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Reverse engineering as history and method: The Portuguese *espingarda* in Chosŏn Korea

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ABSTRACT

How does one reverse engineer a technical artefact, let alone build a system of knowledge, use, and production around it? This article investigates Korean artisans and practitioners in the sixteenth and seventeenth centuries, and their efforts to understand and rebuild the Portuguese *espingarda* (matchlock musket). What emerges, first, is a hitherto untold story of how a global artefact became reconstituted in Korea – a process that generated new practices, practitioners, and unexpected innovations. In telling this story, a second, methodological contribution is made: the demonstration of a hands-on approach to historical research that investigates material objects and, in this case, does so through the very act of reverse engineering, defined here as mechanical dissection.

KEYWORDS

Reverse engineering; experimental history; Chosŏn Korea; historical method; copying; innovation

Introduction

Sometime before 1781, blacksmith Samch'ang (三昌, n.d.) and his assistants toiled beside the unbearable heat of a finery forge. As always, they melted and hammered ingots of pig iron down to the purest form possible, and wrapped the metal around a mandrel (cylindrical rod). The resulting tube was then passed onto their colleagues – borer Oksŏn (玉善, n.d.) and his men – who reamed its interior with a succession of steel bits. But after that intervention this barrel still required over a dozen more craftsmen – including filers, drillers, screwsmiths, brass platers, lacquerers, stock makers and, above all, the workshop supervisor Kim Sihŭng (金時興, n.d.) – to culminate in a Korean matchlock musket (see Figure 1).[1]

This object is still in existence, bearing the marks of its makers. The retrieval of the foregoing vignette, however, was only possible through a thorough disassembly of the gun. I used wooden mallets to hammer out the pins that fastened the barrel to the stock, and then separated the breech plug, ignition lock, and trigger mechanism, by pulling and undoing every possible part. What eventually emerged into view was not only the abovementioned elements, but clues to understanding the very structure of an early modern gun shop, as well as the complex materiality of the artefact and its past.

The experience of disassembling led me to see reverse engineering as both history and method; that is, as a technology of production in the past, as well as a way of writing history in the present. The matchlock – a gun operated by the strike of a match-holding

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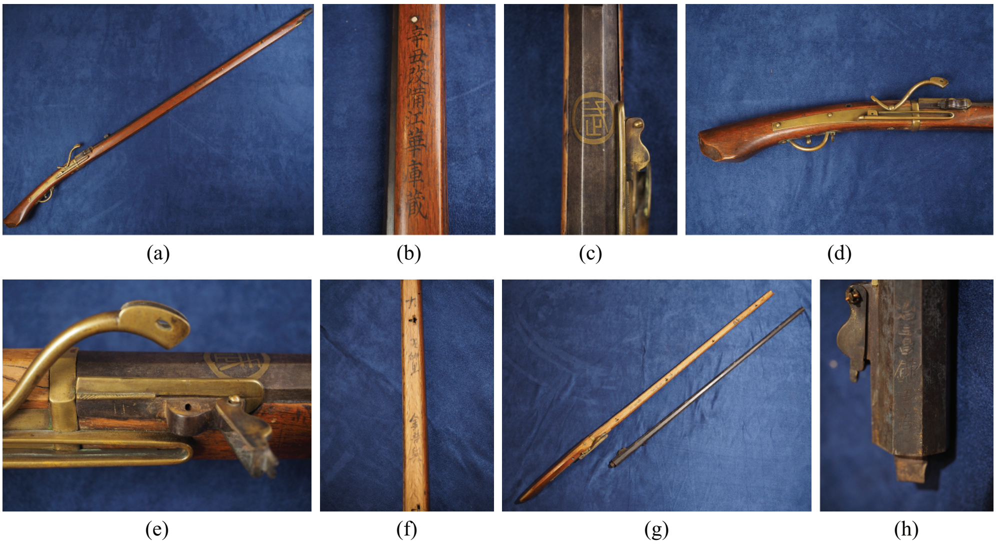


Figure 1. Korean matchlock musket, also known as *choch'ong* ('bird gun' 鳥銃). Shown at the top is a full view, followed by exterior inscriptions (ink etchings on the stock); in the middle, the brass inlaid mark and lock mechanism; and at the bottom, the disassembled barrel and stock. Author's collection.

hammer – was a global artefact that navigated the early modern world: being formed first in late fifteenth-century Germany, it moved in the next century to Portugal and its outposts in Asia – e.g. Goa and Malacca – and then to Japan, China, and Chosŏn Korea (1392–1910).[2] As this globetrotting object met with local hands, an array of responses transpired at each stop: in Korea, for one, practitioners like Samch'ang, Oksŏn, and Kim Sihŭng managed exact replicas, whereas their predecessors had produced more partial resemblances. What held constant across these responses, however, was this: an underlying process of reverse engineering (or simply reversing), which I define here as the 'mechanical dissection' of an unfamiliar object for the purposes of understanding or materializing the embedded knowledge about its making.[3]

To tell this story, in turn, requires taking up reverse engineering as not just historical subject but method: as hinted above, it was only by opening, disassembling, and rebuilding the Korean matchlock that I began to unravel its history.To be sure, taking such an experiential approach is neither new nor uncontested. Starting in the 1990s, experimental historians of science such as Lawrence Principe, H. Otto Sibum, and Pamela Smith demonstrated the utility of 'reworking' historical recipes and processes.[4] Yet, despite the 'recent, almost celebratory, atmosphere' surrounding these works, critics have also flagged their potential pitfalls—e.g. that historical objects, processes, and their modern-day reconstructions do not grant 'unmediated access to how things *really* happened' (more so than conventional historical sources); and that the new data gained from the historian's experience is also socially constructed.[5] Still,proponents have shown, a hands-on approach can offer unique insights, especially when combined with textual analysis, and conducted in multiple, increasingly refined iterations: in the field of early modern European science, it has illustrated 'in practice how various scientific practitioners relied upon artisans, assistants, and family members, and how scientific work could be embedded in wider artisanal, industrial, and social networks'.[6]

I expand the toolkit of experimental history by developing reverse engineering as method. If historians of science can learn by engaging the materiality of science, so can historians of technology from handling directly the objects of material (knowledge) production. The process of dissecting and rebuilding such an object, we shall see, is not merely analogous to that of writing a history, which collects and reconstructs narratives from pieces of recovered data; when it comes to writing about said act, the two are epistemically concurrent: disassembling an old object is like turning the clock back on its past, just as reassembling it is a way of reconstructing that past event progressively 'from the past' (or 'reading history forward'). In their 'products' as well, reverse engineering as history and as method resonate: if dissecting was for the artisans the very act of innovating, it is for me a way to experience and write about the materiality of that innovation as well as its historical conditions and possibilities. And to harness these correspondences between mechanical dissection and historical thinking, a variegated approach is taken here which draws also on archival research, conservation science, and 'gestural knowledge' of working with early firearms in South Korean museums, where the author personally handled, measured, and photographed (but did not disassemble) related objects.[7]

On reverse engineering

Most scholarly works on reverse engineering present it as less a subject for historical scrutiny than a technique to practice. Engineers and professors of engineering, namely, have written 'textbooks' and 'manuals' where know-how is given on the tools and methods of taking things apart and analyzing their traits.[8] The notion of reversing occurs in these works as an 'age-old' technique tracing back to the pyramid builders of ancient Egypt, and one that has advanced greatly in recent years through the development of 3D laser scanning and high-resolution microscopy.[9] This deep history, however, is often left unexplored, relegated to brief mentions and introductory asides.

