding success. Copper provided for faster sailing, more maneuverability, and a near complete protection from the worms and parasites that threatened to cause leaks and decrease the hull's integrity.

Coppering proved so popular that many commanders viewed it as a necessity. Harris quotes one captain as saying, "to bring the enemy to action copper bottomed ships are absolutely necessary."[33] Perhaps the most telling example of copper's success was its speed of adoption by the Royal Navy. One expert estimated that only twenty years after the *Alarm* was coppered, in 1781, the entire Royal Navy had been coppered.[34] Coppering a ship was not cheap,[35] and for every ship to have been coppered within twenty years represented a significant outlay of financial resources. It is unlikely the British treasury would have funded such a project if coppering had not been a great success.

Creating the copper sheets used for sheathing was no easy task. First, the copper ore had to be smelted, heated and treated in such a way as to extract pure copper from the raw ore. This was more difficult than it sounds, and Robert Martello remarks that, "compared to smelting, all other copper fabrication processes seemed simple."[36] Once the copper was purified, it was cast into bar molds, which were then heated and run through large[37] iron rollers repeatedly. The distance between the rollers was adjustable in some fashion, either manually or by the use of a screw, and by making the gap smaller and smaller, sheets of virtually any thickness could be produced.[38] Unlike the bolts and spikes discussed in the next section, however, there was no need to anneal[39] the metal since sheathing did not require a high degree of ductility. There were many other details about which a manufacturer had to be concerned such as the condition of his rollers, cleanliness of the copper sheets, by what method and to what temperature the sheets were heated, and how the sheets should move through the rollers. The amount of knowledge required to make this one particular part of a ship, therefore, was immense.

The sheathing of ships hulls in copper was just one step in a lengthy technological chain stretching back far into history. People had been developing new ways of keeping hulls clean for as long as there had been ships. Most of these methods were fairly simple – they generally involved coating the hull in some type of replaceable substance, whether it was wood, tar, hair, or a combination of all three. There was not a lot of technical knowledge required to apply these types of protection. Rolled sheets of copper, however, required a much higher level of technology than previous methods, and a significant amount of knowledge was required to produce those sheets.

Revere and his son obtained this knowledge in a variety of ways, one of which was to send Joseph Warren to Europe to try and steal the knowledge itself. But unlike the French travelers, Joseph Warren did not try to abduct workmen. Instead he translated the knowledge he acquired into writing and took it back across the Atlantic without the British ever knowing they had been robbed. The Reveres' actions show that the knowledge of how to produce sheet copper was more important than having access to all the tools and resources, something that is a key aspect of a knowledge economy.

Bolts & Spikes

Bolts and spikes were both important components of ships; they held the hull together and prevented the ship from breaking apart. After the advent of copper sheathing, new materials needed to be found for these components because the iron bolts and spikes were being corroded by galvanic action. Corrosion made the ships much more likely to sink or break apart in foul weather. By making the bolts out of copper, the issue of galvanic action could be resolved. But it was difficult to produce fastenings that were not either too soft or too brittle, and that had the strength required to hold ships together. A complex process of rolling, heating, and cutting was eventually developed that allowed vessels to enjoy the benefits of copper sheathing without worrying about the integrity of their hulls. Just as with the process of creating sheet copper, huge amounts of knowledge were required to produce these simple items. Possessing the physical manufacturing equipment was not sufficient.

Galvanic action has been mentioned previously, but has not yet been fully explained. The exact chemical process of the corrosion is not important to a historical study of the effects of galvanic action, but a basic understanding of the mechanism is helpful. Galvanic action[40] is a type of electrochemical corrosion that can take place when two metals with different electron potentials are immersed in a conducting electrolyte solution[41] (such as seawater). One of the metals, the anode, breaks down and leeches into the solution, while the cathode remains unharmed.[42] In the case of copper sheathing, the copper was the cathode, and the iron bolts that held the hull together were the anodes and therefore the part of the ship that was weakened by corrosion.[43] This was a serious problem, as corroded iron fastenings led to the sinking of a significant number of ships in the years immediately after coppering became widespread.[44]

Moreover, the historical context within which these processes were developed leant an additional urgency to technological advancement. Britain had just emerged from the Seven Years War, and found itself only 12 years later fighting the American War of Independence.[45] While the Americans had little naval power of their own,[46] after the Battle of Saratoga in 1777, the French entered the war and Britain needed all the sea-power it could muster. The advantages of coppering were significant: ships could stay at sea for much longer because their hulls did not need to be scraped clean,[47] ships were faster, and they were more maneuverable.[48] These advantages so impressed British officials of the time that the Controller of the Navy, Sir Charles Middleton, argued that coppering the entire fleet would effectively double its fighting power.[49] This attitude created a strong incentive to find a solution, especially, to the problem of galvanic corrosion.

Engineers developed many methods to try to counteract the problem, with minimal success. At first, the problem was simply ignored, since the benefits to speed and maneuverability were so significant. Warships were coppered and then inspected at regular intervals, and any iron bolts that were too corroded were driven out and replaced by new ones.[50] A wide variety of coatings, coverings, and barriers between the copper and iron parts were also tried,[51] but without great success. Paper was even used to coat the hulls before applying the copper sheathing, but it proved no more effective than any of the other methods.[52] Several high-profile sinkings[53] near the end of the Revolutionary War in which hundreds of sailors lost their lives, however, highlighted the need for a more effective solution to the problem.

Since the problem arose from using two incompatible metals, naval engineers tried a variety of other types of bolts. "Mixed metal" was the term used to refer to these new types of fastenings, and this term encompassed a large variety of different alloys. The main component of mixed metals tended to be copper, with any combination of zinc, tin, lead, and iron[54] mixed in to increase the bolt's strength and malleability. However, through tests on various ships, it became clear that mixed metal suffered from a number of flaws; it was either too brittle or not malleable enough to be used in shipbuilding.[55] Mixed metal was dealt its final blow in November of 1783,[56] when the technology to produce bolts of pure copper with the right strength, ductility, and malleability was perfected.

Pure copper was the ideal metal to combat the problem of galvanic action, since the sheathing was also made from pure copper. The difficulty came in getting copper, which is naturally a soft metal, to be hard enough to resist deformation, while retaining its strength and ductility. Hardness was required when bolts and spikes were being hammered into ships during the construction process, whereas strength and ductility were needed to hold ships together under the strains that were a normal part of sailing.[57] A workable, if difficult, process was developed in England in 1783.[58] More importantly, this process required a great deal of metallurgical knowledge to perform successfully. The basic procedure was to cast copper into bars, which were then passed through a succession of grooved rollers, which in turn gradually elongated and thinned the copper into the correct size.[59] Another option was to "draw" rather than roll the copper bars through successively smaller drawplates until it was the correct size.[60] Both of these methods are classified as cold-working, i.e. working the metal at room temperature. According to Martello, "cold-working increases the amount of defects and strain within the metal, making it more brittle and less tough."[61] As noted above, however, the bolts used in ship construction could not be brittle and had to be extremely tough. Cold-working copper alone was not sufficient.

To resolve the issues introduced by cold-working the metal, some amount of annealing was necessary, though different producers annealed the metal at different points in the process. Annealing is a technique where the metal is heated to a certain point (without melting it), and then cooled back down. This process "rearrange[s] its atoms into a more perfect structure with fewer defects."[62] Of course eighteenth century workmen did not understand the process on the atomic level, they simply knew that by performing this procedure the metal would be made less brittle, and it would regain some of its former strength and ductility.

Annealing, however, was not as easy as throwing the bolts in the fire for a while and then pulling them out. Too little heat, or the correct amount of heat for too short a time, fails to remove the defects from the material, and the metal is just as brittle as before.[63] Likewise, too much heat, or too much time of the right heat will weaken the metal, making it soft and useless for ship construction.[64] Finding the right balance of heat and time required a great deal of metalworking knowledge as well as practical experience. Revere was fortunate in that he possessed knowledge of similar procedures (making silver wire utilizes a similar drawing process),[65] and in that he had gained extensive experience with the procedure when he was contracted to resize copper bolts (made in Britain) for the construction of the *USS Constitution* in 1795.[66]

As with copper sheathing, the idea of making fastenings out of copper did not arise in a vacuum. It represented the latest link in a long chain of technological innovation that began with the desire to solve the serious problem of galvanic action. Just as with copper sheathing, all the physical requirements for this new technology already existed. The difficulty was in acquiring the knowledge of how to use current equipment to produce metals with the right characteristics. The British industrialists likely did this by adapting the procedures they had for producing iron bolts,[67] whereas Revere likely[68] adapted his knowledge of silver-working into a procedure for making copper fastenings.[69] Each step in the production process, from the smelting process, to the casting, then the rolling or drawing, and finally the annealing, required a vast amount of knowledge. While the physical goods were relatively inexpensive, the knowledge of how to create them was expensive.

