From Breechloaders to Monster Guns: Sir William Armstrong and the Invention of Modern Artillery, 1854–1880

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Before dawn on Sunday, November 5, 1854, 50,000 Russian soldiers moved out of Sevastopol and quietly arranged their artillery to bombard the British and French positions in the hills around the city. It had rained throughout Saturday, and the British, believing that the thick mud and heavy fog made a Russian offensive unlikely, had no artillery on hand to defend Inkerman, one of their main positions. When the Russians attacked, Lord Raglan, the commander of the British army, ordered that two 18-pounder guns be brought up from the siege train below. There were no draft horses available, however, and it took 150 soldiers and eight supervising officers three hours to haul the 2-ton guns a mile and a half up the muddy hillside.[1] Once in place the guns relieved the pressure from the Russian artillery, and, when French reinforcements arrived in the early afternoon, the attack was finally beaten back. Yet the losses were large, in part because the great bulk and weight of cast-iron guns made it impossible to maneuver them quickly over the rough terrain of the southern Crimean peninsula.[2] The Crimean War, and the losses at Inkerman in

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[1]W. Baring Pemberton, *Battles of the Crimean War* (London, 1962), pp. 125–27, 154–55; Alexander W. Kinglake, *The Invasion of the Crimea* (New York, 1875), 3: 255–56. An "18-pounder" fired an iron shot weighing 18 pounds.

[2]The *Times*, November 7, 1854, p. 6; December 4, pp. 6–8; December 28, p. 9; General Simpson to Lord Panmure, in *The Panmure Papers: Selections from the Correspondence of Fox Maule, 2nd Baron Panmure*, ed. George B. Douglas and Sir George Dalhousie (London, 1908), 1:170; "Report of the Artillery Committee on Ordnance Employed at Sebastopol," November 17, 1855, War Office, Public Record Office, London (hereafter W. O.), 32/7555.

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particular, turned the attention of British engineers toward armaments and made the British government receptive to their suggestions for innovations in artillery.

Relatively little is known about the invention and development of modern artillery that took place after the Crimean War. Historians of science and technology have produced many books on the invention and development of contemporary ballistic missiles and nuclear warheads, weapons of unprecedented destructive capacity that deserve much attention.[3] Twentieth-century missiles, however, have roots in 19th-century artillery, the knowledge of which will broaden and deepen our understanding of contemporary nuclear dilemmas. At the same time, 19th-century artillery technology has its own historical importance. It was a tool of empire, it altered the face of battle, and it formed the basis of great industrial enterprises. As Alex Roland reminds us, while "the history of contemporary military technology will continue to attract productive scholars . . . the historical community should not lose sight of the rewarding and revealing issues from earlier periods that await attention."[4]

General histories of technology are particularly inadequate on 19th-century artillery.[5] There is substantial confusion about artillery technology and those involved in its development. Historians have reproduced each other's errors concerning Sir William Armstrong, one of the most important inventors of modern artillery.[6] The primary objective of this article is to provide an accurate account of the artillery inventions of this important historical actor.

[3]Robert Seidel, "Books on the Bomb," *Isis* 81 (1990): 519–37.

[4]Alex Roland, "Technology and War: A Bibliographic Essay," in *Military Enterprise and Technological Change: Perspectives on the American Experience*, ed. Merritt Roe Smith (Cambridge, Mass., 1985), p. 379.

[5]An essay on 19th-century military technology is conspicuously absent from Charles Singer, E. J. Holmyard, A. R. Hall, and Trevor I. Williams, eds., *A History of Technology*, 7 vols. (Oxford, 1954–78).

[6]Martin van Creveld, in his *Technology and War: From 2000 B.C. to the Present* (New York, 1989), p. 220, commits two errors in the one sentence that he gives to Armstrong and 19th-century artillery technology: Armstrong's name was not John, and there was no such thing as built-up, steel-made, rifled cannon. William H. McNeill, *The Pursuit of Power: Technology, Armed Force, and Society since A.D. 1000* (Chicago, 1982), gives a fair description of one of Armstrong's innovations, but on other points he makes two major errors (see nn. 55 and 97 below). Robert L. O'Connell, *Of Arms and Men: A History of War, Weapons, and Aggression* (New York, 1989), also makes two errors about Armstrong in one sentence (on p. 193). He cites J. D. Scott, *Vickers: A History* (London, 1962), but reproduces McNeill's erroneous citation of that reliable source (McNeill, *Pursuit*, p. 238, n. 26). William Manchester, *The Arms of Krupp 1587–1968* (New York, 1970), is reliable, as is O. F. G. Hogg, *Artillery: Its Origins, Heyday and Decline* (London, 1970), and Ian V. Hogg, *A History of Artillery* (London, 1974).

A weapon, like any piece of technology, is a technical-social artifact. It embodies both specific technical knowledge and a particular political, economic, and social context, and both must be part of any analysis of its invention and development. Some historians of technology see technological change as essentially autonomous and predetermined and see technological efficiency as a consequence of immanent necessity.[7] More recently, historians have given greater emphasis to political, social, and economic context. Contextual and social constructionist models of technology have provided valuable correctives to the idea of technological determinism.[8] These examine how society shapes (as opposed to being shaped by) technological innovations, and they have brought technological change more deeply within the realm of social and political history. Donald MacKenzie, a leading social constructionist, argues forcefully that "technological knowledge . . . is social through and through, . . . the product of a complex process of conflict and collaboration between a range of social actors including ambitious, energetic technologists, laboratories and corporations, and political and military leaders and the organizations they head."[9] Yet technological determinism cannot be completely ignored with impunity. MacKenzie also recognizes that "technical reasons for a course of action, technical superiority, and technical efficiency are all vitally important; in practice, they often seem sufficient to determine a given outcome." The material world, he rightly concludes, "cannot be simply shaped at will."[10] Technology may not be an independent variable, but neither is it merely a dependent effect.

Abstract forces of technology and culture, then, are not the only important factors in technological change. Neither science-fiction fantasies nor social, political, or economic "needs" can simply call new technologies into being. It is individual inventors who transform ideas into working hardware. Their motives are neither singular and

[7]See, e.g., Singer et al. (n. 5 above), 1: vii.

[8]Smith, ed. (n. 4 above); Donald MacKenzie and Judy Wajcman, eds., *The Social Shaping of Technology: How the Refrigerator Got Its Hum* (Milton Keynes, England, 1985); Stephen H. Cutcliffe and Robert C. Post, eds., *In Context: History and the History of Technology—Essays in Honor of Melvin Kranzberg* (Bethlehem, Pa., 1988); John M. Staudenmaier, *Technology's Storytellers: Reweaving the Human Fabric* (Cambridge, Mass., 1985), and "Recent Trends in the History of Technology," *American Historical Review* 95 (June 1990): 715–25; Wiebe E. Bijker, Thomas P. Hughes, and Trevor J. Pinch, eds., *The Social Construction of Technological Systems: New Directions in the Sociology and History of Technology* (Cambridge, Mass., 1987); Donald MacKenzie, *Inventing Accuracy: A Historical Sociology of Nuclear Missile Guidance* (Cambridge, Mass., 1990).

[9]MacKenzie, p. 11.

[10]Ibid., pp. 3, 412.

unchanging nor do they merely express social or biological imperatives. The social constructionists are ambivalent about the role of individuals in the inventive process; MacKenzie admits that they do make relative contributions even to large, complex technological innovations.[11] Hence a second objective of this article is to place the invention of modern artillery within the technological and social-political context of the time and also to show that its inventors were not simply the agents of that context but in important ways its authors. Individual inventors of the mid-19th century, with their individual motives and abilities, confronted the logic of technological efficiency, struggled with their own rivalries, linked themselves to the shifting social, political, and military interests of the day, and invented modern artillery.

* * *

New technologies had been making their way into the armies and navies of Europe and America since the Industrial Revolution, and after the middle of the 19th century these had a fundamental impact on warfare. Railroads accelerated the mobilization of massive armies in Europe and steamships speedily transported British and European soldiers and supplies to Asia and Africa where gunboats took them deeper into the interiors of those continents than was previously possible.[12] Technological innovation accelerated the transformation of war into a conflict between machines; soldiers and sailors were required to learn new mechanical skills, and engineers and scientists became as important as admirals and generals in shaping warfare and determining its outcome.

The effect of steam-powered transportation on war is obvious, but at the heart of the industrialization of war was the application of industrial skills and knowledge to the manufacturing of weapons. In the first half of the 19th century new industrial technologies were applied first in the construction of small arms. Wrought-iron, rifled breechloaders superseded cast-iron, smooth-bored muskets while conical shells and percussion caps replaced round shot and flints. Less attention was directed toward heavy guns, and at midcentury engineers still had not adapted these innovations to artillery.[13] The new

[11]Ibid., pp. 91–93.

[12]Michael Howard, *The Franco-Prussian War: The German Invasion of France, 1870–1871* (London, 1961), pp. 2–4; Daniel R. Headrick, *Tools of Empire: Technology and European Imperialism in the Nineteenth Century* (New York, 1981).

[13]F. S. Stoney and C. Jones, *A Text-book of the Construction and Manufacture of the Rifled Ordnance in the British Service* (London, 1872), p. 2.

rifles were superior to the old artillery in range, accuracy, and rate of fire, and it was now possible for infantry with rifles to drive artillery from the battlefield.[14] However, in the third quarter of the century, amid wars, threats of war, arms races, and imperialist adventures, new kinds of artillery and naval ordnance were developed by engineers in Britain, Europe, and the United States. The industrialization of war expanded into artillery, and armaments businesses were founded, bringing market forces into the contextual web of technological evolution.[15]

William Armstrong, a successful inventor and manufacturer of hydraulic machinery in Newcastle, studied the reports of the battle at Inkerman with professional as well as patriotic interest. He was in the home of James Rendel, with whom he stayed whenever business brought him down to London. Rendel was outraged that British artillery had changed little since the 17th century. Military engineers, he said, were an apathetic and backward lot who remained wedded to heavy cast-iron material. Artillery forged of wrought iron would be lighter for mobility and could be rifled for long range and high accuracy. Rendel pressed his friend to take up the challenge, and Armstrong, confident that he could resolve the technological difficulties, began working on designs for a wrought-iron, rifled artillery piece. Since the technical problems for loading rifled artillery through the muzzle remained unresolved, the gun would have to be breech-loading.