The lack of historiography has in part to do with the continuing myth that reversing is mere mimicry. The equation of reverse engineering with imitation (as opposed to that of 'forward engineering' with invention) is as old as the term itself: the English word emerged in the 1960s, in the context of legislating against the duplication of intellectual property.[10] It is scant wonder then that, by 1985 – when engineers began to write on the topic – it was accepted uncritically as such. 'Reverse engineering is', M.G. Rekoff asserts, 'the process of developing a set of specifications for a complex hardware system by an orderly examination of specimens of that system'. In and of itself, 'developing a set of specifications' does not signify mimicry. But it is noteworthy that the act is confined here by the original system and that system only: data is to be extracted from an existing technology, and the 'ultimate goal' is to approximate that technology through either a surrogate or clone.[11]

This conceptual framework – which subsumes reversing as a means of replication, its sole end – persisted in the pages of subsequent author-engineers: Kevin Otto and Kristin Wood saw it as 'creating a new product based on an older product'; Kathryn Ingle as 'the development of technical data necessary for the support of an existing production item'; and Wego Wang as the 'technology of reinvention'.[12]

But recent works have understood reversing as a more generative process: works by Eldad Eilam and Robert Messler have compared reverse engineering to the scientific method. Eilam emphasizes it as an epistemic process rather than a result – where an 'engineered artefact (such as a car, a jet engine, or a software program) is deconstructed in a way that reveals its innermost details, such as its design and architecture'. 'This', he states provocatively, 'is similar to scientific research that studies natural phenomena, with the difference that no one commonly refers to scientific research as reverse engineering, simply because no one knows for sure whether or not nature was ever engineered'.[13]

Messler pins it down with further specificity – claiming that reverse engineering is 'mechanical dissection, fully analogous to its biological counterpart'.[14] During the vivisection of a machine, he notes, the reverse engineer cuts open an apparatus to view its anatomy, and explores it – through experience, experimentation, and the manipulation of matter – to recognize its workings. Whether reverse engineering manifests in the act – or in principle only – depends on the situation: things can already be falling apart (e.g. an ancient pyramid breaking from within); while engineers can also learn from each another, with or without physical disassembly (e.g. British makers of steam engines in the First Industrial Revolution). The underlying principle, however, is a kind of backward problem-solving, which relies on analysis and deductive reasoning.[15] Reverse engineering, Messler concludes, constitutes a way of 'seeing – experiencing – what has been done before as a means for learning what is possible in the future, which . . . is much more than developing a new product from an old product, reinventing a tired invention, or collecting data'.[16]

The notion of dissection is indeed capacious in capturing various forms of reversing that cut across centuries: the advent of 3D laser scanning and high-resolution microscopy today allow us to penetrate objects with greater depth and precision, but craftspeople throughout history – and arguably still today – have always had their own ways of taking things apart. In Chosŏn Korea, for instance, whence this paper adduces evidence, it was indeed the *modus operandi* of skilled practitioners to learn through disassembly:

> When the Western mechanical clock ('self-sounding bell', *chamyŏngjong* 自鳴鍾) first came to our country [Korea], practitioners in the town of Tongnae learned the technique of spinning the axle from the Japanese. This was not conveyed in detail to the capital, however, such that the machine was had, but its use unknown. Now my late grandfather also possessed a clock and [merely] displayed it, but my uncle thereupon took it to a quiet place and silently inspected its mechanism by pulling out every pin and disassembling each part to lay it all out. Onlookers stood terrified at the sight, but it was when all the pieces were put back together that the principles [of clockmaking] began to be understood.[17]

The reverse engineer (or 'uncle') in this story was Yi Minch'ŏl (李敏哲, 1631–1715), an adroit astronomer who disassembled the clock and attained a surer understanding of its mechanisms. After rebuilding the device, as narrated above, he went on to produce a new armillary sphere driven by clockwork.[18]

In the following pages, I develop this concept of dissection as a historical method, while uncovering the story of how the matchlock musket was reversed in Korea. So far, historians of technology have recognized similar stories of reverse engineering, notably in the postcolonial histories of computing in Brazil, Taiwan, and South Korea, and recently in studies of Chinese maker cultures, from the late nineteenth-century practices of 'emulation' (*fangzhi* 仿製) to modern-day *shanzhai* production in Shenzhen.[19] In this issue, too, the epistemic role of copying, recycling, modelling, and 'unmaking' is richly explored by Hyungsub Choi, Jung Lee, Kaijun Chen, and Yulia Frumer, respectively. The present study, however, adds to the emerging globalist history of technology and innovation in three main ways. It meditates on the epistemology of reversing by building on the works of the engineer-authors above (hitherto ignored by historians). By foregrounding Chosŏn, it also tells – with arguably greater resolution than before – a story of reverse engineering from the preindustrial non-West.Finally, I directly examine and dissect the material objects in question, trying the tools of, if you will, a practitioner-historian of reverse engineering.

Selective imitation as innovation

In the summer of 1587, artisan Chun'gŭm (俊金, active 1587–1592) and his workmen poured their signature alloy of copper and tin into a carefully prepared set of moulds.[20] This practice was a longstanding one at the Chosŏn cannon foundry, where Chun'gŭm and his ilk worked and apprenticed for generations. But this time, a piece of alien knowledge had insinuated itself into the government workshop, directing the metal to flow into a new shape: an unusually long and thin cylinder of cast bronze.

The curious barrel is inscribed with *inter alia* its own name: 'Small Victory's Mark Cannon' (小勝字銃筒; hereafter small victory cannon, see Figure 2). Contrary to its classification, however, handling it in person revealed that the object is no typical cannon. I found that the barrel is light and portable; has a pair of sights (to be matched while holding the piece to the cheek); and also diverges sharply – in these traits and more – from other pieces made up to that point. The exceptionality of the barrel, in fact, is apparent in the name itself: for centuries, Chosŏn Koreans classified their gunpowder weaponry according to an established character sequence, but Chun'gŭm's started afresh with the curious 'Victory's Mark'.[21] Rather than a local mutation, it is likely that the barrel was the result of reversing the *espingarda* – a matchlock gun attributed to the Portuguese in Asia.[22]

Realizing this raised a vexing question: what had happened? The question is vexing because no written record has survived on the 'first' arrival of the *espingarda* in Korea.[23] A wealth of material artefacts has, however, which shows the following. When matchlocks entered Chosŏn in the latter half of the sixteenth century, they fell into the hands of Korean cannon makers (*hwap'ojang* 火砲匠) like Chun'gŭm. These artisans presumably disassembled the guns and exposed their core: an iron-forged barrel. As in most cases of material translation, they then approached the unfamiliar objects with skills that were already available in their hands, which, for them, was the technique of bronze casting. What ensued, hence, was a miniature bronze cannon, appropriately named a small victory cannon. In this process, while a number of details – such as the matchlock mechanism itself – were lost, still more was gained: the new design activated a culture of experimentation on the Korean shop floor, leading to unexpected innovations.