Cannon

Fighting ships had to be armed, and the weapon of choice in the eighteenth century was the cannon. Like other ship components, cannon required a great deal of knowledge and expertise to produce. Having access to the required tools and materials was not enough. Just as with copper bolts or sheathing, the correct procedures needed to be followed to ensure the quality of the final product. The knowledge and skill of the craftsman played a large role from the beginning phases of creating the mold and casting the metal, through to drilling out the bore and proving[70] the cannon. With cannon however, the stakes were higher. An improperly cast piece could crack or rupture during battle. In the best case this meant that a captain now had fewer guns to fight with, but in the worst case it could put a hole in his ship's hull and threaten the entire vessel. Multiple bolts had to fail before a ship would be put in danger, but if a single cannon ruptured it could quickly endanger the ship. The knowledge required to cast high-quality cannon was therefore highly prized in the early republic.[71]

Bronze was the metal most commonly used for casting cannon in Revere's time, due to its low melting point (which made it easier to cast), and its high elasticity (which made it less likely to explode catastrophically if overstressed).[72] The exact proportions of bronze's components—mainly copper with smaller amounts of tin, zinc, and lead—was important in determining the exact characteristics of the final metal. The knowledge of exactly which metals to include and in what ratios was one of the most important factors in determining the final quality of a cannon. The craftsman created a clay mold,[73] which shaped the outside, breech, and interior bore of the cannon, and then placed the mold in a pit, often held in place by iron bars.[74]

Once the mold was in place the metal was melted, mixed, and poured into the mold. The quality of the mold was an important factor in how the cannon would turn out. It was difficult to make a mold where the plug which created the bore would remain perfectly centered while being surrounded with molten metal.[75] An irregular or off-center bore could cause uneven pressure during proving, which could lead to a rupture or explosion.[76] Since this was an issue even for skilled and knowledgeable cannon makers, alternatives were sought, and by the 1750s an alternative method had been found. The cannon was cast as a single solid piece, and then the bore was drilled out using a water powered drill with a hardened-iron bit.[77] This technique solved the problem of irregular and off-center bores, but it added to the knowledge required to produce cannon. Instead of needing only to know about the metallurgical processes of casting metals and making molds, a cannon-maker now had to understand how to integrate water powered apparatus into his workshop, or he would have to subcontract the boring process out to another craftsman.

Once the cannon was cast, bored, and ready to be sent to its new owners, it had to be proved. According to Martello, "proving typically involved discharging a cannon under unusually rigorous conditions, for example, by using triple the normal quantity of gunpowder, discharging the cannonball into the ground, or somehow plugging the barrel."[78] This process was designed to ensure that the cannon did not rupture or explode under battlefield conditions. Many of Revere's cannon were destined for use in land battles, where the consequences, while still severe, were not critical. Cannon that were placed on naval ships could wreak far more havoc if they failed. An exploding cannon could touch off powder reserves, kill many seamen in the cramped quarters that existed on fighting vessels, or simply create a huge hole in the side of ship. The devastating nature of these results explains the high standards of the proving process.

Cannon frequently failed the rigors of proving,[79] and the proving process serves to highlight the large amount of knowledge and skill that was required to produce cannon. Successful casting of cannon relied almost entirely on the craftsman's knowledge of metal composition, mold-making, and the complex boring process. Lack of skill or knowledge in any one of these areas would produce a cannon that was unlikely to meet the rigorous standards required by the state militias and the federal government. Just as with copper bolts or sheathing, having the physical materials necessary was no guarantee of success. The most important resource when producing cannon in the eighteenth century was not bronze or clay, it was the knowledge of the intricate and complex process of cannon casting.

Information Goods

As these few examples have shown, ships of the early nineteenth century incorporated many highly technological items. They required not just physical resources to build, but a great deal of technical knowledge as well. For these goods, acquiring the knowledge needed to construct them was the most difficult and costly phase of construction. However, once the knowledge was available, reproducing the goods was relatively cheap and easy. This is a type of product that is known to economists as a knowledge good,[80] and such goods are traditionally associated with a modern, high-tech economy.[81] As Smith argues, however, associating knowledge goods solely with modernity and new technology is misleading, as the products that Revere was striving to produce in his workshop could be considered knowledge-based goods as well.

There is no firm dividing line at which point a product becomes a knowledge good as opposed to a normal good. There are goods which require almost no knowledge to produce, and there are goods that are made up entirely of information, but all goods exist somewhere within this spectrum. Stan Liebowitz writes that, "in reality, all goods are knowledge based. But for goods that are at the leading edge of technology, the cost of the knowledge is usually a more important part of the cost of production."[82]

For Revere, the cost of acquiring the knowledge of how to draw bolts, or roll sheets of copper was the most important factor. He already had, or could acquire relatively easily the equipment necessary, and he had been using copper and copper alloys for years in his bell making endeavors.[83] Unfortunately, this type of expense is difficult to quantify, and thus it is difficult to prove that Revere's quest for the knowledge of how to draw copper bolts was the most expensive aspect of bolt production. However, Revere's writing leaves some clues to the difficulty. In a 1794 letter, for example, Paul Revere writes that to learn the secret of drawing bolts took "a great many tryals and very considerable expense."[84] Clearly Revere himself felt that knowledge made up a large portion of the cost of producing these types of goods.

Another feature of knowledge-based goods is that while they are costly to develop, they are very cheap to reproduce once the technology has been acquired.[85] This is because once a technology has been invented, it does not need to be reinvented every time it is used. Economists thus argue that knowledge-based goods have high fixed costs, but low marginal costs.[86] Clearly, from Revere's quote in the previous paragraph, developing and producing his first copper bolts must have taken a large amount of time and resources. Unfortunately Revere did not leave any more details than the quote above, so it is impossible to compare directly his expenses in developing malleable copper to the price he eventually charged for it. However, his records show that in the summer of 1798, three years after he had developed the technology to produce malleable copper bolts, he charged 41 cents per pound of bolts, and 37 cents per pound for cast copper products.[87] This small difference in price, which is likely due to the increased amount of labor required to produce malleable copper, shows how once Revere had developed the process, he was able to reproduce malleable copper just as cheaply as any of his other copper products.

The fact that these goods were based on knowledge did not necessarily mean, however, that that this knowledge could be turned into information. Many of the skills needed to produce these goods t could not be translated easily into written form, and without this conversion, they could not be treated as information. Cannon casting for example, was replete with knowledge that could not be articulated in the written word, and as a result, it could not be turned into information. The boring process was extremely difficult, tedious, and required supreme attention to detail as well as a fine eye for keeping the bore centered.[88] However this skill, could not be translated entirely into writing. No matter how much a craftsman had learned about the process and techniques of keeping the bore centered, he would still need to practice the physical skills required to do so. The written information would be insufficient to transfer the skill.

However, some of these skills were ready to be translated into information, which could then flow and circulate much more freely than could knowledge locked up within a person. Both the production of copper sheathing and the production of copper bolts had many aspects which could be translated into information. In his earlier attempts to master the process, Paul Revere had many difficulties with his copper sheathing becoming pitted during the production process. However, as Joseph Warren discovered in Britain, cleaning copper sheets with urine or lye kept the sheets clean during the rolling process, which eliminated the pitting problem.[89] Information such as this would be the focus of Joseph Warren's search when he arrived in Britain.

Conclusion

Technical knowledge was everywhere in the nineteenth century world of naval technology. Great skill was needed to produce even the smallest naval ships, and the larger ships such as frigates or ships of the line required the cooperation of countless skilled craftsmen. Every one of those craftsmen possessed a great deal of knowledge related to the components they produced, and because of that they were valuable. Spies had known this for years, and most efforts at industrial espionage targeted the craftsmen themselves, as repositories of knowledge. Craftsmen were lured with money and other promises and, once removed from their native land, they could transfer their knowledge, via traditional methods such as the apprenticeship model, to the nation that had suborned them.[90]

This type of espionage had been occurring between Britain and France for more than 100 years,[91] and it had left its mark on the British legal landscape. British law dealt harshly with those who attempted to entice artisans, in certain industries, away from the British Isles, and there were also laws restricting the export of certain types of machines.[92] However what the Reveres realized, was that removing the actual craftsman was not always necessary. Indeed, for many skills, the knowledge inside a craftsman's head was all that was required. By turning that knowledge into information, through the action of writing, the Reveres used a fundamentally different type of espionage for their economic benefit.

The Reveres were shrewd businessmen, and by the turn of the century they had already developed, on their own, the technology to produce copper bolts of high quality.[93] However, they also knew how difficult and expensive this approach was. They wanted to find a way to reduce the cost of developing the technology needed to produce high quality[94] sheet copper, since developing that technology independently would be both time consuming and costly. Stealing technical information from Britain would prove much cheaper. It was also safer. British protections at the time were aimed at safeguarding knowledge that was bound up in people's bodies, and British law was thus unable to regulate the flow of information. Once again, existing legal protections were unprepared for the Reveres' tactics, which targeted information itself. It is for this reason that Joseph Warren Revere found himself bound for England in 1801 with nothing more than his experience and a journal. His goal was to steal some of the most valuable military secrets or the age from one of the most powerful empires on earth.