Before proceeding, Armstrong sought the endorsement and financial support of the War Office, the department of the British army responsible for supplying guns to both the army and the navy, either from its own factories or by contract with private manufacturers. Rendel was the chief civil engineer for the British admiralty and was thus able to arrange a meeting between Armstrong and the Duke of Newcastle, the secretary of state for war.[16]

Newcastle was an eager audience. When the Crimean War began, the government had moved quickly to increase the production and raise the quality of small arms; after Inkerman the artillery question became important as well and the government opened its treasury to Britain's civilian engineers, many of whom clamored for the attention of the War Office. Over the next five years the government dispensed nearly £60,000 to twenty-three civilian inventors working on twenty-

[14]Hew Strachan, *European Armies and the Conduct of War* (London, 1983), pp. 111–13.

[15]McNeill (n. 6 above), chap. 7.

[16]William Armstrong, "Report on the Construction of Wrought Iron Field Guns," July 14, 1855, W. O., 33/11; Stuart Rendel, *The Personal Papers of Lord Rendel*, ed. F. E. Hamer (London, 1931), pp. 269–70.

five projects. Rifling experiments were given strong support, and Armstrong received £7,219, by far the largest amount awarded to any individual working on rifled breechloaders. James Nasmyth, whose interest in weapons was prompted by the invasion scare stirred up by the self-declaration of Louis-Napoléon as emperor in December 1852, had designed a large mortar shell in early 1853. He was ignored by the government until after Inkerman, when he was granted £3,000 "to test the applicability of malleable iron to large ordnance."[17] Armstrong and Nasmyth joined forces with another brilliant engineer, Isambard Kingdom Brunel, who also had worked out ideas for a large gun, and together the three engineers carried out the early work on what became known as the Armstrong gun.[18] Armstrong no doubt benefited enormously by working with two of Britain's greatest engineers, but there was no legal agreement or business understanding among the three men, and neither Brunel nor Nasmyth disputed Armstrong's right to have his name attached to the gun that eventually became so famous.

The gun Armstrong developed had a number of remarkable features, but three stand out. First, as with rifled small arms, Armstrong's artillery piece was rifled and fired elongated shells farther and more accurately than the old smooth-bored muzzle-loaders could fire round shot.[19] The second important feature of the Armstrong gun was its breech-loading mechanism. Medieval artillerists had made breechloaders, but they were forced to abandon them when they failed to construct a breech mechanism strong enough to withstand the explosion of the charge; breech-loading artillery had to await the advances in metallurgy and precision mechanical engineering made during the Industrial Revolution. Armstrong perfected breechloading through a complex mechanical arrangement: the shell was

[17]"Return of the Amount of Public Money Advanced since 1852 to Private Persons for the Purpose of Enabling Them to Make Experiments for the Purpose of Improving Weapons of War," *Parliamentary Papers* 41 (1860): 657. Charles Lancaster received £10,000 and Whitworth another £4,247 to develop their rifling techniques. The largest single grant, £11,807, went to Mallet to build large mortars. George Hale was given £7,810 for research on rockets (explosive shells or bombs fired with high trajectories from mortars). On Nasmyth, see the *Times*, January 7, 1853, p. 6.

[18]Isambard Brunel, *Life of I. K. Brunel* (London, 1870; reprint, Devon, 1971), pp. 84–86, 452–53.

[19]An elongated shell offers less frontal surface area to wind resistance and thus has greater range than a round shot fired with the same initial (or muzzle) velocity. Accuracy, or the sureness of flight path, is increased by imparting a spin on the shell during its passage through the grooved barrel. The spin also keeps the shell stable and pointing forward during flight to allow the percussion fuse in the nose to strike the target.

loaded into the chamber through a hollow breech screw and followed by a cylindrical bag of gunpowder. A steel block, or ventpiece, was dropped into the chamber and pressed tightly against the opening of the bore with the breech screw. The shells were coated with soft lead such that their diameter slightly exceeded the caliber of the gun and engaged the rifling immediately on firing. There were percussion fuses and time fuses that exploded the shell before, during, or just after it had penetrated the target.[20] The gun combined all the properties that make up an effective artillery piece. Armstrong mounted his technological tour de force on a carriage that directed the recoil up an inclined slide from which gravity returned it to firing position.

Rifling and breech-loading made the gun a masterpiece that set new standards in gunmaking, but it was the third feature that defined the Armstrong gun as revolutionary and cleared the way for the rapid evolution of artillery and naval ordnance during the third quarter of the 19th century. This was the famous "built-up" method of construction that greatly increased the ability of cannon to withstand very powerful explosions from large amounts of gunpowder and thus fire shells of great size and power. As Armstrong pointed out, guns are made to accommodate projectiles designed to produce a specific effect: "the projectile should rule the gun, not the gun the projectile."[21] Rifling provided range and accuracy; what was needed now was a method of construction to reduce the weight of the gun as far as possible without sacrificing too much power. The weight-power ratio could be reduced by strengthening the walls of the gun and decreasing the force to which it was subjected by slowing the rate of burn of the powder. Both the metallurgical and the chemical approaches were studied by military engineers, but they did not gain precise control of burn rates until the late 1870s. It was construction techniques that strengthened heavy guns and paved the way for enormous increases in their size and power during the third quarter of the century.

The mechanical and metallurgical problems of artillery construction were studied by British, European, and American engineers. In Britain and Europe civilian engineers were the major innovators, led by Armstrong and Joseph Whitworth in Britain and Alfred Krupp in Germany. Several retired British army officers such as Theophilus Blakely and William Palliser were competent military inventors, but they were not in the same league as Armstrong, Whitworth, and Krupp and attained only relatively moderate business success. Two

[20]Ian V. Hogg, *The Illustrated History of Ammunition* (Secaucus, N.J., 1985), pp. 29–31.
[21]Quoted by Sir J. Emerson Tennent, *The Story of the Guns* (London, 1864), p. 245.

civilians, John Anderson and R. S. Fraser, were the leading innovators at the British army's arsenal at Woolwich. In the United States, on the other hand, active army officers were the major innovators of artillery and naval ordnance. General Thomas Rodman of the Ordnance Department of the United States Army and Captain Robert Parrot, the superintendent of the West Point Foundry, developed American heavy artillery while Admiral John Dahlgren produced large naval guns. American military engineers developed very large smooth-bored guns while British and European engineers considered rifling essential.

There were two ways to construct a gun: it could be cast in one piece or forged by shrinking layers of wrought iron around an inner core that itself was either cast or forged. Both approaches were followed in the 1850s. Rodman and Dahlgren tested various cooling techniques to strengthen their cast-iron guns. Rodman cast his iron guns hollow and cooled them from the inside out by running water through the bore while keeping the exterior walls hot with fire. The metal close to the bore solidified first and was then squeezed by the outer portions as they cooled and contracted. Guns manufactured in this way had greater endurance than guns bored from solid castings that had cooled from the outside inward. Krupp was determined to cast steel breechloaders, but steel was not yet a reliable metal for guns, and during the Austro-Prussian War of 1866 many of his breech mechanisms cracked or burst.[22]

Armstrong and Blakely concentrated on the built-up method of shrinking wrought-iron hoops of various diameters around a core, the method that proved the most technologically efficient. Strengthening a gun by shrinking hoops around the barrel had been tried by medieval gunmakers, but, like rifling and breech-loading, the idea had to await the metallurgical developments associated with the Industrial Revolution before it could be successfully adopted. Alfred Thiery in France and Daniel Treadwell in the United States had designed wrought-iron guns in the 1830s and 1840s, but it was not until the 1850s that such guns became technologically practical.[23] Blakely guns were of some merit but it was the Armstrong version that generated the greatest excitement among the experts.

Armstrong constructed his small breechloader with layers of wrought iron. First, wrought-iron bars were forged into a solid tube

[22]Manchester (n. 6 above), pp. 111–12.

[23]Alfred Thiery, *Applications du fer aux constructions de l'artillerie* (Paris, 1834); Daniel Treadwell, *Papers and Memoirs Concerning the Improvement of Cannon Published between the Years 1845 and 1862* (Cambridge, Mass., 1864).

by coiling them around a mandrel and welding the edges with heat and pressure. Next, a second tube was fabricated of a smaller inner diameter than that of the outer diameter of the first. This second tube was then heated until its inner diameter had expanded enough to slip over the cold first tube. As the outside tube cooled, it shrank tightly onto the inside tube, thereby compressing it. After much experiment and calculation, Armstrong developed this procedure so that the outside tube was prevented by the inside tube from shrinking back to its original cold diameter. Thus an even pressure was maintained throughout the walls of the gun, directed inward against the latitudinal forces exerted on the barrel when the gun was fired.[24] The procedure was repeated with a third tube, and the gun was "built up" in layers. Thicker tubes were used near the breech where the bursting pressure from the detonation of the charge was greatest, giving the guns a distinctive telescopic shape [25](fig. 1).

Armstrong built a 3-pounder in this way over the winter of 1854–55 and submitted it to the War Office in July 1855. The gun was small but its performance was extraordinary: from 2,000 yards its 3-pound projectile penetrated over 2 feet of elm timber backed by a thin plate of cast iron. Armstrong built a 5-pounder gun that was successfully tested in 1856 and within two years he had an 18-pounder. Larger versions of built-up breechloaders quickly followed: a 25-, a 40-, a 70-, and finally a 110-pounder, the latter a promising naval weapon. Although Armstrong was not satisfied with the endurance of the breech mechanism of the 110-pounder, the performance of the smaller weapons was flawless and it impressed the right people. The secretary of state for war, Lord Panmure, was "clearly of opinion that this is a most valuable contribution to our Army."[26] The Duke of Cambridge, the commander in chief of the army, declared the Armstrong gun "could do everything but speak,"[27] and in November

[24]The theory held that, when a cast-iron or steel gun is fired, each concentric layer of metal absorbs a strain on the barrel inversely proportionate to the square of its distance from the axis of the bore. There is a point beyond which additional layers or thickness contribute nothing to the strength of the gun and indeed act as deadweight. Armstrong claimed that in his built-up gun the outer layers of the walls received as much of the stress from the explosion as did the inner layers. See Armstrong (n. 16 above).

[25]Armstrong described his gun in ibid. and in the *Times*, November 25, 1861, pp. 12, 17. See also David Dougan, *The Great Gunmaker: The Story of Lord Armstrong* (Newcastle, 1971), pp. 57–61; Frederick Robertson, *The Evolution of Naval Armament* (London, 1921), pp. 200–201; Stoney and Jones (n. 13 above), chap. 2; *Encyclopaedia Britannica*, 9th ed. (1890), 11:288; and A. P. Cooke, *A Text-book of Naval Ordnance and Gunnery* (New York, 1880), chap. 4.