Let us first understand the institution of a cannon foundry in the sixteenth century and how it worked. The operation of Chosŏn cannon casting was captured in detail by the Firearms Directorate (*Hwagitogam* 火器都監)'s illustrated book of procedures in

Figure 2. Small victory cannon. Made by artisan Chun'gŭm in 1587. Cast bronze barrel with inscriptions around the breech: 'In the 6th month of 1587, small victory [cannon], 3 *kŭn* and 3 nyang in weight, by artisan Chun'gŭm, [load] 3 *chŏn* of powder and 3 pellets'. Courtesy of the Chinju National Museum, Chinju, South Korea.

1615.[24] The first step was to prepare a wooden prototype (*mokyang* 木樣), which served as a pattern, or replica of the object to be cast.[25] For this, a team of woodworkers (*somokchang* 小木匠), lathe turners (*majojang* 磨造匠), and clog makers (*chegŭkchang* 蹄屐匠) were put to task: the first and last worked with saws, rasps, and planes; and lathe turners shaped spherical surfaces.[26] The finished prototype – prepared in halves – was then paired with a matching set of moulds. Framers (*kijang* 機匠) prepared these moulds – that is, a drag and cope; and sanders (*sakchang* 塑匠) pressed a mixture of riverbank soil and red ochre against the contour of the prototype. After that, foundrymen (*kwŏllojang* 權爐匠) and casters (*chujang*注匠) melted and poured the metal, respectively, and the casting was cooled, then retrieved. In finishing the piece, its rough surfaces were filed away by polishers (*yŏnmajang* 鍊磨匠), and touchholes pierced into appropriate places (such as gunpowder chambers) by drillers (*ch'ŏnhyŏljang* 穿穴匠). Finally, the cannon maker – a 'knowledgeable' (*saji*事知) master artisan who oversaw the entire process – inscribed his name onto the breech – a mark of authority as well as responsibility, should any accidents or failures occur.[27]

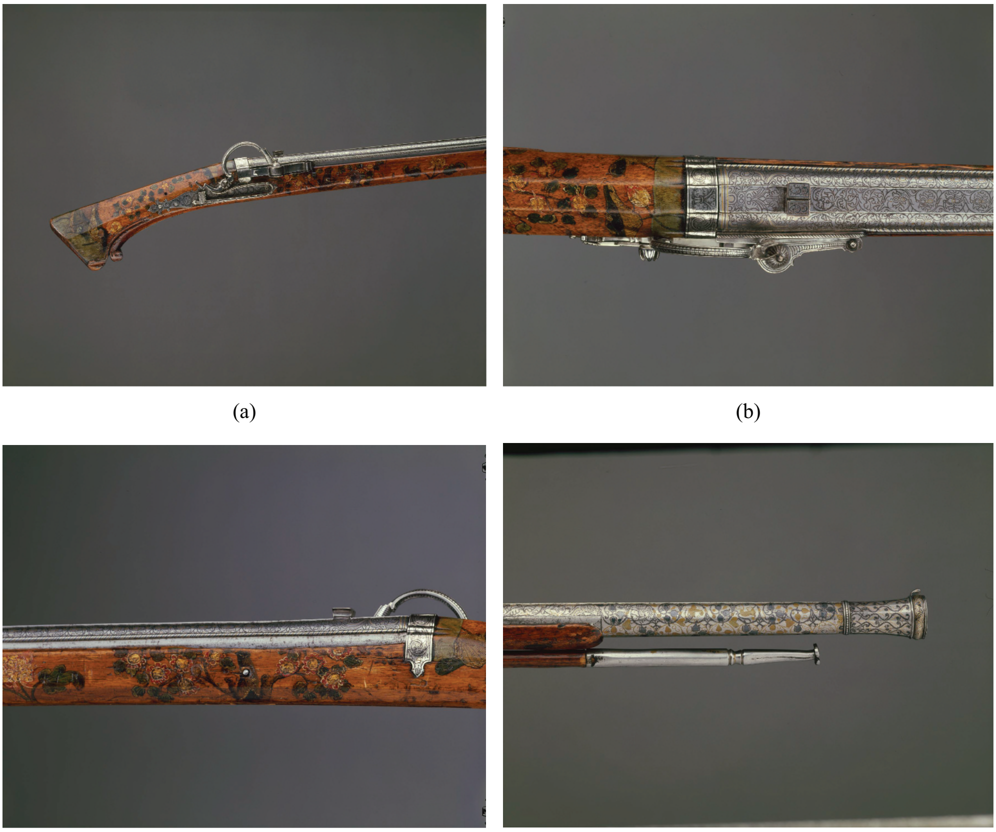
The process described above is that of casting a 'traditional' Korean cannon, whose design had been passed down for generations. In Chosŏn workshops, artisans and practitioners may have inherited the knowledge of their predecessors through technical texts containing drawings and numerical specifications. But more directly and surely, they availed themselves of old prototypes (such as the wooden patterns used for casting), which were stored in the workshops, as well as of finished products in the armouries and warehouses, whose manufacturing details could be reversed. I have detailed elsewhere these practices of reversing: they were part of an artisanal culture of 'prototyping' in Chosŏn known as *kyŏnyang* (lit. 'targeting', K: 겨냥, Ch: 見樣) – the multivalent use of drawings, patterns, three-dimensional models, numerical specifications, and technical writing, to convey a craft idea.[28]

For our purposes, it was through these seemingly 'imitative' practices of casting and moulding, then, that something as new as the matchlock was being absorbed and experimented with. Whether prototyping conveys old forms of knowledge or makes new ones depends in part on the initial pattern, which could be inherited (old) or recently obtained (new). The arrival of the matchlock, in this sense, presented a fresh template (or, in and of itself, a prototype) for the local smiths, as it threw a set of new design ideas onto the drawing board.

Made and remade across the sixteenth-century world, the *espingarda* embodied many novelties (see Figure 3). Its long and thin barrel, for instance, was a key innovation that characterized the 'classic gun': having a large length-to-bore ratio meant that the 'gunpowder [had] more time to impart energy to the projectile' and was 'better able to focus the projectile on its path'.[29] This barrel was also forged expertly from refined iron, rather than cast from bronze – a material that was liable to burst when spread so thin.