CHAPTER II – Industrial Espionage and Joseph Warren's Trip

When Joseph Warren arrived in Britain, he was entering a nation that aggressively defended its industrial secrets. Over the previous century, British engineers had developed a significant lead in many areas of industry, and the governments and militaries of competing nations wanted to close that gap. Governments all across Europe used a variety of methods to try and acquire British technology, some legal, some not. Espionage was a method that had been in use throughout Europe for a long time, and Britain had become the most recent target of many countries' spies. As a result, Britain had enacted laws and other countermeasures that were designed to inhibit the main method of industrial espionage prior to 1800, the suborning of British workers.

This chapter will lay out the methods of espionage that were in use prior to Joseph Warren's trip, using several attempts by the French government and private citizens as a case study. These methods are contrasted with the innovative way Joseph Warren treated information, and the new type of espionage that his trip pioneered. Joseph Warren's method was dependent on the ability to translate industrial knowledge into written information, something that had previously been regarded as useless in the transfer of technology. Translating knowledge into information was extremely difficult, and comprehending the process and its limitations is an important part in understanding the history of industrial espionage in Britain.

Benefits of Writing in Information Transfer

Joseph Warren's ability to turn what he saw of British manufacturing processes into detailed written descriptions and drawings was critical to the success of his trip. What writing does to technical skills such as the rolling of copper sheets, for example, is translate the knowledge contained within those craftsmen into a different form: information. This new form is easily portable and nearly infinitely reproducible, even with the technology of the early 1800s. This portability and reproducibility allows the rapid spreading and dissemination of a technology or technique that has been abstracted into the written word. Furthermore, since British anti-espionage laws at the time were concerned with the export of knowledge, which was contained within the bodies of workers,[95] there was little stopping Joseph Warren from acquiring the information he was searching for.

The use of the word "translate" in the previous paragraph is intentional; the language of physical skill and the language of the written word are quite different. The process of converting one into the other is difficult and time consuming, much more difficult than simply transcribing something from one source to another. The translator may either observe or take part in the process, but he or she must understand the process at least on a basic level to be able to translate accurately. Joseph Warren may not have understood the reasons behind everything that he witnessed in Europe, but he was intimately familiar with metallurgical processes and the organization of his family's copper-works.[96] With this base of knowledge, he was able, as a translator, to take a skill or technique in the physical world and abstract it into written information—information which could then transfer itself to another individual.

This abstracted skill has now been turned from knowledge, resident in a person, into information. The writing is both portable and capable of being sent around the world given the technology of the time. Furthermore, a person need not physically carry the information within him or herself, which in turn meant that vast amounts of information could be moved without large numbers of people having to carry it. This scenario differs significantly from that envisioned by the French government as it attempted to seduce British workers in the eighteenth century.[97]

Indeed, in addition to its portability, this abstracted knowledge was reproducible. While there was nothing like a photocopier, the text could be given to a printer who could make as many copies as were needed. The drawings and illustrations could be made into engravings, which could then be printed in much the same way. The combination of writing's portability and reproducibility, in short, meant that information could spread at unprecedented speeds.

Britain's laws were unprepared for Joseph Warren's type of infiltration and exportation of their knowledge. A law from 1719 provides an example of where Britain's anti-espionage activities were focused. The law prevented the enticement of skilled workers from Britain, and it assessed a fine on both enticers and the worker they were attempting to suborn.[98] This law was designed to limit the flow of knowledge out of the country, but implicit in the law's wording is the fact that knowledge was deemed to reside within the workers—that it could not be transferred into a different medium. There was no recognition in the text that knowledge inside of workers might be extracted and translated into useful information and, as a result, there was no clause that limited the exportation of drawings or written descriptions of manufacturing processes (though a later law did outlaw the exporting of some tools and other equipment).[99] British lawmakers, it seems, did not view people writing or drawing descriptions of their industries as a threat, because it was assumed that knowledge could reside only within the skilled workers themselves.

The benefits of transferring knowledge using writing and espionage must have been appealing to Paul Revere for these reasons. Revere had access to a skilled interpreter of metallurgical processes, his son, who would be able to write down and draw diagrams that would be useful in producing higher quality goods. The writing itself was relatively easy and cheap to obtain, and once he had possession of it he could share or disseminate it if he chose to. Finally it was a low-risk proposition for him and his son as well. British officials were not on the lookout for someone writing about their metal-works. As long as Joseph Warren was not too obvious, and as long as he played the part of the curious traveler, there was little risk that he would be discovered.

Previous Espionage Techniques in the Absence of Information

Espionage was a strategy that had been in use for a long time, and European nations were accustomed to using espionage when other methods of acquiring new technology, such as developing it independently or purchasing it, were not an option. The French government in particular, due to its enmity and rivalry with Britain, was particularly aggressive in its espionage activities.[100] However, the techniques and objectives of industrial espionage before the turn of the nineteenth century were different from those employed by Joseph Warren during his trip. Instead of seeking information, as Joseph Warren did, espionage activities in the eighteenth century were focused almost entirely on one thing: the enticement of skilled workers and craftsmen away from Britain.[101] Drawings, sketches, and written information were almost entirely ignored in this process.

Indeed, the seduction of craftsmen seemed to many governments to be by far the most effective way to acquire a new technology.[102] The French government, for example, was aware of the concept of sending observers to Britain who could bring back written documents—especially when spies were unable to entice any workers .[103] But the main objective of French policy nonetheless remained the enticement of skilled craftsmen. When spies brought back written information, it was almost universally dismissed as being useless,[104] And, as Trudaine de Montigny, a future Director of the Bureau of Commerce in France, wrote in 1752 "the arts never pass by writing from one country to another, eye and practice can alone train men in these activities."[105]

Several other examples can also show the predominant attitude motivating this pre-1800 era industrial espionage. John Holker, for instance, was an Englishman who was recruited in 1755 by Trudaine de Montigny to bring British textile methods to France. The majority of his efforts were focused on bringing British workers to France, and he developed an extensive smuggling system which could bring men and materials safely across French borders. His system was highly developed; he targeted specific groups of workers, such as Catholics or unmarried workers, whom he thought would be able to integrate into French society more easily. He also used ships that were destined for Holland first, since they were inspected less rigorously than those bound for France, and he employed multiple middle men both to distribute the danger and, through competition, to keep the costs of smuggling down. Holker's elaborate system is impressive, but the measures he was forced to take also illustrate a common problem with the recruitment of workers: it was incredibly dangerous, and getting workers to produce goods efficiently in France was often difficult.[106]

Michael Alcock and his wife ran into similar issues recruiting workers in the 1750s and 1760s. Alcock was also an Englishman, though unlike Holker he ended up in France due to a personal entanglement, and was not directly involved with the French government. Mrs. Alcock was the one who made the majority of the recruiting trips to Birmingham, while her husband coordinated their integration and production in France. The Alcocks' story shows the danger and risk involved in acquiring new workers from Britain. The two of them lived in constant fear of discovery. Michael Alcock once had a servant girl who had wandered off arrested while his wife was in Britain for fear that she would have betrayed Mrs. Alcock to British representatives in France. These fears were not at all unfounded, Mrs. Alcock was eventually betrayed by one of the workers she was trying to recruit and was jailed for several months, though she was eventually released due to a lack of evidence.[107]

In the 1760's Michael Alcock left his original production center at La Charité and set up a new facility at Roanne. In doing so, he assumed that everything would continue to function smoothly at his original facility, but that was not the case. Soon after his departure, workers developed a problem with an English gilding technique that they had been using. Though Alcock had left a detailed description of the technique behind, there was no attempt to make any use of it to resolve the issue. Instead, someone was sent to England to attempt either to learn the technique for themselves, or to bring back a worker who was familiar with it. Considering the danger and risk that were inherent in this trip, it seems shocking that not a single attempt was made to use the written account to solve the production problem. Implicit in the way this situation was handled is the innate dismissiveness towards written information that was typical among workmen and factory managers of the time. [108]

The countermeasures used by the British manufacturers and government officials also demonstrate their areas of highest concern. These countermeasures were designed to keep workers on

British soil and to prevent interaction between knowledgeable craftsmen and foreigners who might entice them to leave the country. High walls were commonly employed around factories, and though foreign visitors were often allowed access, they were not given unsupervised contact with workers.[109] Some production facilities were simply off limits, such as a sulfuric acid center at Prestonpas (171). The division of labor that was common in British factories also presented a problem; one French spy wrote that, "there is no country where labor is so divided as here… where the whole of trade is so difficult to seize hold of."[110] To transfer technology effectively, governments either needed to transfer multiple workers, which increased the risk, or a knowledgeable person such as a foreman.