[26]"Confidential Report," W. O., 33/9, p. 813.

[27]Scott (n. 6 above), p. 28.

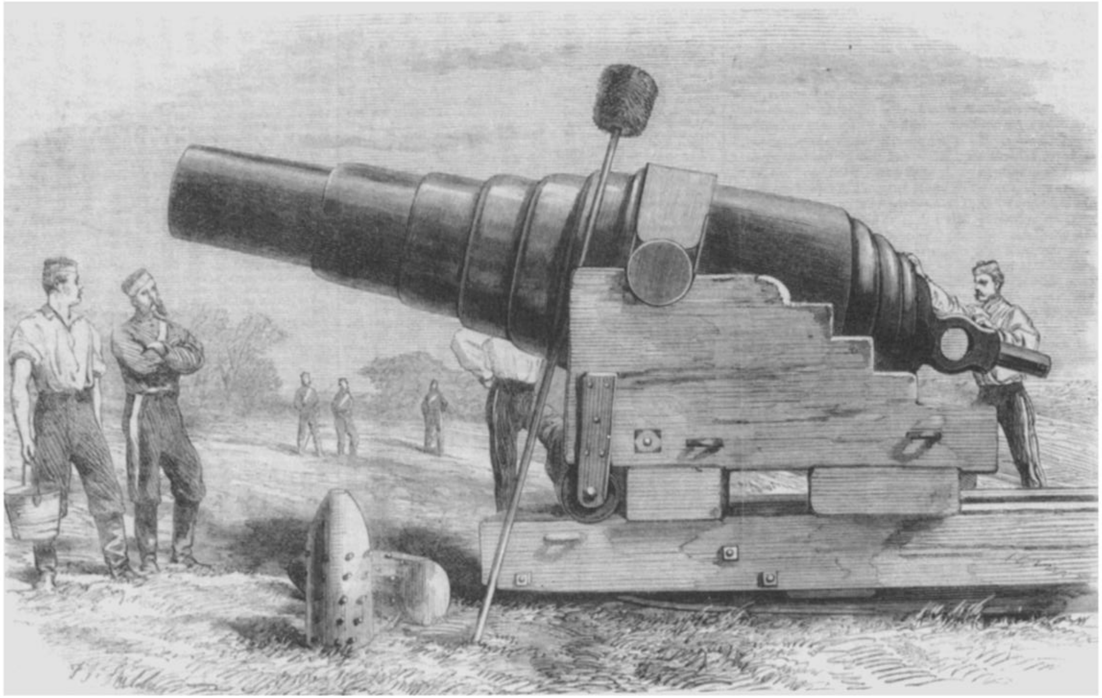

Fig. 1.—The Armstrong 600-pounder monster gun (*Illustrated London News,* December 26, 1863, p. 645)

1858 a special committee recommended the "immediate introduction of guns fixed on Mr. Armstrong's principle."[28]

Armstrong was free to sell his new weapon to anyone. The British government, anxious that France not obtain the gun or its patents, approached him "in order to ascertain the terms on which he would be willing to enter into an engagement with the Government."[29] The secretary of state for war, General Peel, admitted that, "having ascertained the superiority of the gun, the Government could have no hesitation in at once doing everything in their power to make themselves masters of it [and he] had not the slightest hesitation in saying that there was hardly any sum which the Government would have felt themselves justified in refusing for those patents."[30]

Armstrong's business ingenuity matched his engineering talent, and he invented a new kind of relationship with the government that added organizational and political momentum to the development of British military technology. He had spent £12,000 to erect a gunshop beside his crane factory in Elswick, a village on the outskirts of Newcastle. Additional capital investment was now necessary but, before he launched further into the armaments business, Armstrong realized that "some understanding with the Government should be come to on the subject." In a surprising and astute move Armstrong proposed to *give* his patents to the British government and furthermore agreed not to sell his guns to any foreign nation. In return he demanded a guarantee that the capital investment in the new company would not be lost if the government decided to build all the guns at Woolwich or contract them out to others. The government accepted this offer immediately, and a ten-year contract was signed in January 1859. Armstrong transferred his patent rights to the secretary of state for war, and the Conservative government of Lord Derby amended the patent act to ensure their absolute secrecy.[31] The War Office was obliged to buy guns from Elswick "sufficient to keep the works erected and to be erected as aforesaid in full and adequate employment." Further research costs were borne by the government and not included in the prices of the various sizes of guns, which were to be "fair and reasonable." Government approval was required for all experiments and trials. Unresolved disputes would go to the attorney general for arbitration. Armstrong received £2,000 per year in salary,

[28]"Confidential Report" (n. 26 above), p. 813.

[29]Ibid.

[30]*Hansard,* March 4, 1859, col. 1319.

[31]The Patent Bill was introduced on March 21 and passed April 11. See *Hansard,* March 21, 1859, col. 482; the *Times,* April 12, 1859, p. 7; and Armstrong's testimony to the Royal Commission on Warlike Stores, *Parliamentary Papers* 15 (1887): Q. 9265.

backdated to 1856 to compensate for expenditures that the government grants at that time had not covered. Finally, Armstrong was made a knight.[32]

The contract between Armstrong, the Elswick Ordnance Works, and the British government delicately balanced the interests of the state and the business interests of Armstrong and his partners. Each side in the agreement had clear obligations and privileges, but Armstrong benefited most. The success of the new armaments business was guaranteed by the government. Armstrong was appointed engineer of rifled ordnance at Woolwich, where he trained the army's engineers to make his guns and, more important, where he could develop his built-up method for larger guns at government expense. France had been installing steam engines and armor sides on its fleets, and a great invasion scare swept across England in the summer of 1859. Orders to Elswick increased sharply, and the government raised the guarantee to £50,000, then to £85,000 as Armstrong rapidly shifted his main business from hydraulic cranes to armaments. The contract that Armstrong negotiated with the British government was a tour de force that matched the technological feat of his new gun.[33]

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The 40-pounders were given their first battlefield test during the Anglo-French invasion of China in 1860. Palmerston, whose Liberal government had taken power in June 1859, was reluctant to send the breechloaders on this joint venture for fear of allowing the French a close look at them. He suggested that the old smoothbores would "probably do well enough for the Chinese."[34] Nevertheless, the military were anxious to use the guns in action and some were sent on the expedition as supplements to the standard muzzle-loaders. The guns pleased everyone. The commander of the expedition, Sir James Hope Grant, praised the accuracy of the Armstrong guns and the

[32]The *Times*, February 26, 1859, p. 5; *Hansard*, March 4, 1859, cols. 1320, 1322–24, 1332.

[33]The negotiations are in App. 11 of the "Report from the Select Committee on Ordnance," *Parliamentary Papers* 6 (1862), and in the testimony of that report, Qs. 2339–51. Copies of the contracts signed on January 15 and 16, 1859, are in the "Report of the Committee on Military Organization," App. 10, *Parliamentary Papers* 7 (1860): 723–27. See also *Hansard*, March 11, 1859, col. 38. Armstrong's responsibilities as engineer of rifled ordnance are described in W. O., 33/9.

[34]Palmerston to Herbert, October 5, 1859, in Arthur (Lord) Stanmore, *Sidney Herbert, Lord Herbert of Lea: A Memoir* (London, 1906), 2:298–99.

power of their shells.[35] The Duke of Cambridge felt convinced that "the efficiency of the Armstrong guns [was] completely established," and to him this was "even more important than the whole expedition to China."[36] The *Times* proclaimed the guns "in every respect a success": range, accuracy, power, ease of firing, and the small amount of fouling which required only infrequent washing. Armstrong breechloaders cost more than muzzle-loaders but they were "a good investment," and the *Times* advocated that breechloaders be introduced into all land and sea forces, believing that Armstrong guns were "not likely to be practically superseded for some time to come."[37]

The navy, also much impressed by the new breechloaders, immediately requested, "in the strongest manner," that the War Office send them a "large number" of 70- and 110-pounders. Armstrong cautioned that the explosive force of the 110-pounder had approached the limits of what its breech mechanism could withstand, but the admiralty insisted on having the guns without subjecting them to trials.[38] The price of this imprudence was paid during another of Britain's imperialist campaigns in Asia. The 40-pounders performed again without trouble in the naval bombardments of two Japanese ports, but ventpieces blew out on the 110-pounders, confirming Armstrong's fears about the limits of their strength. After the second engagement the admiralty ordered a full report and captains of the British ships confirmed that, while the 40-pounders performed without technical problems, the ventpieces on the 110-pounders were inadequate.[39]

Meanwhile, two technological innovations reduced the need for breech-loading on any gun. First, rifling techniques were developed by Armstrong and others that allowed rifled artillery to be loaded through the muzzle, and second, a young Irish major, William Palliser, developed a method by which rifled wrought-iron tubes could be inserted into the barrels of old smooth-bored muzzle-loaders, thereby transforming them into rifled muzzle-loaders. There was no need for loading at the breech, nor was it necessary to build new guns. Palliser's innovation meant that Britain's very large inventory of cast-iron guns could be converted into rifled guns at one-third the cost of manufacturing new rifled muzzle-loaders.[40] Since breechloaders cost even

[35]Grant to Herbert, August 18 and September 8, 1860, ibid., pp. 335–36, 338.

[36]Cambridge to Herbert, November 3, 1860, ibid., p. 338.

[37]The *Times*, November 5, 1860, p. 6.

[38]"Report from the Select Committee on Ordnance," *Parliamentary Papers* 11 (1863): 5.

[39]"A Copy of the Report of Admiral Kuper in Reference to the Armstrong Guns in the Action of Simonosaki," *Parliamentary Papers* 32 (1865): 309–18.