Beyond the barrel, several other traits had no precedent on the peninsula: the matchlock mechanism – featuring a sophisticated spring-loaded action; a pair of front and back sights – to align while aiming; a metal lug on its underside – for fastening the barrel to the stock; a screwed breech plug – to seal the rear end of the barrel; and a wooden stock – conveniently tapered to aid in holding the piece steady at eye level.[30]

Korean artisans like Chun'gŭm grasped these traits and put them through rigorous testing at the local cannon foundries. As a result we find a whole new genre of objects that emerged in a short span of 12 years (1579–1591): the victory class. Today, 40 some victory cannons and their subsidiary models (such as the abovementioned small victory cannon) exist. Most of these objects bear inscriptions near the breech, which – if still (or made) intelligible – reveal information about when they were made and by whom, how to load and fire them, as well as their classification within the local system of production. These constitute, I argue, a veritable material archive of the Korean efforts to reverse engineer the *espingarda*.[31]



(a) (b) (c) (d)

Figure 3. *Epingardamade* in Portuguese Goa. Presented in 1587 to the Saxon Elector Christian I by Francesco I de Medici, Grand Duke of Toscana, and recorded in the Dresden Armory's inventory in 1606. Rüstkammer, Staatliche Kunstsammlungen Dresden. Photo: Elke Estel/Hans-Peter Klut.

A tentative story emerges from this archive when we follow recurring artisan names: during the 12 years of experimentation, four cannon makers – Kŏmga (検加, active 1579–89), Ch'ŭngŭn (忠云, active 1583–7), Hŭison (希孫, active 1587–92), and the aforementioned Chun'gŭm – can be distinguished as innovators, digesting much of the alien design.

Kŏmga, for instance, was the first to make the standard victory cannon in 1579, which captured a key design feature: the slender barrel. His piece is in fact twice as long as earlier domestic models (about 57 cm), and it henceforth became a template for others to work from. In the 7th month of 1583, when Kŏmga made his cannon again, he may have shared its design to Ch'ŭngŭn, because the latter made the same thing in the same month. Curiously, the pattern of development repeated after four years: at that point, Ch'ŭngŭn rose to the occasion and inaugurated a small victory cannon, whose knowledge he then conveyed to latecomers Hŭison and Chun'gŭm. Made by all three artisans during the same month, these small victory cannons were long and thin (58 cm), like Kŏmga's 'original', but they now carried other features of the *espingarda*: a pair of sights, and a lug for the wooden stock. From this point onwards, Hŭison and

Chun'gŭm experimented further, by 1592 developing the 'Special Victory Cannon' (*Pyŏlssŭngja* 別勝字) – and its pilot version, the 'Special Prototype Cannon' (*Pyŏryangja*別樣字). Curiously, these new models lost the sights and the lug, focusing only on growing longer (77 cm). Yet, they likely laid the ground for the 'Special Make Cannon' (*Pyŏljoja* 別造字). Appearing only two months later, this final model elongated further (90 cm), to the point of matching the length of standard matchlocks; it also brought back the sights and the lug, as well as even copying the octagonal shape of matchlock barrels.[32]

Not all characteristics of the *espingarda* materialized. But, in the process of selective reconstruction, Korean cannon makers went beyond reproducing the original. A chief challenge of making elongated tubes with thin walls is how to keep the weight of the flowing metal from shifting the inner mould, or core. This challenge is endemic to casting any hollow object, but it magnified drastically with the design of the victory cannons, since thinner and longer tubes meant that it was much more difficult to keep an even gap between the core and outer mould throughout.

If the technical problem originated with the Korean insistence on casting, not forging, these long tubes, it set them on an unexpected path towards a new solution: to devise a coordinated system of chaplets – or metal spacers inside the mould – to support the core.[33] The use of chaplets is an ancient technology that goes back, in China, to bronze ritual vessels from the eleventh century B.C., and in Korea, to Buddhist objects from the twelfth century C.E.[34] The technology is also found in various other cultures, including European and Southeast Asian ones. But the first time it became codified in writing was in *De la pirotechnia* (1540) by the Italian metallurgist and cannon founder Vannoccio Biringuccio (1480–1539).[35]

The victory cannons, however, were cast with a new system of chaplets. Whereas, for example, cannon founders in Europe deployed a single iron 'collar' or 'castle' around the core and only at the breech (see Figure 4), their peers in Korea devised a multiple chaplet system that spread its spacers along the length of the core(s). As conservation scientists Hŏ Ilgwŏn and Kim Haesol have shown compellingly with computed tomography (CT) scans (see

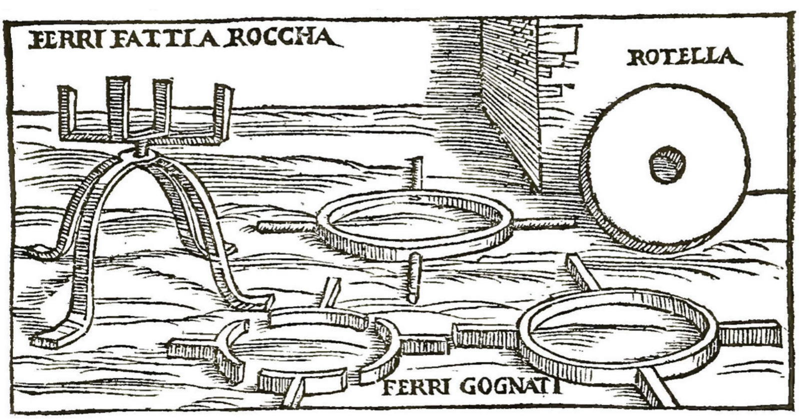


Figure 4. Various chaplets for holding the cores in gun moulds. Shown, from left to right, are an iron 'castle', 'collar' and 'wheel'. Described and illustrated in Vannoccio Biringuccio, *De la pirotechnia* (Venice: C. Navò, 1540), 89. Courtesy of the Smithsonian Libraries and Archives.

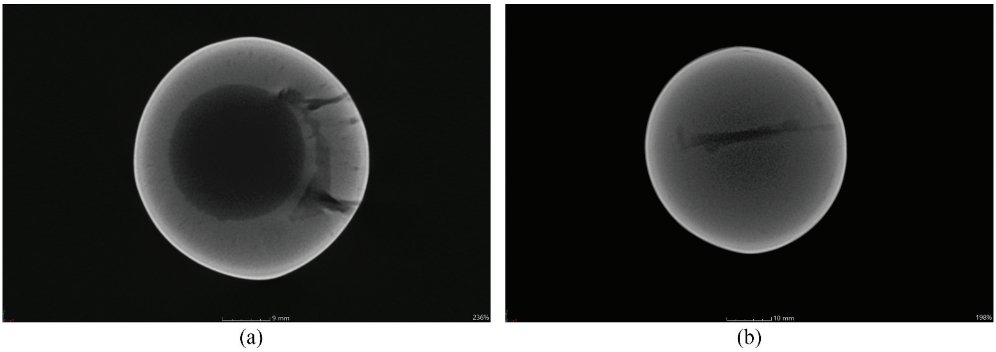


Figure 5. Computed tomography (CT) scans of a Korean victory cannon. Shown above is an M type chaplet and below an L type. Courtesy of the Chinju National Museum, Chinju, South Korea.