Several counter-espionage techniques that seem almost ludicrous appeared actually to have been effective. One French nobleman, attempting to get details on sulfuric acid production, was stymied when the entire plant was staffed only by women from Wales, who spoke nothing but Welsh.[111] Welsh, a regional language with hardly any speakers outside of Wales, was unlikely to have been intelligible to any foreign spy. In another case, several English workers were already being employed in France when a British diplomat discovered them. The diplomat's secretary exploited the workers' weakness for alcohol, and while the workmen were drunk, the diplomat put pressure on the French government to return them. This tactic was effective, and the workers were returned.[112]

Industrial espionage targeted at Britain before 1800 had an overarching aim: it sought to seduce workers. Every significant attempt to bring technology out of the British Isles aimed at convincing workers to abandon their homes and set up facilities in France. Knowledge was the objective, while information was almost totally ignored. Information was sometimes obtained on espionage trips, but it was never the main objective. As the Alcock story shows, even when information was available, it was not used to spread new technologies. The techniques of counter-espionage also show this emphasis on the movement of knowledge within workers. The fact that all of the countermeasures were designed for this particular threat shows how seriously the British took it, and how much they disregarded the threat of information based espionage.

Joseph Warren's Trip

Joseph Warren's trip dispensed with the previous methods of espionage that were so prevalent in the French attempts to acquire British technology. Neither Martello nor Revere's papers themselves discuss the thought process behind attempting this type of espionage in detail, but there are several factors that would have driven the Reveres to take this new step. Paul Revere's products in 1802 were of good quality, and many Americans were willing to buy them instead of British ones, but he still wanted to increase his quality. To do this Revere needed information from British manufacturers, and he tried unsuccessfully to acquire this by writing to his contacts in England. His letter to a Mr. Bennoch, for example, has many requests, mainly about the rolling process and type of rollers used in Britain. Most importantly, Revere says that, "I should be glad to give good wages to a Man aquainted [*sic*] with the business."[113] Here Revere is attempting to do exactly what the French had been doing for decades—entice British workers to emigrate. Critically however, Revere's letter went unanswered, and the Reveres were forced to take a more drastic step.[114]

Joseph Warren prepared extensively for his trip. Having just been made partner in his father's firm,[115] he would have been intimately familiar with their production methods. Most importantly, he would have known which areas they were looking to improve, and which technologies he should focus on. Whether or not he had physically seen Paul Revere's letter to Mr. Bennoch, he certainly would have known that key questions were, "the size & thickness of the pieces when first put into the Roles; what kind of Furnace or Oven they Aneal their Copper in; wether they role it single, or double; to what length they role it hot; & when they role it cold, wether they role it in water, and particularly how they clean it for finishing [*sic*]."[116] The Reveres also acquired extensive documentation to cover Joseph Warren in case his motivations were questioned. He obtained a passport from Massachusetts, letters of introduction from many of Paul Revere's contacts higher up in the social order, and once he arrived in

Britain, a passport from James Monroe, then foreign minister. With these documents he was able to access almost everything he wished to see, and was never detained for his industrial activities (though he was briefly detained by Napoleon's men).[117]

Joseph Warren had great success in Britain. He was able to send back many letters and bring back his journal, which contained detailed notes and drawings. One manufacturing problem that his trip successfully addressed was the difficulty Paul Revere had in keeping his copper sheets clean during the rolling and finishing process. On December 22nd 1804, for example, Joseph Warren found himself in a copper works at a place he called Harefield.[118] This was the exact type of place that the Reveres had been hoping to access, and Joseph Warren emerged with pages and pages of useful notes. In particular he noted that when the copper was being brought to the finishing furnaces there was, "a bag with a mop which he dips into Urine or Chamber lye & coats the copper before it is put into the furnace... [it] becomes completely clean & not liable to tarnish."[119] The underlining present in this text shows how important Joseph Warren thought this information was. This simple technique would almost completely solve the problems the Reveres had been having keeping their copper clean during the finishing process.

The cleaning of copper with urine or lye is a perfect example of a technological innovation that could easily be translated from knowledge into information. There was no great physical skill required to mop a sheet of copper with urine, indeed it was almost comically easy. Unlike some other skills such as puddling, years did not have to be invested in the development of physical skills that enabled production. This simple piece of knowledge—that copper would be cleaned with urine or lye—could easily be turned into information, which could then transfer itself to other production facilities that required that information.

Another easily transferrable technique that Joseph Warren described was how the copper sheets were put through the rollers. Paul Revere was particularly keen to find out more about the rolling process, since the manner in which the sheets were rolled was critically important. In particular, Revere wanted to produce a sheet that was of a uniform thickness and hardness—but irregularities in the rolling process could result in sheets that were of uneven thickness, or oddly shaped. Unfortunately, neither Paul nor Joseph Warren records how the Reveres rolled their sheets prior to Joseph Warren's trip, but while visiting the copper works at Harefield Joseph Warren was able to observe the British process. He wrote that the sheets were rolled, "square then corner ways then square until got to the width then length ways until thin enough to shear."[120] As Martello writes, "these simple, easily copied processes immediately found a home in the Revere mill."[121] Just like cleaning the copper sheets with urine, the rolling methods were easy for the Reveres to duplicate in their quest for higher quality products.

Another crucial aspect of uniformly rolled sheet copper was the mechanism that drove the rolling mill itself. This mechanism was almost always a water wheel of some type, and the Reveres were in the process of optimizing this technology in their Canton mill.[122] While they did have a functioning set-up at their Canton property, Joseph Warren hoped to learn much about efficient wheel configurations and how the gear systems functioned. He was particularly intrigued by one mill that was powered by a wheel, where by switching which cogs the wheel was connected to, the direction of the rollers could be reversed.[123] This allowed the copper sheets to be rolled back and forth time after time without interruption, a much more efficient method than the process in use at Canton. Joseph Warren's journal includes notes on the quality and height of streams and several detailed drawings of wheel powered roller systems.[124] This information would have been useful to the Reveres, who were trying to improve their roller processes and make their overall production method more efficient and standardized.

Joseph Warren also brought back information on industrial organization and factory layout. The Harefield works were much larger than their own facility in Canton, and these works had much to teach the Americans about running an efficient metallurgical production center. Harefield employed 150 men, and the facility had divided the production processes into discrete steps that allowed for near continuous production. The facility was also remarkably quiet and orderly, a testament to its organization; Joseph Warren remarked that, "there is no noise, no chattering, but all goes like clockwork."[125] While Paul Revere never wrote down exactly what details he incorporated into his own works, these organizational methods would certainly have found a home as he expanded his operations in Canton.[126]

Besides information related to the technique of production, Joseph Warren was also able to obtain information of another type. By observing production practices in Britain, he could see in what ways the Reveres were ahead of their British counterparts. Despite an overall superiority of British goods, Joseph Warren discovered that in certain areas the Reveres were using more efficient and standardized practices.[127] While this information would not help the Reveres build better products, it was important to their competition with British manufacturers. If the Reveres were unable to supply the Boston shipyards with high-quality copper products, those shipyards would happily buy goods from well-respected British manufacturers (which is exactly what they had been doing before the Reveres began producing malleable copper). This vital information, while not of a technical nature, circulated in exactly the same way as the other information that Joseph Warren brought back with him.

An example of this type of espionage occurs early in Joseph Warren's diary. On the 12th of December, 1804, Joseph Warren toured a bell foundry in London and made detailed notes on the foundry's processes, equipment, and workspace. It might seem odd that he examined a bell foundry, which did not employ technology that was directly related to the production of sheet copper. But the setup and facilities of the foundry could give Joseph Warren ideas on how to modify practices in Canton, and the Reveres certainly used bronze in many of their other works, such as bell and cannon casting. In addition, the Reveres were relative newcomers to bronze and copper, as well as running large furnaces, whereas this location had been operating for at least 60 years;[128] it would have been natural for Joseph Warren to take every chance he could to learn from these experienced craftsmen.

His journal from this foundry is mostly concerned with the process of melting and refining the bell metal, and it contains details on the type of oven, molds and how the composition of the metal was determined. He was surprised by the small size and poor ventilation system of the oven, and thought that, "it would have burnt the first time they used it."[129] Joseph Warren was also surprised that the tin was not weighed before being added to the copper to make bronze.[130] The percentage of tin in bronze is vital to the finished product's physical characteristics, but the state of the art facility in Britain simply added tin until the craftsmen felt that the consistency was correct.[131]

Martello notes that this difference in approach showcases a divergence between British and American industrial practices. The Reveres were keen to quantify their production processes, whereas the British craftsmen kept to traditional methods that had worked in the past.[132] While the Reveres could not use this information to better their practices, knowing that the competition was using an inexact manufacturing method could be of great use to their business. When Paul Revere had to try and sell his products next to British goods he could claim that his were more consistent and standardized due to this difference in production methods.

Conclusion

Writing as a means transferring useful technical information was not a novel concept when Joseph Warren made his trip, but it was certainly under-appreciated and under-utilized. The focus of espionage prior to 1800 had been the enticement of workers, and all serious efforts to acquire new technology used this method. It is true that technical information in the form of writings or drawings was acquired as a byproduct of this espionage, but these writings and drawings were almost universally discounted. Even when they were readily available and contained pertinent information, as in the case of the Alcock's gold plating problem, the usual course of action was to acquire new workers from England rather than using the information to transfer technology.