[40]*The Dictionary of National Biography* (1921), 15:118.

more than new rifled muzzle-loaders, the War Office purchased the rights to use Palliser's conversion techniques and, in 1863, stopped all production of breechloaders, paying Armstrong's company compensation according to the 1859 agreement. The British army and navy relied henceforth on the new muzzle-loaded artillery and naval ordnance. The Duke of Cambridge, one of the earliest and most enthusiastic supporters of breechloaders, demanded proof that the advantages of converted muzzle-loaders were sufficient to warrant the high costs of changing back.[41] After trials confirmed the technological value and tactical worth of Palliser guns, Woolwich busied itself converting the army's stock of cast-iron guns into rifled muzzle-loaders.[42]

General John Adye reopened the question of breech-loading field guns when he became director of artillery in 1870. But he said he was "bound to point out the grave defects which have since become apparent in the Armstrong system": the "complicated" and "delicate" breech system; the sophisticated ammunition; the need for constant attention; the necessity to use the best and most costly materials; the fact that "skilled artificers and special tools" were required to service and repair it; the need for highly trained gunners to operate it without accident or breakdown. Armstrong insisted that accidents were due to careless or untrained gunners and that breakdowns were the consequences of the inferior materials and the cost-saving modifications of his design used by Woolwich engineers. There is no doubt that both Conservative and Liberal governments were always pressing for Woolwich to find ways to reduce their military budgets. The report ignored the excellent performance of the smaller breechloaders, and Adye's claim that rifled muzzle-loaders were sturdier and "better adapted for the rough purposes of war" than breechloaders was as much a result of the general political context of financial restraint as it was a consequence of technological comparisons. Muzzle-loaders were much cheaper to build and maintain than breechloaders, and their limitations had not yet been demonstrated in battle. For example, they had been sufficient in the successful campaign in the mountains of Abyssinia in 1868,[43] and performance in

[41]General John Adye, "Memorandum by the Director of Artillery, on the Breech-loading System of Field Artillery, April 1870," *Departmental Papers Relating to Muzzle-loading versus Breech-loading Rifled Field Guns*, W. O., 33/21A.

[42]O. F. G. Hogg, *The Royal Arsenal* (London, 1963), 2:1417.

[43]General John Adye, "Memorandum on Breech-loading," W. O., 33/9; the *Illustrated London News*, May 16, 1868, p. 484, July 4, 1868, p. 5, August 1, 1868, pp. 104, 110. Breech-loading was brought back in the 1880s with the second wave of technological innovations in armaments.

war was the main determinant of attitudes toward innovations in weapons technology.

* * *

In 1860, amid the excitement over Armstrong's breech-loaded artillery, the first ironclad warships were launched, challenging artillery engineers to build more powerful guns. Interest in protecting the sides of wooden ships with iron plates had been growing since Henri Paixans introduced his exploding shell in the 1820s as a means by which the French navy could overcome the numerical advantage in ships enjoyed by the British navy. Soon all navies carried shells as well as shot. The British used shells with great effect against Burma in the 1820s and China in the 1830s and 1840s, but the Russians demonstrated the devastating effect of shells against wooden ships when they destroyed the Turkish fleets at Sinop in 1853 and drove back the British and French naval assaults on Sevastopol in 1854. The allies, led by France, responded by constructing low-draft gun vessels with sides protected by 4-inch iron plates. The thirteen "floating batteries" built during the winter of 1854–55 could not be sunk by Russian shells and played an important role in driving the Russians out of Sevastopol.

After the war the British admiralty laid up its ships and floating batteries. British naval supremacy rested on sailing-ship technology, and the British admiralty believed that the adoption of new technologies such as steam engines and iron-covered hulls would cost Britain, with its very large fleets, much more than other countries. Thus the policy was to resist technological change until such time as other navies made it imperative. The French admiralty, on the other hand, continued its search for a technological solution to end its humiliation before the mighty British fleets during diplomatic confrontations over imperial spoils. Under the personal eye of Napoléon III, the French navy installed more steam engines in its fleets and drew up plans for an ironclad frigate, a midsized ocean-going warship.

The surveyor of the British navy, Sir Baldwin Walker, watched events in France closely and in 1858 declared that the time had come for Britain to build a navy of iron and steam.[44] Walker's report on the naval balance with France compounded the anxieties in Britain over signs of a rapprochement between France and Russia. This had prompted the admiralty to warn that British naval strength should be

[44]"Report from the Select Committee on the Board of Admiralty," *Parliamentary Papers* 5 (1861): Q. 1703.

greater than the combined forces of France and Russia.[45] Sir John Pakington, the first lord of the admiralty, was "mortified and vexed" by Walker's report.[46] The queen, on her return from a visit to the naval dockyard that the French were extending at Cherbourg, added her voice to the alarm.[47] The Conservative government of Lord Derby accepted Walker's analysis of the situation and accelerated the pace of conversions to steam power.[48]

In addition, Pakington took "very strong representations" to the Cabinet on the need for iron ships where his colleagues "entirely acceded to the necessity of taking action as soon as possible."[49] The admiralty, determined to maintain indisputable British naval superiority, resolved to build two ironclads which were technologically superior to the French.[50] They learned more about the French ship to ascertain what specifications met that objective.[51] The government called on Britain's civilian shipbuilders, who had been building iron ships for many years, to help design and build the new warships. The contract went to a private shipyard, and the first British iron warship, the *Warrior,* was launched on December 29, 1860, only a few weeks after the French ironclad, *La Gloire,* had finished its sea trials.

The 4.5 inches of iron that both ships carried could not be penetrated by any gun. *Warrior,* built before the weakness of the breech mechanism on the 110-pounder had been demonstrated in battle, carried ten Armstrong 110-pounders and four 70-pounders along with twenty-six 68-pounder smoothbores, still the navy's most powerful weapon at short range. But none of these guns threatened the French ironclad. When news of *La Gloire* had reached Britain in 1858, the admiralty immediately began testing the strength of iron plates and soon discovered that only 4 inches of wrought iron was impervious to the shot fired from the 68-pounder at the very close range of 100 yards.[52] Artillery experts at the War Office scrambled to respond, and General Jonathan Peel, the secretary of state for war,

[45]James P. Baxter, *The Introduction of the Ironclad Warship* (Cambridge, Mass., 1933), pp. 119–20; Kenneth Bourne, *The Foreign Policy of Victorian England 1830–1902* (Oxford, 1970), pp. 78–80, 96–98, 100, 114.

[46]"Report on the Board of Admiralty" (n. 44 above), Q. 1706.

[47]Andrew Lambert, *Battleships in Transition: The Creation of the Steam Battlefleet 1815–1860* (Annapolis, 1984), p. 71.

[48]Ibid., pp. 75, 77–78.

[49]"Report on the Board of Admiralty," Qs. 1287–88.

[50]Ibid., Q. 1706; Baxter, pp. 123–24.

[51]"Report on the Board of Admiralty" (n. 44 above), Q. 1287.

[52]Baxter, pp. 123–28.

set up a Special Committee on Rifled Ordnance to investigate the state of British artillery and suggest improvements.[53]

Peel's committee examined the guns of seven inventors but five of these were quickly eliminated, leaving only those of Armstrong and another civilian engineer, Sir Joseph Whitworth.[54] Whitworth had been developing rifled projectiles to be fired from the navy's standard 68-pounder (which he rifled on his own design). His shell failed to have any appreciable effect on iron plates, however, and, more important, did not seem likely to have an effect in the near future. It was during these trials that Armstrong's breech-loading guns had impressed everyone. They were not designed to penetrate iron and Armstrong realized that a breech mechanism could not be made to withstand the explosive power required to send a shell through thick iron.[55] But he was confident that, using his built-up method and a new kind of rifling, he could construct a gun that would sink *La Gloire*. His technological ingenuity had been demonstrated, and he convinced the government that he could build a gun to sink ironclads.

Breechloaders had reached the limit of their strength and thus Armstrong turned to designing a second generation of built-up guns, rifled muzzle-loaders. Rifling had made breech-loading essential in 1855, but by 1859 innovations in rifling techniques made possible the loading of heavy guns through the muzzle. Armstrong developed a version of rifling first proposed by a French colonel in 1842, which took a shell with three rows of studs attached to its sides. First, at the muzzle end, three wide grooves were cut in the barrel, each with a deep and a shallow end (like the bottom of a swimming pool, or a continental shelf). This two-level groove continued down the barrel several inches, at which point the shallow end began to cut gradually deeper until it was level with the side that was deep throughout the length of the barrel. The point at which the floor of the shallow side began to drop varied according to the caliber of gun, as did the distance over which it fell to the same level as the deep side.

In loading the gun, the studs slid easily down the deep side of the grooves. When they reached the point at which the entire bottom of

[53]"Confidential Report" (n. 26 above); "Report from the Select Committee on Ordnance Expenditure Incurred since 1858," *Parliamentary Papers* 11 (1863): iv; Tennent (n. 21 above), pp. 125–26.

[54]"Report from the Select Committee on Ordnance" (n. 38 above), p. 4.

[55]McNeill (n. 6 above, p. 239) suggests that the admiralty rejected Armstrong's 110-pounder because it failed to penetrate the armor on *La Gloire*. This is incorrect. No one at the time who was familiar with gun technology, and certainly not Armstrong, expected or claimed that his breechloaders would sink ironclads.

the groove was level, the studs struck a switch that shunted the shell to the "shallow" side of the cut (which was now at the same depth as the loading side of the groove). When the gun was fired, the centrifugal force caused by the rifling pressed the shell against the shallow side of the groove. It rode up the slope until it was firmly against the walls of the barrel just before it emerged from the muzzle.[56] Thus a rifled gun was built which eliminated the weak moving parts of a breech mechanism. It was to construct very large muzzle-loaders on the built-up method and with this ingenious rifling that the British government turned over the facilities at Woolwich to Armstrong in 1859. Breechloaders had reached a technological plateau, but the limit of the built-up method remained unknown. Armstrong set out to find it.

* * *

The rifled muzzle-loaders that Armstrong built were truly extraordinary in size and power. His largest breechloader, the 110-pounder, weighed 4 tons, and the navy's 68-pounder, just under 5 tons. But Armstrong soon produced rifled muzzle-loaders of 12 and 22 tons that fired shells of 300 and 600 pounds, respectively. They exploded 60–140 pounds of powder, while the largest breechloader, the 110-pounder, used only 10–14 pounds. These guns had various names. Their generic name was rifled muzzle-loaders, Armstrong's version sometimes being identified as a "shunt" gun, but these enormous machines became known popularly as "monster" guns, a name that perhaps better reflected the excitement and the anxiety over the new level of destructiveness that was being brought into existence.