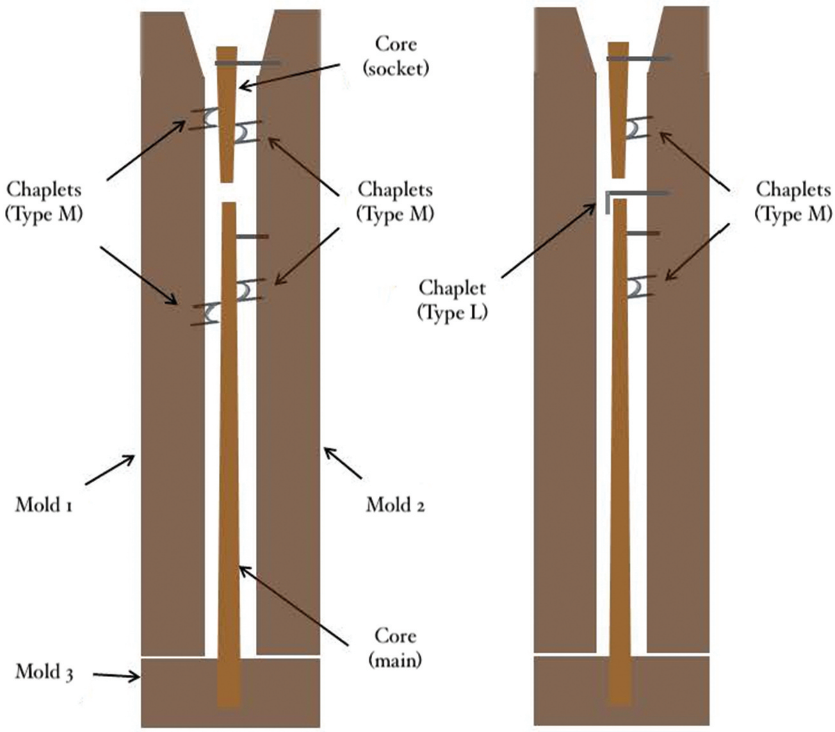


Figure 6. Multiple chaplet systems. The first one on the left uses M type chaplets on both sides of the vertically erected mould, forming a 'wrap' around the suspended cores. The second system places the same spacers only on one side and brackets the main core with an L type. Courtesy of Höllgwŏn, image modified by the author with permission.

Figure 5), two Korean systems emerged: one employing so-called M type chaplets placed on both sides of the vertically erected mould, and another with an L type (and M types only one side) to bracket the main core (see Figure 6).[36] This is not the only multiple chaplet system known;Southeast Asian cannon featured one as well, but theirs was a series of European-style iron collars that ran the whole barrel and with earliest evidence dating to the eighteenth century.[37] The Korean chaplet systems, however, are wholly distinct, suggesting that they were developed independently and specifically for the victory cannons.

The Chosŏn foundries show that there is no straight path to reverse engineering a given artefact. Instead, reversing is a deeply experimental process, and it was up to the relevant experts and practitioners to seize the new design features and reassemble them in any way they saw fit. To be sure, the Korean trials were hemmed in by certain parameters – like the existing workshop culture and its resolve to cast instead of forge. Yet, these trials still managed to ramify in unexpected ways: they produced a notable variety of models and prototypes in little over a decade, as well as raising local bronze casting techniques to a new level of sophistication.

This is one way in which reverse engineering can unfold: under a significant degree of freedom on the part of the local smiths to radically dissect and rebuild. The particular manifestation has in part to do with the antebellum environs – where Korean artisans worked mostly in isolation from the influence of the objects' originators (German gunsmiths) and other makers (such as Goan, Japanese, and Chinese). Yet, as the next and final section shows, an entirely different process of reverse engineering developed through an international war that entangled Korean practices with their global counterparts.

Cloning as retooling

The emergence in Chosŏn of a fully-fledged matchlock is a story that begins with the East Asian War of 1592–1598. Set off by a Japanese invasion, this war broke out on Korean soil and further embroiled the Ming Chinese (1368–1644). The unprecedented conflict brought to the peninsula an array of horrendous war machines that matched its international scope. Alongside bows, spears, and swords, it featured some of the latest means of destruction: mortars, gunpowder arrows, Frankish cannons, caitiff exterminators, matchlock muskets, and so on.[38] Among these machines, however, it was ultimately the Japanese matchlock musket – or *teppō* (鉄砲) – that captivated the Korean authorities. In 1593, only a year after the outbreak of the war, King Sŏnjo (宣祖, r. 1567–1608) declared matchlock the most 'divine' of weapons and promoted their domestication with great zeal. The story after that is well-known: during the course of the seventeenth century, Koreans learned avidly, made high-quality muskets, and produced professional musketeers who won some international fame.[39]

A crucial impetus for this development was indeed Sŏnjo's enthusiasm to adopt foreign technology. For instance, the king welcomed foreign craftsmen and experts during the war. Hundreds of Japanese (and Chinese) practitioners joined the Korean shop floor in this way, and transmitted their techniques, including *teppō*-making.[40] Sŏnjo's eagerness to adopt the Japanese gun, moreover, was such that he even took matters into his own hands: the king tinkered and invented – allegedly – a multi-barrelled musket that could repeat fire.[41]

To Sŏnjo, however, exercising ingenuity was less important than copying the Japanese matchlock. He clarified in a declaration of 1593:

> All muskets produced in our country are roughly constructed and useless. Do not make these from now on. Instead, take the most intricate of Japanese muskets as the new target (*chunjŏk*準的) of production, and have [the artisans follow] only that prototype (*il ŭikiyang* 一依其樣).[42]

The king wanted his guns manufactured exactly like the Japanese matchlock. Domestic models – whether victory cannons or their latest spin-offs – needed to go.

During the seventeenth century, Chosŏn Koreans indeed adopted wholesale Japanese methods of production, and managed to replicate the *teppō* – as Sŏnjo had wished. Even in this process of cloning, however – arguably the most constrained form of reverse engineering – unexpected outcomes arose in the process of reaching similarity (or identicality).