Though Joseph Warren was able to return from his trip overseas with his journal, his physical return was unimportant to the espionage he conducted. Even if only his journal and letters had made it back to America his espionage would still have been effective. He routinely sent letters home during his trip, and sending back the journal would have been just as easy given the infrastructure of the time. It is important to recognize that the functional part of his espionage was the written material that he produced, not anything retained in his head as knowledge. This central place of information, as well as its portability once in written form are key characteristics of the information economy. As Joseph Warren's trip shows, these two characteristics were in place at the beginning of the nineteenth century, though they were not yet widely exploited.

Chapter III – Links to the Modern

Joseph Warren's trip marked a change in the way information was treated by both people who wanted to acquire technology, and those who wished to safeguard it. After the turn of the nineteenth century, others would visit Britain to try and acquire the technical secrets possessed by British manufacturers. The British possessed advantages in many areas of manufacturing,[133] and this made them an attractive target for people wishing to exploit the advantages of information based espionage.

This chapter will demonstrate that the information-based methods used in Joseph Warren's trip were not isolated techniques, and that they represented a turning point in the history of industrial espionage. Examples of both French and American espionage conducted shortly after Joseph Warren's trip will be used to support this argument. In addition, this chapter will link the information based espionage techniques of the nineteenth century with those of the late twentieth and twenty-first centuries. Some of the espionage techniques used in the modern world are almost identical to those used by Revere and his contemporaries. In other cases the methods are not identical, however they still share a common bond in that their focus is on information, not knowledge.

Charles Dupin

The Reveres were not alone in taking advantage of the wealth of technical information that could be extracted from Britain. After Waterloo, French industrialists, for so long wedded to the idea that enticing workers to move to France was the only effective way to acquire their knowledge and skills, began to follow in Joseph Warren's footsteps. Technical advancement in France had been hindered by over twenty years of warfare, whereas British industrialists, already ahead of their French counterparts in many areas, had continued to develop.[134] Once Napoleon was finally defeated in 1815, French industrialists were quick to send technical observers to Britain. Several men travelled to Britain in the first few years to study a wide range of industries including coal mining, railways, foundries, forges, and iron production.[135]

The work of Charles Dupin, a naval engineer who made a total of six visits to Britain between 1816 and 1824[136] provides an illuminating example that highlights the similarities and differences (and there were significant differences) between Joseph Warren's techniques and objectives and those of the French after the Napoleonic Era. Despite these differences, the basic technique of these two examples of industrial were identical: a skilled observer would be able to take technical knowledge and skill that was contained within workmen and translate it into information, which could then move freely out of Britain and transfer those skills to new workers in a foreign country.

Dupin, like Joseph Warren already possessed a great deal of technical knowledge before he made his trip to Britain. Born in 1784, he studied at the École Polytechnique, graduating in 1803, and continued his studies at the École Spéciale du Génie Maritime.[137] By July 1816, the date of his first trip to Britain, he was an experienced naval engineer with a background in mathematical research and naval construction.[138] Like Joseph Warren, this knowledge allowed him to observe and remember minute details of the places he had visited, which he then later transferred into a volume of copious notes to bring back to France. He had spent six months in Britain and had observed a staggering range of facilities including shipyards, arsenals, docks, hospitals, canals, schools, jetties, and barracks (Bradley, 52).[139]

Just as Joseph Warren did, Dupin arranged for letters from prominent scientists, politicians, and members of society to facilitate his access to these facilities. His letters mention the special help of the French ambassador. In his own words Dupin wrote that "I have permission... to see all that I wish to see."[140] With all of this access not only to facilities, but also to the workers within them, the break between older French methods is made clear. Dupin writes of no attempts to entice English workers to come to France. All he pursued was the information that was made available to him by the British. Of course, since it was still illegal to entice workers to emigrate in 1816, Dupin might not have wished to admit to any crimes in writing. However, upon his return to France no workshop sprung up that could mysteriously produce goods previously only made in Britain. Dupin appears to have been honest in his objectives.[141]

The main difference between Joseph Warren's trip and Dupin's efforts lies in the scope of their excursions. Joseph Warren aimed to acquire details about a specific technology, the production of copper sheathing, and he focused his efforts on that one technology. Joseph Warren was also able to tighten his focus further because he was intimately familiar with the manufacturing processes used in the Reveres' Canton workshop. He could thus look mainly at the aspects of production that were giving the Reveres trouble, such as pitting.

In contrast, Dupin knew that British manufacturers had advantages over French industrialists in many different engineering related areas, and as a result, he was not trying to acquire one specific technology. He therefore, cast his net far wider than Joseph Warren did. Furthermore, Dupin was explicitly trying to bring back technology for the use of France as a nation, and he did so with the acknowledgment and support, both monetary and otherwise, of the French government.[142] Joseph Warren, contrarily, brought his information directly back to Paul Revere, and it was used exclusively for business. There is also no evidence to suggest that the U.S. Government ever compensated the Reveres for the trip in any way, except by contracting them to provide copper sheathing and bolts for ships.[143]

Despite these differences, Dupin's trips demonstrate the broader nature of this shift in the treatment of information. His six trips between 1816 and 1824 resulted in no workers or machines being brought back to France. The only tangible results were the volumes of notes with which he returned. Instead of bringing back knowledge, in the bodies of workers, he had brought back information. Dupin was intelligent and talented, and his espionage activities were successful. His information was used to improve a wide array of industries in France including naval construction, water storage, anchor cables, naval equipment and armament, bridges, and canals.[144] Perhaps one of the most striking testaments to his success is that the British Government, when unable to obtain information about their own industries quickly and easily, consulted the works of Dupin to find out what they wished to know.[145] In the years after Joseph Warren's trip information was being used by practitioners and targets of espionage alike, a strong sign of a budding information economy.

Francis Cabot Lowell

The characteristics of information were not exploited only by European spies in the period following Joseph Warren's trip. Francis Cabot Lowell, the famed industrialist of Lowell's textile mills, was a notable user of information-based espionage in those years. In June of 1810 he, along with his wife and children, undertook a European tour of England, Scotland, and France, ostensibly for pleasure, though he may have justified the expense to others by claiming that it was an attempt to stave off his declining health.[146] 1810 was an interesting year for a wealthy American to travel to Britain. The Napoleonic Wars were in full swing, Napoleon's brother had just been installed as King of Spain, and the armies of Britain, France, Portugal, and Spain were fighting for control of the Iberian Peninsula.[147] Mainland Europe was far from stable, and the Atlantic Ocean was a war zone. French and British ships dueled throughout the Atlantic and Caribbean, with battles even being fought off the American coastline.[148] American trading vessels were captured, and American sailors pressed into British service. This situation caused so much tension that it became a main cause of the War of 1812 between Britain and America.[149]

Nevertheless, in 1810 there was a minor lull in the tensions between Britain and America, and Francis decided that his family would continue with their long planned trip, which was supposed to take two full years.[150] After arriving in Liverpool, the family quickly made their way to Edinburgh, where they planned on staying for a good portion of their trip.[151] Lowell wrote frequently to his family and business associates, and he began thinking seriously about the effects of the war in Europe on Britain's economy, and about how America could begin to break free of its dependence on European goods.[152] It was in Edinburgh that Lowell conceived of the idea that, "American factories would be built with American money, machines designed and built by Americans, and employing American workers."[153] To do this of course, Lowell would need a great deal of information. He needed to know how the machines functioned and were built, how the factories were laid out and organized, and how the rivers were used to power the mechanisms. Fortunately, he was in the best place in the world to study these things, since Britain in the early 1800s was at the center of textile innovation.[154]

Francis Cabot Lowell began his espionage while touring England and Scotland in 1811 with his family. The family first visited Glasgow, a booming industrial town, in May, before continuing on to London, where they stayed for several months. From there, they went on through Lancashire and Shropshire, in the northwest of England, where Francis was able to examine many mills and factories. After returning to Edinburgh, he continued to travel throughout Britain, visiting mills and production centers whenever he was able.