These great guns had a dramatic impact on British defense policy. However confident Armstrong was that he would build a gun that would penetrate iron, such a gun would be so large and heavy that no existing ship could carry it or absorb the enormous recoil force when fired. Even the secretary of the admiralty, Sir Clarence Paget, accepted the idea that technology required that the army take on a greater role in defending British shores. He admitted that "naval men naturally prefer ships to forts"—he did not add that military men naturally prefer forts to ships—and proclaimed that "there can be no doubt that forts must ever be stronger than ships." He insisted "that as regards ships, there must be a limit . . . to the size of the gun and

[56]Stoney and Jones (n. 13 above), pp. 2, 14–15; Alexander Holley, *A Treatise on Ordnance and Armor* (New York, 1865); Warren Ripley, *Artillery and Ammunition of the Civil War* (New York, 1970), p. 139.

the thickness of the plate which they can carry. But in a fort there is no limit."[57]

Marine architects studied new and radically different ship designs to overcome the problem, but in the meantime the size of gun required to defend against ironclads provided an opportunity for the British army to claim that it was now the front line against invasion. For twenty years the army and marines had been accumulating prestige at home by protecting proclaimed British interests abroad: China and the Middle East in 1840, Crimea in 1855, India in 1857, and China again in 1858. Shortly after taking office in 1859, the secretary of state for war in Palmerston's second government, Sidney Herbert, proposed a fundamental change in British defense strategy, which greatly expanded the responsibilities and prestige of the British army. "We must," he argued in cabinet, "look at our Army now altogether from a different point of view. Our insular security as such is lost. No mere preponderance of our fleet in the Channel can insure perfect safety."[58]

Palmerston agreed and appointed a Royal Commission on the Defense of the United Kingdom to design a series of coastal fortifications that were safe from guns fired from ironclads. Sir William Armstrong would supply the forts with guns that would sink those ships. The two Spithead forts at the mouth of the Thames overlooked 2,400 yards of water. Hence, to ensure that an ironclad like *La Gloire* must come within effective range of the guns in one or the other fort, the guns had to penetrate 4.5 inches of iron from a distance of 1,200 yards. The forts were expensive (£12 million), were undertaken before Armstrong had produced a gun to put in them, and were the subject of vociferous debate over their military value. Armstrong's position as engineer of rifled ordnance at Woolwich was attacked as one that gave him an unfair advantage. Thus, the pressure to deliver the gun for which millions were being spent and strategic policy changed was, to say the least, intense. As Palmerston reported to the queen, if Armstrong could make a gun to sink *La Gloire* from 1,200 yards, "then there can be no doubt as to the usefulness of the forts," but if he failed then "some other arrangement" for the defense of British arsenals and dockyards would be necessary.[59]

Armstrong completed his first 300-pounder in the spring of 1862 and delivered it to the government firing range at Shoeburyness, at

[57] *Hansard,* March 31, 1862, col. 285.

[58] Stanmore (n. 34 above), 2:211–12.

[59] Palmerston to Victoria, June 22, 1862, in George E. Buckle, *The Letters of Queen Victoria,* 2d ser. (Toronto, 1926), 1:38. See *Hansard,* April 11, 1862, cols. 842 and 846, for comments by the Duke of Cambridge.

the mouth of the Thames (fig. 2). The test, held in April, was observed by an illustrious audience: the Duke of Cambridge on behalf of the army, the Duke of Somerset and Lord Clarence Paget from the admiralty, Sir John Hay of the Special Committee on Iron Plates (a government committee made up of military and civilian experts, including Sir William Fairbairn, the ironmaster who made the plates), and Samuda the shipbuilder. Behind them stood many lesser witnesses from the War Office and admiralty. The day after the test the *Times* published an enthusiastic and dramatic account of the event. The gun, the editor wrote, "was tried against that great champion of heavy weights which has hitherto come off victorious in all encounters—the redoubtable Warrior target." After several shots all doubts were resolved about the new champion. "With an indescribable crash that mingled fearfully with the report of the gun, the shot struck upon a comparatively uninjured plate, shattering the iron mass before it into little crumbs of metal, splintering the teak into fibres literally as small as pins." Another shot, with a larger charge behind it, drove completely through the target and "even the fondest believers in the invulnerability of our present ironclads were obliged to confess that against such artillery, at such ranges, their plates and sides were almost as penetrable as wooden ships. . . . Admiralty officials and armour shipbuilders could only admit to each other in a kind of confidential dismay, that artillery had at last proved too much for them."[60] The report exaggerated the effects of the gun—the target had been weakened by previous tests and the shot had not passed completely through the iron skin behind the wooden backing[61]—but it was obvious that the *Warrior* target, which had defied gunmakers for two years, was about to fall to the Armstrong gun. Fears of a French invasion had disappeared, but the development of monster guns continued, pushed along by the growing numbers of politicians and military authorities who had committed themselves to the project, by Armstrong's desire to press his built-up method to its limits, and the excitement over monster guns among the population at large.

* * *

At this moment Sir Joseph Whitworth returned to challenge Armstrong for the title of Britain's greatest gunmaker, thus generat-

[60]The *Times,* April 10, 1862, p. 9.

[61]*Hansard,* April 10, 1862, cols. 765–66. The skin referred to was five-eighths of an inch of iron plate attached to the wooden backing of the target to represent the iron hull of the *Warrior.* That is, the total thickness of iron on the *Warrior* was close to 5 inches. However, it was customary to speak only of the thickness of the iron plating in front of the wood.

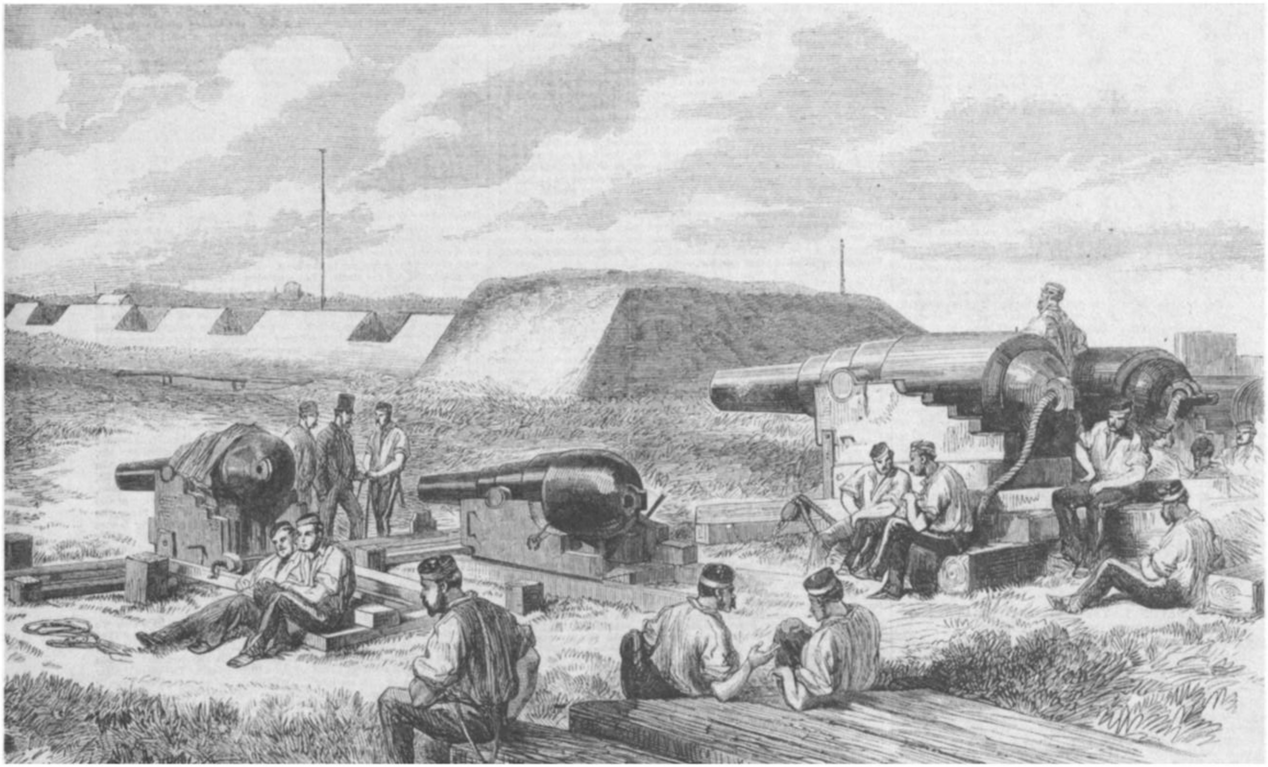

Fig. 2.—Shoeburyness artillery test range (*Illustrated London News*, August 20, 1864, right-side half, p. 189)

ing further interest and imparting greater momentum to the development of modern artillery. Whitworth was Armstrong's only serious rival. Trained in the engineering works of the great Henry Maudsley, Whitworth had opened his own business in 1835 in Manchester where he produced cutting, planing, drilling, and shaping machines of unprecedented accuracy and helped Britain establish its reputation as the workshop of the world. By the early 1850s, when Armstrong was still a relatively obscure engineer in Newcastle, Whitworth had gained a national prominence as an adviser to British governments. In 1854 he served on a committee that investigated technological developments in the United States, was granted nearly £13,000 by the government to improve the machinery to manufacture rifles for the Crimean War, and developed his famous device that could measure a millionth of an inch. After the war he received a further grant to rifle artillery.[62] Thus, the Crimean War brought both Armstrong and Whitworth into the armaments industry, and they remained fierce competitors for the next three decades.

After losing out to Armstrong in 1858, Whitworth returned to Manchester and continued his rifling experiments. His immediate goal was to penetrate the *Warrior* target before Armstrong did. In 1860 he attained partial success against the *Trusty* target (4 inches of iron on 25 inches of wood).[63] Armstrong's 300-pounder test in April 1862 indicated he was close, but on September 25, 1862, Whitworth became the first to pierce the *Warrior* target completely. Moreover, he did so from 600 yards. A second series of tests against a new *Warrior* target—held in early November and witnessed by representatives from the War Office, the admiralty, and a number of civilian engineers—repeated the success.[64]

This test became the first shot in a battle between Armstrong and Whitworth over whose gun would best sink ironclads. Armstrong was well aware that the definition of technological efficiency could be affected by social and political factors, and the publicity over Whitworth's success prompted him to responded immediately. In a letter to the editor of the *Times*, a popular forum for technical disputes among inventors, he claimed that the test had been carried out by Whitworth supporters at the War Office and thus represented "not so much what is to be fairly said upon the subject as what can be said upon the subject by the friends of Mr. Whitworth." The Armstrong

[62]See n. 17 above.