But first: what made the Japanese gun so exceptional, when the Koreans had already been experimenting with its basic template? The *teppō* was distinguished by faithfully copying the *espingarda*, and in particular, three traits that had previously eluded the makers of victory cannons: the iron-forged barrel, screwed breech plug, and matchlock mechanism. Unlike in Korea, where said barrel met a turn in the hands of bronze casters, the same artefact in Japan became adopted as it was. Other than from pure chance, this was because the matchlock there had been introduced directly into the hands of sword-smiths – by trade, forgers of iron – rather than refracted through a strong tradition of cannon makers, which Japan lacked. However, Japanese artisans still struggled with regard to the breech plug, and only managed to master it with the help of direct instruction: in 1555, a Portuguese blacksmith imparted the peculiar skill of making screw threads to the locals. Finally, while the sources do not elaborate on this point, the gun lock was likely also conveyed in this manner. The matchlock mechanism is the most intricate part of the gun, and what gave it its name: it is a technological system that assembles a pivoted hammer (that clamps a slow-burning match) on one end, a finger-pulled trigger on the other – and a combination of levers, springs, and sears connecting the two.[43]

All three traits materialized in seventeenth-century Chosŏn. But this fact only became apparent by immersing myself in the material archive of Korean matchlocks – an archive that poses its own problems. For earlier objects like the victory cannons, time and wear had begun such a process of 'reversal' that they have come down to us mostly as naked barrels, if not fragments. Yet, most Chosŏn muskets are better preserved – with their wooden stocks intact – which hide more than they reveal: most inscriptions appear in the underside of the barrel, rendering them undetectable without disassembly. This leads to a paradox of preservation: the less unspoiled the objects, the more afraid we are of taking them apart. Museum curators, understandably, decline requests for disassembly, while conservation scientists, by professional inclination, prefer to conduct non-destructive analyses.

To initiate a new understanding, then, I had no other way than to get my hands dirty, so, after several months of research and consulting with antique specialists across the globe, I managed to procure my own Chosŏn musket.

My first impulse as a historian was to try and date the piece. For this, marks found on the exterior of the stock were helpful, which read in ink: 'Newly prepared in the year of *sinch'uk* and stored at the Kanghwa armoury' (*sinch'uk kaebi Kanghwago chang* 辛丑改備江華庫藏).[44] Tracking down the 'year of *sinch'uk*' took archival research as, in the

Sino-Korean calendrical system, *sinch'uk* occurs every 60 years, so this could refer to 1601 – the first possibility – or 1661, 1721, 1781, 1841 or 1901. In the end, after enquiring into all these possibilities, a set of records was found that confirmed the date to be 1781.[45] Evidence suggested that the object in question had actually been made sometime before 1781, when it was repaired and stored in the armoury; then, in 1866 – during the French campaign on Kanghwa Island – it was presumably taken as booty to France, which is also where I acquired it through an American antiques specialist.

More significant revelations appeared during the disassembly, which went as follows. By gently removing the pins that enter from the sides of the stock, the barrel was released and lifted out. The first thing that came into view were the squiggles on the interior of the stock, showing *inter alia* the name of the master artisan who had overseen production (*kamjop'yŏnsu* 監造邊首) – Kim Sihŭng. Then, turning the barrel over revealed two other craftsmen: blacksmith Samch'ang (*ya Samch'ang* 冶三昌) and borer Oksŏn (*ch'an Oksŏn* 鑽玉善). Moving towards the bottom of the barrel, I also found a metal protrusion that sealed it. This breech plug has screwed threads around the top, which – contrary to modern screws – move counter-clockwise to tighten and clockwise to loosen. Returning to the wooden stock, I disassembled the lock mechanism, which was mounted on a separate brass lock-plate and fastened to the stock through round-headed bolts. Pulling these bolts out released the match hammer and the mainspring (a U-shaped metal) that loads the hammer. Finally, by retrieving the long bolt from the top of the stock, and sliding forward the brass ring, I loosened the lock-plate itself and, with it, other internal mechanisms such as the lever and sear.

The dissection revealed, first, that the makers of this object had mastered the techniques of producing the matchlock musket. The exterior appearance hinted at this, but examining its mechanisms under the stock confirmed the following. The operation of the Korean gun showed that it classifies as a 'snap matchlock', named after the characteristic spring-loaded action of its match hammer. The snap lock system is the most intricate and expensive type. It first emerged in Bohemia in the late fifteenth century, only to fall out of use in Europe. Yet in Japan, some areas of China, and Korea, it enjoyed centuries-long use. Remarkably, the Korean snap lock is identical to its Japanese counterpart, on which it was certainly based.[46]

After pondering with the disassembled pieces in my hand, and matching them with textual sources, I also solved the puzzle that was the Chosŏn gun shop. Even before acquiring my gun, I had been aware of a set of textual clues in the *Records of the Palace Guards Division* (*Kŭmwiyŏng tŭngnok* 禁衛營謄錄, 1709–1852), which listed every artisan involved in the manufacture of thousands of matchlocks from 1684 to 1715 – a total of 17 unique types.[47] The problem, however, was that many of these artisanal identities – and their skill – proved difficult to pin down from words alone, let alone translate into English. But knowing the gun inside out helped. A good example of this is the nebulous 'inner grasp makers' (*naejipchang* 內執匠). 'Inner grasp' is a unique gun term, and one that was impossible to solve through philology alone. The disassembly showed, however, that it corresponded to a part named the sear. Hidden inside the stock, this small iron piece functioned as a catch that restrained the spring-loaded hammer, hence its name. It also stood out from its peers (such as levers and springs that are bronze) due to the rusting on its surface, and indeed, the 'sear makers' were iron workers: for instance, Pak Ŏnsin (朴彥信, active 1639–1661) - one of the earliest sear makers identifiable by name – practiced outside the military workshop as an iron lock maker (*soeyakchang* 鐵鑰匠).[48]

Proceeding in this way – piece by piece, artisan by artisan – exposed the workshop in full (see Table 1).[49] Even a quick glance into this workshop can surprise historians: it is unusual to find a designation such as 'screwsmith' (*nasajŏngjang* 螺絲釘匠) outside of early modern Europe, which is often presumed to be the only place where the trade took root (see Figure 7). But other craftsmen – e.g. the borer and accessory makers (powder flask maker, priming flask maker, cartridge maker) – are also noteworthy. These were artisanal identities born specifically from matchlock manufacture: for instance, as hinted in the introduction of this paper, a borer specialized in the task of reaming the hole in the barrel. Still others – like the blacksmith – had traditions that traced back to time immemorial, but in these workshops, they had newly risen to a prominent position alongside the borer. The two were, in fact, the most crucial members of the Chosŏn gun shop: as clarified in a regulation of 1715, they were the only people allowed to mark the barrel, and this was the very practice that left the names of Samch'ang and Oksŏn on my gun (Figure 1).[50]

Finally, my dissection amounted to an important revelation about the nature of reverse engineering: that under the cloak of mimicry, even cloning – its most constrained form – was an engine of change. As discussed above, Korean efforts to replicate the *teppō* spawned a whole new workshop model. While the antebellum cannon foundry employed a crew of metal-casting professionals such as sanders, framers, and foundrymen, the Chosŏn gun shop centred around the blacksmith, borer, and a slew of precision metal workers. The ascendancy

Table 1. Musket production scheme at the Palace Guards Division, 1684–1715.