His method of obtaining information was similar to Joseph Warren's. Lowell visited the mills in the guise of an interested tourist of the upper class and spent hours looking at the workings of the machinery and asking questions of the mill operators. The Cartwright power loom, one of the most advanced machines in Britain, was a special focus of his espionage because it could produce high quality textiles quickly with a minimum amount of training required for the operator. Unlike Revere, however, Lowell did not make drawings, write descriptions, or engage in any of the activities previously discussed to convert knowledge into information. What he stored in his brain, however, was still information, not knowledge. Lowell had done all of the work of converting knowledge into information through his observations and questions while in England, he simply had not yet written it down.[155]

Lowell's espionage was conducted in this way because he needed to keep the information in his head to escape detection. Once back in America he would be free to write all of the information he had acquired down, and translate into information in the traditional sense. On the surface this makes his espionage seem different than Joseph Warren's, but in fact they were both stealing information. The difference is only that Lowell had a pause in between acquiring the information and writing it down; this pause was his method of avoiding detection. Joseph Warren, operating earlier when British laws and countermeasures had not adapted to combat information based espionage, took almost no steps to ensure his journals and writings were not uncovered. There was no need because at the turn of the century the concept of espionage was so tightly wrapped up in the enticement of workers. Lowell on the other hand was returning almost a decade later, when the concept of information based espionage was more recognized. In addition, Lowell left England just before America's declaration of war arrived, whereas Joseph Warren travelled during peacetime. The tension and suspicion between the two nations in 1812 drove Lowell to take drastic measures to avoid detection. Indeed, those measures were necessary; the Lowell's ship was detained and searched twice for plans of looms or other manufacturing technologies.[156]

Lowell, like the Reveres, was able to use information based espionage effectively. He returned to America and started the Boston Manufacturing Company, based on the information he had obtained in Britain on power looms and factory organization. His company was successful, and the Boston Manufacturing Company quickly grew to dominate the American textile market.[157] The espionage he had conducted in Britain was crucial to his success, and information was at the heart of that espionage. The techniques used by Revere, Dupin, and Lowell to acquire information bear a strong resemblance to modern espionage techniques, and in some cases are identical.

Modern Techniques of Industrial Espionage

Industrial espionage has evolved greatly in the past two hundred years, but many techniques of acquiring information that are in use today have their roots in methods used by Joseph Warren and his contemporaries. Even in techniques that share no obvious traits with the actions of Joseph Warren, there is still a shared emphasis on targeting information, not knowledge. Techniques that fall into this category include the use of electronic listening devices, dumpster diving, and theft of documents or computers. Electronic collection of information using the internet is another frequently used method. While at first this method seems different from what Revere did, it is actually a similar type of espionage—the factory visit is simply taking place electronically. Finally, agents are still sent in person to collect information on scientific labs, factories, and other industrial targets.[158]

Theft of physical repositories of information is indeed common in the modern world. Laptops and briefcases are targeted when businessmen travel, either to foreign countries or domestically. Information is especially exposed during this traveling phase, in airports or other transportation hubs, but agents have even been known to give bribes to hotel staff in exchange for access to a target's room. Once inside they collect as much information as possible. A similar tactic is that of dumpster diving, where agents will examine the trash and recycling of a targeted company hoping to find information. Neither the Reveres nor any of the others examined for this paper employed this method of direct theft in their espionage operations. In all three cases, it is almost certain that written information about the process they wanted to acquire did not yet exist. Nevertheless, the modern technique of theft is linked to their methods because it targets information, not an actual product. Businessmen do not usually travel with a jet engine in the seat next to them, but one could carry the entire plans for a Boeing 777 on a hard-drive that is very easily stolen.[159]

Another modern method is the use of electronic listening devices to record conversations between workers or businessmen without their knowledge.[160] While there is no direct equivalent of this method in the world of nineteenth century espionage, Revere likely did manage to overhear some conversations while he examined the various production facilities. Listening in to conversations is inherently information-based however. A recorded conversation can be easily represented in written form, and while slight details of intonation and inflection will be lost, the majority of information contained within a recording and its transcription will be identical. Even though Revere was unable to plant listening devices in the factories he visited, this modern method of espionage is still linked to his methods through their exploitation of information.

Perhaps some of the most well-known modern espionage techniques are those that involve the use of the internet to obtain information.[161] There are many varied and inventive ways of using computers and the internet to acquire information, and the individual techniques will not be examined in this paper. However, this method of obtaining information is strikingly similar to the factory visit that was so prominent in nineteenth century espionage. Instead of sending a physical person to acquire the technology, the visit is conducted virtually, through the internet. This technique has the advantages of not putting an individual at risk, and it can be performed much more quickly than Revere's trip was. However despite the differences in technology, the essence of the collection method is the same.

Finally, companies or governments often still send actual agents into factories, labs, and other industrial sites to steal information. In many cases, the agents are graduate students who are continuing their studies, but also have a secondary motive. In other situations the agents are officials, visiting either from foreign governments or other companies, who try to acquire information during the course of their visit. These methods are nearly identical to those used by the Reveres, Dupin, and Lowell.[162] One advantage that modern industrial spies have is that many of these collection methods require few resources, and little risk. As a result, many modern espionage attempts make use of more than one collection method. However, just as with Joseph Warren's trip, the focus is on collecting information, not knowledge.

Modern Case Studies – Shearer & Worden

The case of Jack Shearer and his turbine production company provides a modern example of information based espionage. Shearer worked as a sales representative for a company called Solar, a producer of industrial turbines and replacement parts for 26 years, mainly in the Middle-East region.[163]

His employment was terminated in 1992, and he founded several competing companies: Tejas Procurement Services, Tejas Compressor Systems, and Procurement Solutions International.[164] At some point either during his final days of employment, or after his termination, Shearer was able to steal proprietary information from Solar in the form of technical specifications, designs, drawings, and production information,[165] which he planned to use to benefit his own companies.

Shearer's plan was to take this technical information and have third parties manufacture the parts, which he could then sell at a discounted rate to customers. This proved to be an effective method, and his companies posted millions of dollars in profits in the 1990s. He continued to obtain technical information through a pair of workers who were still working at Solar, paying them thousands of dollars in cash for plans and technical information. In 1999 Shearer, along with his two accomplices, were tried and convicted by a Federal court and ordered to pay restitution as well as serve jail time. Just as in industrial Britain, the penalties for espionage could be severe, provided that the laws were designed to handle the type of espionage being performed. By the 1990s, information based espionage was fully covered by the law; in Joseph Warren's time the laws were still trying to catch up to new espionage methods.[166]

Shearer's espionage initially seems as if it might rely more on the pre-1800 methods of enticing workers, than on the information based espionage of Joseph Warren, but in reality his own knowledge was not of a technological nature. During his 26 years with Solar he worked as a salesman, and he would have had little insight into the technical aspects of production. The important achievement of his espionage efforts were the plans and technical drawings that he obtained from Solar, not his own knowledge and sales skill. It is those documents that were used to produce counterfeit parts and were sold to other companies.[167]

Importantly the two employees who provided him with many of his documents did not come and lend their knowledge of production processes to his business. They merely provided documents, or information, not knowledge. Shearer's sales knowledge was important to his own business; the network of contacts that he had built up throughout the Middle-East during his years at Solar would have provided him with a sizable client base to offer his cheap, counterfeit goods to. Despite the advantages conferred to his business by his knowledge, the espionage activities he undertook were strictly information-based. He never attempted to bring in experienced Solar workers and set up his own production facility, he simply stole the information that described how the parts were made.

At the same time that Jack Shearer was stealing turbine secrets, an even larger espionage network was being run by a former Kodak employee, Harold Worden. Worden's plan was similar to Shearer's. He was a former Kodak employee who used current employees to steal plans and other technical information. The main difference between the two operations was their relative size. Shearer had two workers who obtained new information for him,[168] whereas Worden had sixty workers funneling him documents and technical specifications. When the FBI finally was able to search Worden's residence, they turned up tens of thousands of documents containing proprietary information belonging to Kodak. Worden's agents stole information relating to a wide variety of Kodak products, but they focused especially on something dubbed the "401 machine," which was involved in the production of film base. The base, and the emulsion that lines it, are critical to the resolution and appearance of the final photograph, and the information that Worden acquired was valuable.[169]

As in Shearer's case, Worden founded a company that he used to sell his stolen information. However unlike Shearer, Worden did not set up a third-party distribution method. His consulting company, Worden Enterprises, simply sold Kodak's proprietary information to whomever would buy it. There was no attempt to produce their own 401 machines, or manufacture any other type of counterfeit Kodak product. Worden's method was purely that of an information broker, and as such the relationship between his espionage and the espionage of the nineteenth century is clear. Information was the critical ingredient without which neither Worden nor the Reveres could succeed.[170]

Conclusion

Information was at the center of every espionage attempt detailed in this chapter. Whether the spy was Charles Dupin in 1816, or Jack Shearer in the 1990s, the target of their espionage was information. While their specific actions differed, mainly due to the technology available to them, the basis of their espionage was the same. This information based espionage which was developed at the turn of the nineteenth century represents a marked shift from the espionage that took place prior to Joseph Warren's trip. The focus on knowledge, resident inside of workers, was gone. Instead highly portable information was the target, just as it is in modern espionage.

These espionage techniques arise out of the centrality of information to the economy of the period. In the modern information economy, information is portable, and it can be transported across the world and over national borders or other barriers easily. It also moves rapidly. With the internet information can travel across the world in minutes. While limited by the technology of the time, information in the nineteenth century featured these same characteristics. Once written down, information in the form of letters or journals could be moved around the world with relative ease and speed. The similarity of modern industrial espionage techniques, and those used by Joseph Warren and his contemporaries, derives from these common characteristics of the modern and nineteenth century information economies.