[63]The *Times*, February 27, 1860, p. 5, and May 28, p. 12. *Trusty* was one of the floating batteries used in the Crimean War.

[64]The *Times*, November 4, 1862, p. 12 (reprinted from the *Army and Navy Gazette*); Tennent (n. 21 above), p. 298.

gun, he said, fired "much slower in the columns of some of the newspapers than they do anywhere else." Armstrong ended his letter with two important points. First, he claimed that the gun used by Whitworth to penetrate the *Warrior* was neither of Whitworth's own design nor constructed by Whitworth himself. It was, he said, built on the Armstrong built-up design in the Royal Gun Factory by Woolwich engineers. Second, he proposed a competition to determine whose gun—or, actually, whose shell—was the most efficient against ironclads.[65]

The opportunity toward which Whitworth had been working since 1858 had come, and he promptly grasped it.[66] He accepted Armstrong's challenge a few days later, claiming that the trials in 1858, from which Armstrong had gained so much, had been controlled by Armstrong's friends. He pointed out that Andrew Noble, the secretary of the 1858 Committee on Rifled Cannon, had joined the Elswick Ordnance Company shortly after the competition. Whitworth did not deny that he had used the built-up method to make his gun, but he claimed that he had used that method in 1855. The general idea of shrinking coiled hoops around a core had been known long before Armstrong had come along and each of them, he said, simply used the idea in their own way. His gun had to be constructed at Woolwich only because his Manchester factory was too small. Whitworth admitted that the general manager of the government arsenal, John Anderson, had provided him with assistance in making the gun, but he insisted that the gun was rifled in a manner developed by him.[67]

Except for the reference to rifling, this was all extremely misleading at best. The War Office, in its continuous quest for cheaper guns and its policy of promoting competition among the private inventors, had become interested in Whitworth again after his shell nearly penetrated the *Trusty* target in 1860. It requested Anderson to advise Whitworth on the construction of the gun with which he could test his shell against the *Warrior* target. Anderson examined the design of Whitworth's cast-iron gun and insisted that it be changed into an Armstrong built-up gun of wrought iron. Anderson realized that Whitworth's cast-iron gun would not withstand the explosions required, and he was not going to be held responsible. Whitworth was forced to accede to the demands of technological efficiency. This was the gun that Whitworth used against the *Warrior*.

The question of whether the gun used by Whitworth was an Armstrong built-up gun became a topic of intense debate in the press,

[65]The *Times*, November 6, 1862, p. 4.
[66]Ibid., November 10, 1862, p. 5.
[67]Ibid., November 13, 1862, p. 9.

as indeed did the general question of artillery design.[68] Armstrong was willing to spend a great deal of time and effort protecting his reputation as the inventor of the built-up method. Whitworth was not the only one who had attempted to claim developing it separately from Armstrong. Armstrong was correct when he said that he had "just reason to complain of Mr. Whitworth, Mr. Lyonal Thomas and others having guns made for them in the R. G. F. upon my principles, by my methods and according to drawings supplied by persons who have derived all their information and experience under me—and that these guns should be used in competition with my own guns and should go forth to the world as the inventions of my opponents."[69]

The question was investigated by the Select Committee on Ordnance. The crucial witness was John Anderson, a civilian engineer who had been at Woolwich since 1842 and had been appointed Armstrong's assistant in 1859. Armstrong had taught Anderson how to manufacture a built-up gun and Anderson had supervised the building of them at Woolwich while Armstrong carried on further research and development.[70] He meticulously prepared to prove that the gun with which Whitworth had penetrated the *Warrior* was an Armstrong gun. Armstrong asked a young lawyer, Stuart Rendel (son of James Rendel, the man who had encouraged Armstrong to take up the artillery question in 1854), to help him. He wanted to ensure that the right questions were asked of Anderson and Whitworth by two supporters of Armstrong on the committee, Henry Jervis and Sir John Hay. Rendel also coached Anderson to ensure his evidence about the construction of Whitworth's gun would be clear.[71] Anderson, who had nothing to hide, confirmed to the committee that Whitworth had used an Armstrong built-up gun to penetrate the *Warrior* target.[72]

[68]*London Review of Politics, Society, Literature, Art and Science*, November 14, 1862, pp. 423–24, and December 6, pp. 490–91, 505. Whitworth replied on December 6, 1862, pp. 490–91 and the *Review* added a final comment on December 6, p. 505. Tennent (n. 21 above) was sympathetic to Whitworth. Stuart Rendel no doubt wrote on behalf of Armstrong in "Mr. Whitworth and Sir Emerson Tennent," *Fraser's Magazine* (May 1864), pp. 639–54. Tennent replied briefly in the July issue, pp. 133–34. The case for the superiority of the Armstrong design was provided by Stuart Rendel's brother, George, in "Rifled Ordance in England and France," *Edinburgh Review* (April 1864), pp. 480–529.

[69]Rendel Papers, Newcastle, Tyne and Wyre Public Archives, 31/3372.

[70]See Anderson's testimony to the Select Committee on Military Organization, *Parliamentary Papers* 7 (1860): Qs. 5716–81.

[71]Rendel Papers, 31/4.

[72]"Report from the Select Committee on Ordnance" (n. 38 above), Qs. 858–64.

Armstrong also prepared Jervis and Hay to question Whitworth. He asked Rendel to ensure that the correspondence between Whitworth's Manchester Ordnance Company and the Royal Gun Factory, which showed Whitworth had agreed to use a built-up gun, was in front of the two committee members. He sent Rendel to visit them and acquaint them with Anderson's role.[73] Finally, Armstrong provided specific questions to be put to Whitworth. If, for example, Whitworth repeated the claim that he had made in the *Times*—that he had made a built-up gun in 1855—he should be asked to produce it and explain why he did not use it at the competition with Armstrong in 1858.[74]

This preparation paid off. Jervis and Hay questioned Whitworth closely and, when forced to state that either Anderson must "eat the words which he used before the committee" or admit that his design had been changed, Whitworth conceded the latter.[75] When he repeated the claim that he had used the built-up principle in 1855 and Jervis asked where the gun was, Whitworth admitted that he had never finished it.[76]

This sort of factional infighting is the kind of process on which the social constructionists focus as *determining* technological invention. It was very important—Armstrong certainly knew so—but it remains a process of revealing reality, not formulating it. A Whitworth cast-iron gun could never be socially constructed into a gun that had the technological efficiency of an Armstrong built-up gun.

The relative efficiencies of a Whitworth and an Armstrong *shell* did, however, open the way for some social construction of artillery. Armstrong had successfully defended his reputation as the man who invented the built-up gun. Nevertheless, a Whitworth shell had been the first to penetrate the *Warrior* target. His great rival had moved ahead of him in armor-piercing shells. A new competition was therefore in order. Each inventor proclaimed that he could penetrate the *Warrior* target from at least 1,000 yards, which was very close to the standard on which the government's forts depended, and each challenged the other to a new battle of the guns.[77] More than anticipated profits drove these two; indeed, there is no evidence that either of them expected to harvest large profits. The government

[73]March 8, 1863, Rendel Papers, 31/3372.

[74]Ibid.

[75]"Report from the Select Committee on Ordnance" (n. 38 above), Qs. 1131–54.

[76]Ibid., Qs. 1204–9, 1488–1509.

[77]"Report of the Defence Commissioners on Spithead Forts," *Parliamentary Papers* 27 (1862): Qs. 702–53, 309–23. For the exchange between Armstrong and Whitworth, see the *Times*, November 6, 1862, p. 4, and November 19, p. 12.

could choose and, as it turned out, did choose, well before the end of the competition, to build all its heavy guns in the Woolwich factory. The rivalry between Sir William Armstrong and Sir Joseph Whitworth was intense because each man had a reputation to defend and each had an unyielding desire to win over both the other and the great ironmasters, like Sir William Fairbairn and John Brown, who made the plates for ironclad ships. Ironmasters had the advantage over gun manufacturers, and they guarded their reputation closely. For example, when in 1861 the Duke of Somerset claimed that a shot from an Armstrong gun had penetrated 8 inches of iron, the Earl of Hardwicke protested that this was impossible; the Armstrong gun had never penetrated 4.5 inches of plate, and to claim otherwise was "calculated to be highly injurious to the iron manufacturers" of England.[78] Innovations in artillery were rapidly becoming an important matter to Britain's economic and political elite as well as to the military and naval authorities.

In any case it had become clear that both Armstrong and Whitworth would soon send projectiles through armor of even-greater thickness than the *Warrior.* A committee was formed by the admiralty and the War Office to compare and contrast the relative merits of the two kinds of rifling and shells advocated by Armstrong and Whitworth. Both guns were constructed on the Armstrong built-up method, but each used different projectiles and employed distinctive forms of rifling. The object of the Armstrong-Whitworth Committee was to determine what kind of projectile and rifling (and hence whose gun) sank ironclads more efficiently. Armstrong used conical shells and shunt rifling; Whitworth relied on flat-headed shells and hexagonal rifling. The two shells had quite different effects on iron plate. Armstrong's shell delivered greater explosive power, but Whitworth's penetrated deeper. On the other hand, Whitworth's flathead shell punched only a neat hole in the armor while the conical shell crushed a relatively large area. There were other significant differences between the two systems. Armstrong's 300-pound shell contained 50 pounds of powder; the Whitworth shell weighed 130 pounds and required only 25 pounds of powder.[79] The Armstrong-Whitworth Committee investigated various permutations and combinations of power, range, accuracy, size of projectile, amount of charge, and

[78]*Hansard,* June 14, 1861, col. 1058.