Artisan Type		Description of Work
Planners	Grandmaster Artisan	Senior artisan who presumably assembled parts and assisted the officer-manager in coordinating craft types
Barrel Makers	Blacksmith	Wrapped strips of iron into a tube (crude barrel) and made breech plugs
	Borer	Enlarged the hole in the barrel through boring bits, and cut female screw threads on the interior wall of the breech
	Filer	Filed the cylindrical barrel into an octagonal shape
	Sight maker	Made and attached a pair of front and back sights onto the barrel
Locksmiths	Brass worker	Cast all brass parts of the lock – including the lock plate, U-shaped spring, match hammer, trigger, pins, and powder pan
	Sear maker	Made the only iron part of the lock – the sear – a pivoted metal arm inside the stock that catches the match hammer
Stock Makers	Hewer	Hewed logs of red oak (discussed below) into appropriate pieces
	Stock maker	Cut and polished the wood into the shape of the stock, carved out crevices for the barrel and lock
	Stock decorator	Decked the stock with brass embellishments. Presumably also carved and inlaid the institutional mark onto the barrel
	Lacquerer	Applied lacquer to the wooden stock
Accessory Makers	Powder flask maker	Made powder flasks to store the main charge
	Priming flask maker	Made priming flasks to store the charge for the powder pan
	Cartridge maker	Made paper cartridges for quick loading
Other	Brass plater	Made *tanjisoe* (丹只[金]) to plate the exterior of the stock, for instance, the bottom end
	Drafter	Drew patterns onto the surface of the barrel on ornate pieces for submission to the court
	Polisher	Polished the surface of various metal pieces on the gun
	Driller	Originated holes in the gun, for instance, the underside of the barrel and the wooden stock (for wooden pins to pass through them both and hold them together)
	Screwsmiths	Made small, screwed nails to fasten the lock to the stock

Source: *Kŭmyŏng tŭngnok*, 1684/10/6; *Kŭmwiyŏng tŭngnok*, 1701/11/24, 1714/3/3, 1715/1/9.

Figure 7. Brass screw on a Korean musket. Courtesy of the National Museum of Korea, Seoul, South Korea.

of the latter, in fact, was so disruptive that the category of cannon maker vanished in history after this point, as well as their victory cannons.

But the Chosŏn gun shop also represented innovation in its own right. Because many of the components that filled this workshop were formed in Korea through global entanglements – that is, the war, an influx of foreign craftsmen, and of course, the *espingarda/teppō* itself which had traversed the world – they contain a collection of rare skills that were managed on the peninsula for the first time. And in the coming centuries, as the gun shop took on a life of its own, these skills also became a stimulus for other fields of knowledge and material production. Starting in the late seventeenth century, for example, military officers took over as managers of musket production, and they eventually codified a sophisticated system of classifying iron by weight (and purity) – in a manual replete with recipes and conversion ratios.[51] The initiation of these officer-practitioners into the shop, moreover, brought out one of its techniques: the Korean screw. Formed first in gun construction, these threaded pins also found their way into the construction of an ivory scaphe sundial, made by none other than a family of officer-managers.[52]

Conclusion

This essay has made a twofold argument, consisting of historical analysis and methodological proposition. It argued, first, that the processes of reverse engineering the *espingarda* in Chosŏn were far from uninspired mimicry: cannon makers in the late sixteenth century produced a radical reinterpretation of the foreign design, which led in turn to an unexpected innovation in bronze casting techniques; likewise, gunsmiths of the subsequent century made more precise replicas, but in the process they also engendered new skills, practices, and entire workshops. A second, methodological contribution was made, moreover, in discovering and telling these stories: a hands-on approach to historical research that investigates material objects and, in this case, through the very act of reverse engineering, defined here as mechanical dissection.

These shouldn't surprise us. Historians of technology have already shown us other cases from modern Brazil, Taiwan, South Korea, and China. Also, historians of science, art historians, arms collectors, and museum curators have long married material analysis with archival work, articulating the 'material turn' in historical studies.[53] Yet the present study has offered a historically granular and methodologically specific case study of reverse engineering.

And that case study may hold unique lessons for the field of the history of technology. As told with Koreanguns, the reversed artefact itself is not the be-all and end-all of reverse engineering nor its history. By shifting focus to the broader assemblage of production – both material and epistemic, one can bring the makers of reversed objects, as well as their culture of skill, into the picture. From this then ensuesa rich panorama of reverse engineering as a truly generative act: it carries old knowledge as well as crystallizes new ones; its products also transcend material goods, to include new skills, practices, workspaces, identities, and as shown here, histories. By mimicking the process of reverse engineering, historians too can achieve greater penetration into material objects and their pasts, but their challenge is to further contextualize, historicize, and narrativize the granular view without sliding into technical essentialism.

Notes

1. Author's collection. For more discussion on its manufacture, see the last section of this essay.
2. Kang, "The Korean Snap Matchlock"; and Kang, "Crafting Knowledge," 205–33. Also see Daehnhardt, *Espingarda Feiticeira*, 20–43.
3. Messler, *Reverse Engineering*, 11, 13, 17. I use "reversing" interchangeably with "reverse engineering" in this article, although the former is generally used more frequently for software. Eilam, *Reversing*.
4. Fors, Principe, and Sibum, "From the Library to the Laboratory"; and Smith, "Historians in the Laboratory." Also see the Making and Knowing Project at Columbia University (http://www.makingandknowing.org). I also teach an undergraduate course on reworking historical artefacts and recipes at Washington University in St. Louis: Kitchen, Studio, Factory: Making in East Asia" (http://www.kitchenstudiofactory.com).
5. Experimental history of science was particularly controversial in the 1990s, but surprisingly few have published critiques. For a useful summary, see Fors, Principe, and Sibum, "From the Library to the Laboratory," 88. Also consider the issue of technical essentialism in early modern botany – what a "focus on the technical arrangement of plants could not do" in Menon, "What's in a Name?"
6. Fors, Principe, and Sibum, "From the Library to the Laboratory," 88.
7. I conducted material research at the National Museum of Korea, the Korean Army Museum, and the National Folk Museum of Korea, among others.
8. To name a few: Rekoff, "On Reverse Engineering"; Chikofsky and Cross, "Reverse Engineering"; Eilam, *Reversing*; Wang, *Reverse Engineering*; and Messler, *Reverse Engineering*.
9. Messler, *Reverse Engineering*, 16; and Wang, *Reverse Engineering*, 1.
10. Searching for terms such as "reverse engineer" and "reverse engineering" – with and without a hyphen – in the Google Ngram Viewer shows that they took off in the 1960s, although there are a few mentions from earlier. For an early example, see *Government Patent Policy*, 699.
11. Rekoff, "On Reverse Engineering," 244.