General Conclusions

The world has changed immeasurably since Joseph Warren sailed across the ocean in 1804 to steal the secrets of rolling sheet copper. The trip that took him multiple weeks in a cramped sailing vessel could today be accomplished in six hours. The planes that carry people across the Atlantic every day rely on technologies and concepts that could not have been imagined in Revere's time. The first flight of the Wright brothers at Kitty Hawk would not take place for another 99 years.[171] The technologies that move information have also changed drastically since Revere's trip. The internet allows for nearly instantaneous communication throughout the world, and massive quantities of information travel this network every day.

Despite the technological differences between 2014 and 1804, the Reveres would recognize the way that information operates in the modern world. Joseph Warren exploited the same properties of information that the internet emphasizes and makes easily recognizable. The information that Joseph Warren stole was portable. It was much easier for him to transport writings and drawings back to America than it would have been to smuggle experienced copper workers out of Britain. It was also reproducible. If the Reveres had wanted extra copies of the information (perhaps to sell in the same manner as Harold Worden) it would have been simple to have the documents printed by a shop in Boston. Furthermore, once Joseph Warren acquired the information, his physical presence was no longer required. Paul Revere could have learned all he needed from the writings of his son, whether or not his son had returned from England. The information, in the form of writing, could transfer itself to Paul Revere without the aid of another person.

Joseph Warren's espionage trip marks the beginning of a turning point in the way information was understood and used in the economy. Like most historical turning points this change did not happen in an instant, but developed over years as more and more businessmen realized how information, as opposed to knowledge, could be utilized. This turning point also marks the true beginning of the development of an information economy. Just as in today's information economy, there was a plethora of information of economic value, and information based goods were common in industries such as naval technology. The development of the information economy was also responsible for the change in espionage techniques that occurred in the early 1800s. Previous knowledge-based espionage strategies gave way to strategies based on the properties of information. These techniques were also very similar to modern espionage methods, which take full advantage of the properties of information. This similarity of espionage techniques also points to a similarity of economies that are based on information.

Prior to Joseph Warren's trip, governments, manufacturers, and engineers believed that knowledge was more useful than information. They believed that the technologies involved in industries such as naval construction were dependent on the knowledge contained within craftsmen. However, as we saw in the first chapter of this thesis, much of the knowledge that was needed to produce those goods could in fact be turned into information. The new prevalence of information-based goods was an early step in the development of an information economy; without valuable information, there would have been no incentive for people like Revere to take advantage of information's properties.

Prior to Joseph Warren's trip, there had thus been almost no use of information-based espionage. The techniques used before the nineteenth century focused on the acquisition of knowledge, and they usually centered on seducing workers. Even when information on production techniques was readily available, it was not used, and it was generally regarded as useless by craftsmen and industrialists. After 1800, however, a broad change took place in the techniques of espionage, and the acquisition of information was central to these new techniques. What started with Joseph Warren's trip was soon emulated by others in America and Europe, and Joseph Warren's strategies became the new way of conducting espionage. These techniques were indeed quite similar to those employed by spies in the modern, information-based world.

Once Paul Revere had gained the information he desired, he shared it freely with other American entrepreneurs who were trying to develop similar technologies.[172] He wrote frequent letters in response to people who wrote to him with questions about his process, and who described the difficulties they were having in establishing their own copper works and rolling facilities. To a modern reader this seems to be an interesting and somewhat questionable business move. After going through great expense and risk to acquire this information, why would Revere give it up again so easily?

There are several possible answers to this question. Martello suggests that Revere was willing to share his information due to the camaraderie among industrialists at the time, because there were so few American copper producers, because there was such a high demand for malleable copper products, and because there was thus no risk of hurting his own business.[173] This explanation is perfectly valid, and likely played a part in Revere's decision to share information. However it was not the only factor.

Throughout Paul Revere's journey into the world of naval copper production, he also seemed to be engaged in a type of proto-branding, in which he hoped to establish himself as the foremost producer of malleable copper. By sharing his knowledge Revere furthered this branding attempt in two ways. First, by helping other Americans produce high quality copper he improved the brand recognition of all American copper producers in an industry that was previously dominated by the British. Secondly, Revere established himself as the premier American producer, putting his brand of copper products in the highest position in the hierarchy of American copper. Revere also pursued standardization of his copper goods as a way to further his brand. Indeed, eventually Revere was able to sell his products by weight as opposed to by the unit, something Martello calls, "a major milestone,"[174] on the path to standardization. In the same way that a consumer expects to find that each pair of Nike sneakers is the same, so too could Revere's customers expect that each of his bolts would be the same length, width, and weight.

However this early attempt at branding is not the only facet of this story that has the potential for further research and exploration. A question that hangs heavily over the counter-espionage techniques used in Britain is why any foreign visitors were allowed into factories at all. Had British factory owners simply closed their doors to anyone but employees, many of their technologies would have been safe from the information-based espionage techniques of the time. In one of his articles, Harris suggests that:

> among those socially advancing industrialists with genteel or intellectual claims or pretensions in most European countries in the Age of Enlightenment it would have been regarded as sinning against the light to deny foreign scientists or savants, members of this Academy, or Corresponding Fellows of that, the opportunity to see some celebrated mine or manufacture. ...Foreign army officers were expected to be honourable [*sic*] and gallant fellows of no particular technological skill, but an honest curiosity. Some of those on industrial travels claimed, and probably did have, a code which voluntarily limited their investigations. But the Baron, the Chevalier, the geologist, the naturalist, the chemist, the aeronaut, the Brigadier, the Captain was very likely an ironmaster, an artillery technologist, a member of a Bureau of Commerce, an inspector of industry.[175]

But where did this expectation that a visitor of a certain rank should be given access to sensitive manufacturing sites come from? Harris implies that it arose out of a shared Enlightenment ideal that knowledge and information should be shared, but this expectation could be traced back further. Baron and Chevalier are feudal titles, and perhaps this expectation of honorable conduct on the part of both visitors and factory owners can be linked to a kind of feudal host/guest relationship.

This type of feudal relationship still exists in the modern world. Hedieh Nasheri, for example, discusses the use of graduate students and other academics to steal industrial secrets in today's world, and these agents exploit a very similar type of relationship: an academic instead of feudal host/guest relationship. As is clear by the many court cases related to the espionage activities of academics, the possibility of this type of espionage is well known, however there is still an expectation of honorable conduct on the part of both parties. The similarities, origins, and connections of both of these types of relationships would be an interesting area for continued research.

The world of industrial espionage provides scholars with a different angle for viewing the development of the information economy. Instead of a focus on the changes in technology of the past fifty years, trips such as Joseph Warren's, Dupin's, and Lowell's shed light on the very beginnings of an information based society. These men were among the first to translate knowledge into information, and to use it effectively in their business endeavors. The information of their age may have been taken up more space and moved more slowly than the information that travels across the world today, but those differences are due to discrepancies in technology, not a difference in the nature of information. Then, as now, information played a central role in the fabric of society.

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[1] Paul Revere was actually court-martialed for his role in the disastrous Penobscot expedition of 1779. Though he was eventually acquitted of all charges, it permanently ended his military career.

[2] Robert Martello, *Midnight Ride, Industrial Dawn: Paul Revere and the Growth of American Enterprise,* (Baltimore: Johns Hopkins University Press, 2010), 78.

[3] Ibid, 157.

[4] Ibid, 191.

[5] Ibid.

[6] Ibid, 220, 232.

[7] John R. Harris, *Industrial Espionage and Technology Transfer,* (Aldershot: Ashate Publishing, 1998), 13.

[8] Ibid.

[9] Ibid, 8.

[10] Hedieh Nasheri, *Economic Espionage and Industrial Spying,* (Cambridge: Cambridge University Press, 2005), 31.

[11] Ibid, 30-32.

[12] Ibid, 30-31.