[79]Tennent (n. 21 above), pt. 3, chaps. 3 and 4. A description of the Armstrong 600-pounder is in the *Times,* July 21, 1864, p. 12; and two letters from Armstrong to the editor: July 25, 1864, p. 7, and June 27, 1865, p. 14. See also Stoney and Jones (n. 13 above), pp. 12–28, and Ian V. Hogg, *Illustrated History of Ammunition* (n. 20 above).

muzzle velocity, as well as the kind of damage inflicted on the target by each type of gun.[80]

In early 1863, when the competition began, Whitworth rightly claimed to have accomplished the primary goal of piercing 4.5 inches of iron. Armstrong's opportunity to match that claim came in December 1863, when he tested his monster 600-pounder at Shoeburyness. This gun measured over 15 feet long, weighed 22 tons, and had an exterior diameter of over 4 feet and a bore of 13.5 inches.[81] It threw its 600-pound shell 4.5 miles.[82] The shell smashed through a floating *Warrior* target from 1,000 yards and strengthened Armstrong's case for explosive power over simple penetration.[83] In March 1864 the Armstrong 600-pounder fired a 345-pound steel shell against an 11-inch plate made by John Brown. One foot behind this massive iron wall stood a plate of 6 inches made by Sir William Fairbairn. The shell struck the front target at 1,560 feet per second. Never, said the *Times*, had a greater blow been struck by a human agent. "The mass of steel driven by the tremendous charge of powder must have struck the target with a power almost inconceivable, for everything went down before it. The solid oak beams behind the plate itself hurled bodily back against the Fairbairn target and split into two pieces. . . . The 11-inch plate . . . was torn apart."[84] This time there was no exaggeration. Artillery had attained a new level of destructive power. Armstrong's built-up method of constructing large naval guns was never in question and, after March 1864, his conical shell and shunt rifling became standard for heavy naval guns.

Each gun was a piece of superb engineering, each a highly complex machine with particular advantages and disadvantages over the other. The enormous destructive power of the Armstrong shell was certainly impressive but did not alone guarantee the majority of votes on the Armstrong-Whitworth Committee. Armstrong was fully aware of the importance of public opinion and the role the press played in creating images in the public mind. Armstrong's use of the press—and the willingness of the press to be so used—was demonstrated after the December 1863 test of his 600-pounder at Shoeburyness. On December 26, 1863, the *Illustrated London News* published a description and

[80]"Report of the Special Committee on Armstrong and Whitworth Guns," *Parliamentary Papers* 42 (1866).

[81]About this time guns began to be named according to their caliber. Thus the 600-pounder was also called a 13-inch gun.

[82]The *Times*, July 25, 1864, p. 7.

[83]*Illustrated London News*, December 26, 1863, p. 645.

[84]The *Times*, March 19, 1864, p. 7.

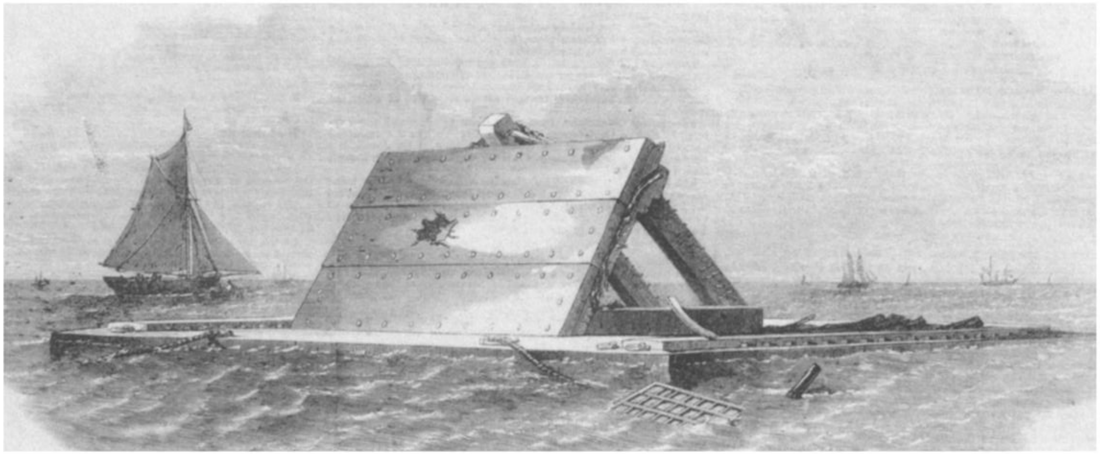

Fig. 3.—Front of the target showing the effect of the Armstrong 600-pounder. (*Illustrated London News*, December 26, 1863, p. 648.)

two illustrations of the damage inflicted on the *Warrior* target. The illustration of the back of the target showed substantial damage and was "right enough," said Armstrong, but the illustration of the front showed only a neat hole, hardly larger than one made by a Whitworth flathead shell (fig. 3). Thus, Armstrong wrote to Rendel, "a very inadequate idea of the injury [was] in consequence conveyed." Armstrong moved swiftly to correct this unhelpful image. "Now it is very important," he told Rendel, "that the Public should know to the full the damage that was done and they will be much more impressed by pictures than descriptions. . . . Under colour therefore of supplying *additional* information (not of correcting errors), I want to get the enclosed communications and sketches inserted in the next number of the Illustrated paper."[85] Rendel visited the editor who published Armstrong's illustration, which conveyed a far more dramatic sensation of his gun's power [86](fig. 4).

The competition between Armstrong and Whitworth continued for another year. A mass of data had been recorded on 50,000 rounds fired over a three-year period, and the "best" system did not simply reveal itself (fig. 5). The Duke of Cambridge had attended the opening trial and recorded in his diary that all the guns tried were "admirable in their way, and leave but little to choose between them."[87] The *Times* had followed the trials closely and saw no obvious conclusions.[88] The complexities of the new armaments and the changes they were bringing about in ships left room for doubt and uncertainty as to the future direction of British ordnance development. The inconclusive results gave added importance to the final stage of the inquiry, the writing of the report. What could not be answered on the testing range would be answered in committee rooms.

It is at this point that the arguments of the social constructionists take on weight. Test results were matters of interpretation and the conventions of technological testing in effect at the time. The committee thus entered the most difficult stage of its work in which elusive, nontechnical factors came into play. Evidence had to be marshaled, rhetorical strategies devised, and arguments organized. All of this was carried out by individuals on the committee who looked

[85]Armstrong to Rendel, December 27, 1863, Rendel Papers, 31/19.

[86]The *Illustrated London News* often illustrated Armstrong weapons; see March 10, 1877, p. 233, and August 16, 1879, pp. 159–60. The articles that accompanied the pictures were written by Stuart Rendel. See J. D. Campbell to Rendel, August 7, 1879, Rendel Papers, 31/4970, and August 13, 1879, 31/3876.

[87]Edgar Sheppard, ed., *George Duke of Cambridge: A Memoir* (London, 1906), 1:249.

[88]The *Times,* May 9, 1865, p. 8; June 8, p. 11; June 27, p. 6. The raw technical data on the guns are in the "Report from the Select Committee on Ordnance" (n. 38 above).

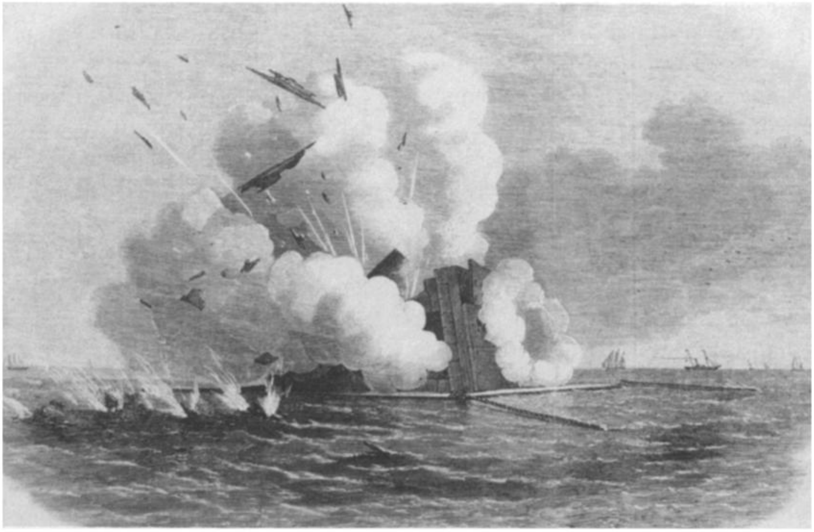

FIG. 4.—Effect of the Armstrong 600-pounder gun revised: "In our Number of the 26th ult. we gave Illustrations of Sir Wm. Armstrong's 600-pounder gun and the floating target which had been built to represent the side of the Warrior. Since the experiment to which these Illustrations referred the target has undergone a most careful survey; and, pursuing the subject we are now able to give additional particulars of the effect produced by the penetration and explosion of a single shell." (*Illustrated London News,* January 9, 1864, p. 37.)

at the facts from different positions within the political-military hierarchy on the one hand and from the scientific-technological community on the other. Each gunmaker had his supporters inside the War Office, and each had been allowed to appoint one member of the committee. Thus, the agents of both gunmakers could point to some evidence from the trials to support their contentions. Armstrong's advocate on the committee was Stuart Rendel. He was not an engineer but made himself an expert on artillery and overcame his initial intimidation at finding himself arguing with generals and admirals.

The debate among the members of the committee continued for months. Alas, they left no minutes of their deliberations. Unlike investigators of contemporary weapons, the historian cannot interview participants to gather evidence on the social construction of technology.[89] Nevertheless, there is evidence that the technological

[89]MacKenzie had the relevant historical documents. "The documents alone, however, would have made little sense to me. The most important input into the research came

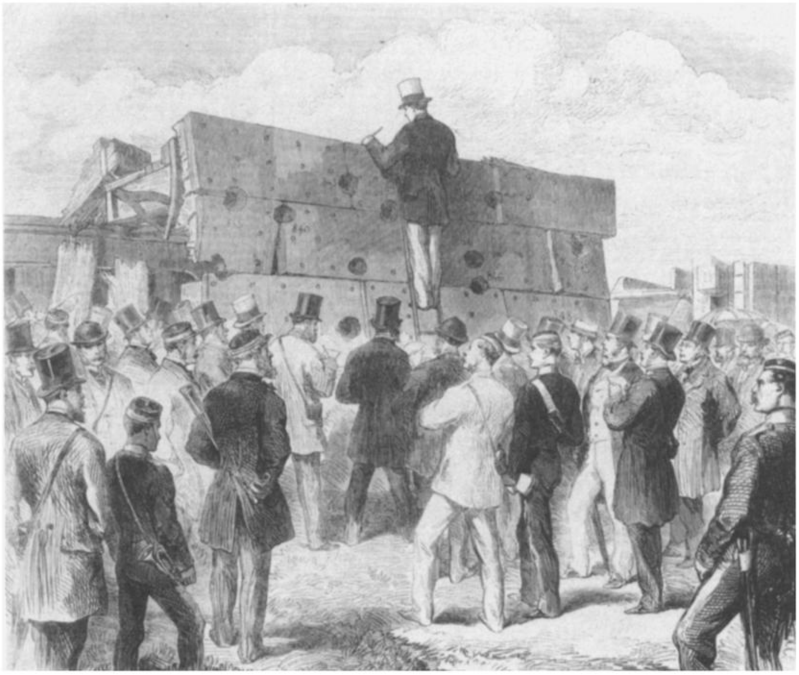

FIG. 5.—Inspection of the *La Gloire* target during artillery experiments at Shoeburyness. (*Illustrated London News,* August 20, 1864, p. 181.)

efficiency of shells was at least in part socially determined. Rendel recalled many years later that "how we came to produce a report fairly capable of construction as generally favourable to Armstrong I can scarcely understand. But so it was, and I may here declare unblushingly the plain fact that but for me the Whitworth case would have triumphed." The committee did recommend the Armstrong shells and Rendel's boast may not be too greatly exaggerated.[90] Yet it must be emphasized that the built-up design for modern artillery was not disputed. Its technological efficiency was accepted by all military engineers. That is why so many inventors like Whitworth tried to claim it as their invention and why Armstrong was determined to protect his reputation as its true inventor.