[13] Harris (1998), 1-3.
[14] John R. Harris, *Essays in Industry and Technology in the Eighteenth Century: England and France,* (Hampshire: Ashgate Publishing, 1992), 166-167.
[15] Ibid.
[16] Puddling was part of a process used to create high quality iron, and later steel.
[17] Harris (1992), 28-29.
[18] Martello, 214.
[19] Ibid.
[20] Tyrone G. Martin, "Building the Constitution," accessed on 12/28/13, https://www.ussconstitutionmuseum.org/constitution-resources/the-captain-speaks/building-constitution.
[21] Harris (1992), 176.
[22] Ibid, 178-9.
[23] Galvanic action has been mentioned previously, but has not yet been fully explained. The exact chemical process of the corrosion is not important to a historical study of the effects of galvanic action, but a basic understanding of the mechanism is helpful. Galvanic action is a type of electrochemical corrosion that can take place when two metals with different electron potentials are immersed in a conducting electrolyte solution (such as seawater). One of the metals, the anode, breaks down and leeches into the solution, while the cathode remains unharmed. In the case of copper sheathing, the copper was the cathode, and the iron bolts that held the hull together were the anodes and therefore the part of the ship that was weakened by corrosion. This was a serious problem, as corroded iron fastenings led to the sinking of a significant number of ships in the years immediately after coppering became widespread.
[24] Harris (1992), 177.
[25] Michael McCarthy, *Ships' Fastenings: From Sewn Boat to Steamship,* (College Station: Texas A&M University Press, 2005), 101.
[26] Ibid.
[27] Harris (1992), 177.
[28] Harris, McCarthy, and Martello fail to provide an explanation for why lead sheathing was discontinued due to corrosion, whereas copper was extensively used in spite of it, but an explanation can be found in the historical context. When lead sheathing was tried, Britain had just emerged from civil war, and had no urgent need to project their power on the high seas. When the *Alarm* was coppered in 1761, Britain was engaged in a continent-spanning war against the French, and would soon be at war with the American Colonies as well. The need for effective fighting ships was so great that it outweighed the concerns about the corrosive nature of copper sheathing.
[29] McCarthy, 101.
[30] Ibid, 102.
[31] Harris (1992), 178.
[32] Harris (1992), 178. McCarthy, 102. Martello, 220 (Martello uses 1758 as the date of the *Alarm*'s coppering. Since the other sources I examined used 1761, that is the date I used, though with the qualifier "approximately")
[33] Harris (1992), 180.
[34] Ibid.
[35] Ibid, 179. Martello, 225.
[36] Martello, 233.
[37] The ones Revere used initially were 20 inches long and 9 inches in diameter according to Martello, 231.
[38] The entire description of the rolling process can be found in Martello, 230-33.
[39] Annealing is a technique where the metal is heated to a certain point, but not melted, and kept at that temperature for a certain amount of time. This causes internal changes in the structure of the metal which increase its ductility. For more information, see Martello, 193.
[40] Or galvanic corrosion, the two terms are interchangeable.
[41] Jerome Kruger, "Electrochemistry of Corrosion," accessed on 8/3/13, http://electrochem.cwru.edu/encycl/art-c02-corrosion.htm.
[42] Ibid.
[43] Harris (1998), 264.
[44] Ibid.
[45] The Seven Years War, despite its name, spanned from 1754-1763. The *Alarm* was coppered in 1761, just before the end of that conflict.
[46] George C. Daughan, *If by Sea: The Forging of the American Navy—From the Revolution to the War of 1812,* (New York: Basic Books, 2008), 17.
[47] Harris (1998), 264.
[48] Harris (1992), 180.

[49] Ibid, 179.
[50] Harris (1998), 263.
[51] McCarthy, 103.
[52] Ibid.
[53] For details on the *Glorieux, Ville de Paris,* and *Centaur*, see Harris (1992), 180-181.
[54] McCarthy, 104-105.
[55] Ibid, 105.
[56] Ibid.
[57] Martello, 192.
[58] Both Harris and McCarthy discuss exactly which British Industrialist was the first to patent the process. Three patents were filed almost simultaneously by different innovators for three very similar processes of rolling copper bolts. Harris gives a more full description of the development of this technology in Britain in his 1992 book, pages 181-186.
[59] Harris (1992), 184.
[60] Ibid.
[61] Martello, 193.
[62] Ibid.
[63] Ibid.
[64] Ibid.
[65] Ibid.
[66] Ibid, 197.
[67] Harris (1992), 183.
[68] Unfortunately Revere left no written record of how he developed his procedure of manufacturing copper bolts and spikes. However Martello surmises that due to the similarity between bolt production and silver wire production it is likely that Revere adapted this known process to his new material requirements.
[69] Martello, 193.
[70] Proving was a type of stress test for artillery pieces where they would be fired under worse than expected conditions. If the cannon did not crack or explode it was considered fit for use.
[71] Martello, 178.
[72] Ibid, 176.
[73] Making molds was a difficult and time-consuming process in its own right. Martello discusses the difficulties involved in his section on bell casting.
[74] Martello, 177.
[75] Ibid.
[76] Ibid.
[77] Ibid.
[78] Ibid, 178.
[79] Ibid.
[80] Or knowledge-based goods, to distinguish them from information which has value independent of any physical product.
[81] Keith Smith, "What is the 'Knowledge Economy'? Knowledge-intensive Industries and Distributed Knowledge Bases," accessed on 10/21/2013, ftp://ftp.cordis.europa.eu/pub/innovation-policy/studies/studies_knowledge_based_economy_wp4.pdf.
[82] Stan Liebowitz, "The Economics of Knowledge Based Goods," accessed on 10/21/13, http://www.utdallas.edu/~liebowit/knowledge_goods/notesf2000.html.
[83] Martello, 163.
[84] Ibid, 191. Revere Family Papers Microfilm, Massachusetts Historical Society.
[85] Carl Shapiro and Hal Varian, *Information Rules: A Strategic Guide to the Network Economy,* (Boston: Harvard Business School Press, 1999), 3.
[86] Ibid.
[87] Martello, 198.
[88] Ibid, 177.
[89] Ibid, 292. Revere Family Papers Microfilm, Massachusetts Historical Society.
[90] Harris (1998), 13.
[91] Ibid.
[92] Ibid.
[93] Martello, 191.
[94] By this time the Revere's were able to produce sheet copper on their own, but their products were not as good as their

British counterparts.
[95] Harris (1998), 13.
[96] Martello, 290.
[97] Harris (1998), 13.
[98] Ibid, 9.
[99] Ibid, 461.
[100] Harris (1992), 166-7.
[101] Ibid, 167, 173.
[102] Ibid, 167.
[103] Ibid, 169-171.
[104] Ibid, 173.
[105] Ibid, 167.
[106] Ibid, 167-8.
[107] Ibid, 168.
[108] Ibid.
[109] Ibid, 166, 171.
[110] Ibid, 171.
[111] Ibid, 169.
[112] Ibid, 172.
[113] Martello, 289. Revere Family Papers Microfilm, Massachusetts Historical Society.
[114] Martello, 289.
[115] Ibid, 289-290.
[116] Martello, 289. Revere Family Papers Microfilm, Massachusetts Historical Society.
[117] Martello, 290-291.
[118] Revere Family Papers Microfilm, Massachusetts Historical Society.
[119] Ibid.
[120] Ibid.
[121] Martello, 292.
[122] Ibid.
[123] Revere Family Papers Microfilm, Massachusetts Historical Society.
[124] Ibid.
[125] Martello, 289. Revere Family Papers Microfilm, Massachusetts Historical Society.
[126] Martello, 289. Revere Family Papers Microfilm, Massachusetts Historical Society.
[127] Revere Family Papers Microfilm, Massachusetts Historical Society.
[128] Ibid.
[129] Ibid.
[130] Ibid.
[131] Ibid.
[132] Martello, 291.
[133] Margaret Bradley and Fernand Perrin, "Charles Dupin's Study Visits to the British Isles, 1816-1824," *Technology and Culture,* Vol. 32, No. 1 (Jan, 1991), 47.
[134] Bradley, 47.
[135] Ibid, 49.
[136] Ibid, 64.
[137] Ibid, 48.
[138] Ibid, 49-50.
[139] Ibid, 52.
[140] Ibid.
[141] Ibid.
[142] Ibid, 50.
[143] Even if these contracts are viewed as a type of compensation, the fledgling Federal government was chronically late in paying the Reveres. The government was often so late in their payments that the Reveres were unable to acquire sufficient raw materials to complete the government contracts. Martello, 208.
[144] Bradley, 68.
[145] Ibid, 66.
[146] Chaim M. Rosenberg, *The Life and Times of Francis Cabot Lowell, 1775-1817,* (Lanham, MD: Lexington Books, 2011), 170-171.

[147] Gregory Fremont-Barnes and Todd Fisher, *The Napoleonic Wars: The Rise and Fall of an Empire* (Oxford: Osprey Publishing, 2004), 228.
[148] Rosenberg, 169.
[149] Daughan (2008), 396-397.
[150] Rosenberg, 169.
[151] Ibid, 172.
[152] Ibid.
[153] Ibid.
[154] Ibid.
[155] Ibid, 186-193.
[156] Ibid, 214.
[157] *Public Broadcasting Service,* "Freedom, a History of Us: Francis Cabot Lowell," accessed on 3/12/2014, http://www.pbs.org/wnet/historyofus/web04/features/bio/B13.html.
[158] Nasheri, 82-83.
[159] Ibid, 83-84.
[160] Ibid, 83.
[161] Ibid, 83, 89.
[162] Ibid, 86-88.
[163] Ibid, 166-167.
[164] Ibid, 165.
[165] Ibid.
[166] Ibid, 166-167.
[167] Ibid.
[168] Ibid, 167.
[169] Ibid, 144.
[170] Ibid, 144-145.
[171] *Smithsonian National Air and Space Museum,* "The Wright Brothers: The Invention of the Aerial Age," accessed on 3/17/2014, http://airandspace.si.edu/exhibitions/wright-brothers/online.
[172] Martello, 294.
[173] Ibid, 295-296.
[174] Ibid, 303.
[175] Harris (1992), 165.