This second victory over Whitworth did not mean orders from the British government for Armstrong's factory at Elswick. There was no

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from people involved in the development of missile guidance and inertial navigation." He interviewed more than 150 individuals. MacKenzie (n. 8 above), pp. x, 440–45.

[90]Rendel, *Personal Papers* (n. 16 above), pp. 275–76.

contract to supply the British army and navy with rifled muzzle-loaders, and the government decided to manufacture all its heavy guns at Woolwich. Armstrong had been selling his guns on the world market since 1863, however, and the conclusions of the Armstrong-Whitworth Committee enlarged his reputation as one of the world's leading manufacturers of modern artillery and naval ordnance.[91] The interplay between technological efficiency and the "flexible interpretation" of efficiency was transferred to the international arena.

* * *

Between 1865 and 1880 wrought-iron rifled muzzle-loaders were brought to full maturity. The 22-ton gun that appeared so powerful in 1864 was succeeded by guns of even greater power. In 1875 Armstrong built two 18-inch rifled muzzle-loaders for the Italian navy. Each gun weighed 100 tons and could break 22 inches of armor (fig. 6). In 1880 his 16-inch gun, at a distance of 1,000 yards, sent its 1,800-pound shell through 34 inches of armor.

Armstrong had long recognized that the world had entered a new era of naval power during which the rapidly increasing size of ordnance would bring into existence ever-larger ships of war. As early as December 1858 a committee on naval estimates reported that it had been stated to them (presumably by Armstrong) that the Armstrong gun "may supersede the use of ordinary ship's guns, and possibly affect even the size and structure of ships of war."[92] In 1862 Armstrong warned that "we must be prepared for vessels stronger even than the *Warrior,* and should, therefore, go on increasing the size of our guns until we reach some practical limit. The weight of such guns, however objectionable, must be accepted as a necessity, and ships must be adapted for their reception." Whatever the technological difficulties, he said with mid-Victorian optimism, the British people could "rest assured that they [were] of a nature to be overcome by engineering skill."[93]

And so it seemed. The first generation of ironclads—the *Warrior* class—consisted of broadside ships with two dozen or more large guns placed under the deck in rows along each side of the ship. But

[91]The expansion of Elswick into world markets is examined in Marshall J. Bastable, "Arms and the State: A History of Sir William G. Armstrong and Company, 1854–1914" (Ph.D. diss., University of Toronto, 1990).

[92]"Report of a Committee Appointed by the Treasury to Inquire into the Navy Estimates from 1852 to 1858 and into the Comparative State of the Navies of England and France," *Parliamentary Papers* 14 (1859): pt. 1, p. 723.

[93]The *Times,* April 10, 1862, p. 9.

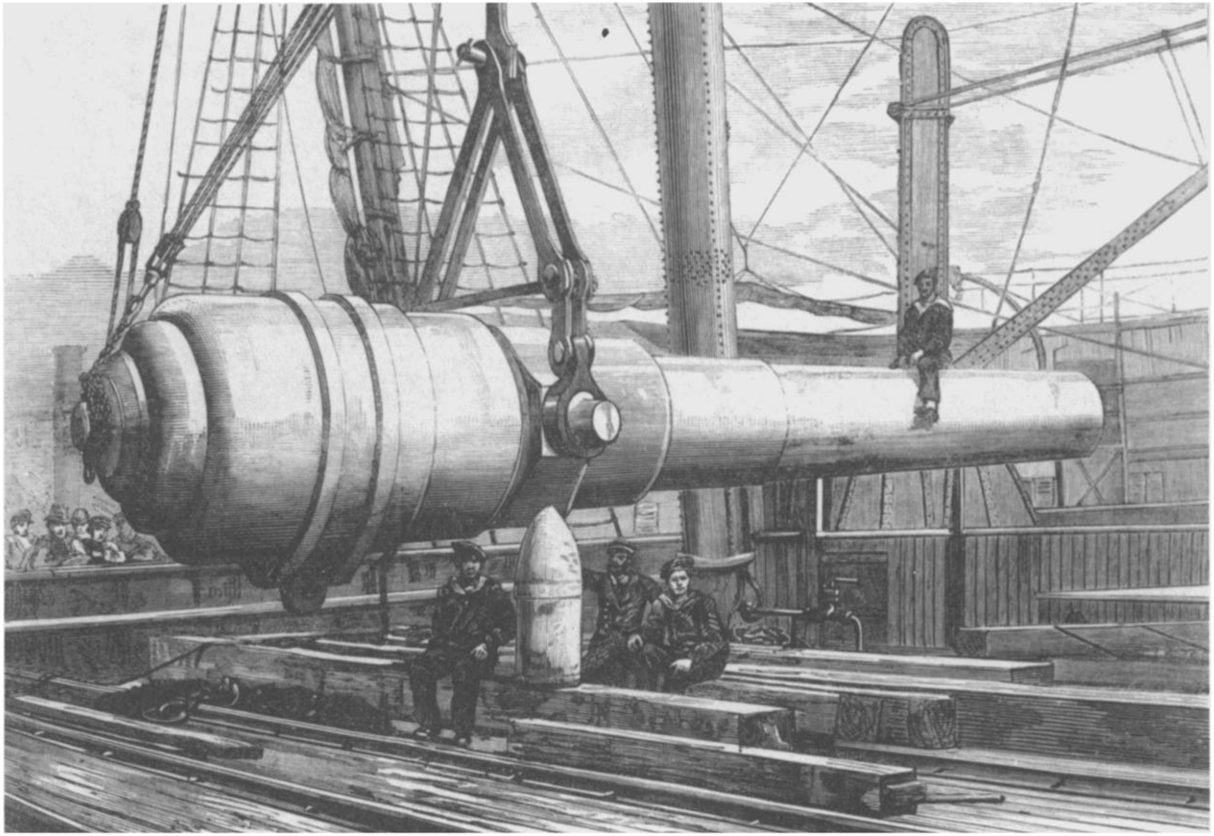

Fig. 6.—Shipment of an Armstrong 100-ton gun to Italy (*Illustrated London News*, July 29, 1876, p. 117)

Armstrong's monster guns were far too heavy and the force of their recoil far too great for the traditional broadside arrangement. Naval architects were forced to adapt warships to accommodate the new ordnance and—after much public controversy, much experimentation, and one major accident with loss of many lives—the turret ship finally emerged as the kind of vessel most capable of carrying monster guns.[94] There were usually four guns placed in the center of the deck in revolving turrets that were protected by extra thick armor (sacrificed by other areas of the ship). Armstrong's great rifled muzzle-loaders had triumphed in the battle between guns and armor and forced the pace of change in battleships.[95] The golden age of monster guns ended in 1880 when steel replaced wrought iron in the making of armaments and set off another wave of technological innovations in military and naval weapons.

* * *

Armstrong's first breechloaders and his monster guns set in motion technological, political, bureaucratic, and industrial forces that established a more intimate link between industry and government. This new relationship reflected the fact that the ability to wage war and build empires had come to depend more than ever before on the industrial capacity of an economy and continual technological innovation by its engineers. The focus on innovation assured a steady increase in the destructive capacity of armaments, limited only by the expansion of scientific and technological knowledge, the creativity of scientists and engineers, and the willingness and ability of governments to finance industrial warfare. The British government encouraged and financed research and development of armaments at first to meet the exigencies of war and later in reaction to innovations developed by the French, who in turn were innovating to overcome the existing superiority of the British navy. The uneven development of weapons technology exacerbated the search by Britain and France for security at home and imperial control abroad.

The decision to introduce technological innovation in the production of weapons was taken by governments, but the major changes in armaments—more so in Britain and Germany than in the United

[94]Articles on the navy began to appear in the better journals in 1864, at the climax of the Armstrong-Whitworth competition. See, e.g., "The Fleet of the Future," *Blackwood's Edinburgh Magazine* (March 1864), pp. 267–82, and "The Condition and Prospects of the Navy," *Fraser's Magazine* (January 1865), pp. 61–82.

[95]Robertson (n. 25 above) argues that navies had always redesigned their ships to accommodate guns developed for land warfare. See pp. 266–95 for the period between 1860 and 1880.

States or France—came from private entrepreneurs and civilian engineers.[96] Men like Armstrong quickly expanded the military applications of metallurgical, chemical, and ballistic knowledge and imparted to weapons technology a momentum toward increasingly greater destructive power delivered over increasingly longer ranges. With his built-up method, Sir William Armstrong overcame a fundamental technological problem that had frustrated military engineers for centuries.[97] Others also made artillery that performed very well, but there was more to armaments than technology. As *The Engineer* pointed out in 1868 in its report on a major battle in South America, "the Defeat of the Spanish fleet at Callao is undoubtedly a triumph for the Blakely and Armstrong guns (the first more especially), used by the victorious Peruvians. . . . It will be Captain Blakely's own fault if he does not make political, or, rather, commercial capital out of the affair."[98] But by then it was too late. Armstrong was forging ahead with his new technology, developing political and military support around the world, expanding his armaments business, and speeding along the industrialization of war and the militarization of technology and culture.

[96]Major Palliser and Colonel Edward Boxer are important British exceptions to the often expressed belief, lately repeated by van Creveld (n. 6 above, p. 220), that "all the most important nineteenth century military devices originated in the minds of civilians."

[97]McNeill (n. 6 above, p. 240) gives the false impression that "Woolwich experts" developed rifled muzzle-loaders.

[98]*The Engineer,* June 15, 1868, p. 437.