12. Otto and Wood, *Product Design*; Ingle, *Reverse Engineering*; and Wang, *Reverse Engineering*, 1.
13. Eilam, *Reversing*, xxiv.
14. Messler, *Reverse Engineering*, 17.
15. Ibid., 9–12, 29–67.
16. He also wrote that reverse engineering "has greater value for creating anew than for simply re-creating! It is – or could and should be – a stimulus for ingenuity and creativity, not a shortcut for laziness or complacency or mindless mimicry." Ibid., 16.
17. Yi, *Sojaejip*, 172:309b.
18. *Hyŏnjongsillok*, 1669/10/14.
19. Da Costa Marques, "Cloning Computers"; Tinn, "Illegal Copies"; Jo, "Vernacular Technical Practices"; Lean, *Vernacular Industrialism in China*; Yi, "Malfunctioning Machinery"; and Lindtner, *Prototype Nation*.
20. On the use of a special alloy tested for robust elasticity, see Hŏ and Kim, "Kungnae sohyŏng ch'ongt'ong," 421–30.
21. This character sequence is according to the Thousand Character Classic (千字文; Ch: *Qianziwen*; K: *Ch'ŏnjamun*) – a primer for Chinese characters. All 12 domestic models produced prior to this point followed the sequence, going from "Heaven's mark" (*Ch'ŏnja* 天字) and "Earth's mark" (*Chija* 地字) to "Wax's mark" (*Yŏngja* 盈字) and "Wane's mark" (*Ch'ŭkcha* 昃字) – according to size or their order of invention. But the new class diverged from this trend entirely. Sŏ, "Munhŏn kirok kwa myŏngmun," 398–99; and Hŏ, *Chosŏn sidae hwayak*. This implies an inflection in the existing culture of making, created by the inclusion of a radically new design.
22. *Espingarda* is a generic Portuguese word for firearms, but in the context of sixteenth-century Portuguese Asia, arms historians have identified it as the "snap matchlock," a gun whose lock mechanism had a characteristic spring-loaded action. Originating in late fifteenth-century Bohemia (and its surrounding Germanic region), the snap matchlock was reverse engineered in Portugal – becoming *espingarda* – before spreading east to its outposts in Asia, such as Goa and Malacca. For more, see note 2.
23. An alternative possibility is independent innovation within Korea. This was suggested in recent studies by the Chinju National Museum, which state that the victory cannons prove that Koreans had reached the 'final stage of small cannon development' on their own, and that this prepared them well for the advent of the matchlock. To be sure, the lengthening of barrels – a key feature shared by both victory cannons and matchlocks – was not just a European phenomenon; the so-called "classic ordnance synthesis" was occurring similarly in China too. See Hall, *Weapons and Warfare*, 87–108; Andrade, *The Gunpowder Age*, 103–23. However, the sudden appearance of a cluster of traits that are directly traceable to the*espingarda* cannot be explained with this thesis of independent innovation. It also helps to remember that the sixteenth-century world – and maritime East Asia in particular – was one in which artefacts became increasingly adopted and adapted between its polities. The Frankish cannon (C: *folangji*, K: *pullanggi* 佛狼機), for instance, is a technology that found extensive use in Portuguese hands across Asia, and – in complete silence, in terms of written records – became reverse engineered by Korean cannon makers in 1563; this is a fact that was only discovered through an archaeological dig and the reading of inscriptions. Historians have had no trouble labelling the unearthed replicas as Frankish cannons, but they have yet to recognize the external influence on the formation of the victory cannons. For more, see Kang, "Crafting Knowledge," 234–40. My view that victory guns were "first generation muskets" finds further support in Tomio, *Teppō*, 346–7.
24. *Hwagi togam uigwe*, 140–43.
25. See note 22 above.
26. *Hwagi togam uigwe*, 143. For more on Korean lathe turners and their techniques, see Ch'oe, "Karit'ŭl ŭi myŏngch'ing."

27. *Hwagi togam uigwe*, 104–5. Conventionally, early Chosŏn cannons carried just the name of one cannon maker. For examples, see Yi, *Han᾿guk ŭi hwap᾿o*, 47, 54, 64, 65. But sometimes, the workshop's supervisor (or "production manager" *kamjogwan* 監造官) also inscribed his name. For more on production managership, see Kang, "Crafting Knowledge," 50–54, 85–95.
28. *Kyŏnyang*is an artisanal technique that developed in the early Chosŏn, if not earlier. The vernacular word means to "target" (*kyŏ-nyang* 겨냥), as in levelling one's eye at an object (*kyŏ-nyang taeda* 겨냥대다) or in sighting a projectile weapon (*kyŏ-nyang hada* 겨냥하다). But more to the point, it had a secondary meaning – that is, to convey an object's specifications (*kyŏ-nyang naeda* 겨냥내다) by laying it against a backdrop and tracing its perimeter. For a Korean artisan to "target" something, then, meant to capture and represent its size and shape. Starting in the early Chosŏn, this practice entered the bureaucratic language and figured in the state archives as *kyŏn-yang* (lit. "observed shape"見樣) in the literary Sinitic. For more, see Kang, "Crafting Knowledge," 124–43. Also see Kang, "Cooking Niter," 3; Yi, "Chosŏn mitkŭndae kongye."
29. Andrade, *The Gunpowder Age*, 105.
30. The Portuguese Goan matchlock in Dresden, Germany (Figure 3) is a fine example that combines these traits. Described here, however, are common features found on most matchlocks in the early modern world. The historical arms and armour literature is well developed on the topic. Representative works include: Stone, *A Glossary*; Elgood, *Firearms of the Islamic World*; Morin and Held, *Beretta*. A useful primary source to understand techniques of *espingarda*-making is Rodrigues, *Espingarda Perfeyta*.
31. I drew on existing compilations as well as personal visits to museums, where I had the chance to handle, measure, and weigh artefacts. Existing compilations are thorough, but show slight differences in measurements. For the most comprehensive examples, see Chinju National Museum, *Sohyŏng hwayak mugi*; Yi Hyŏnsu et al., *Han'guk chŏnt'ong mugi chosa*. Some inscriptions – such as ink writing (*muksŏ* 墨書) – were not visible to the naked eye and needed to undergo conservational work to be revealed. See Yi, *Sŭngja chŏngt'ong e taehan*, 147.
32. See note 25. Most musket barrels are filed to an octagonal shape; in iron barrel manufacture, edges are preferred because they can be more easily shaped on a flat anvil and filed.
33. Conservation scientists Hŏ Ilgwŏn and Kim Haesol revealed through CT scanning that cannon makers during this period had inaugurated the use of chaplets in Korean cannon manufacture. See Hŏ and Kim, "Kungnae sohyŏng ch'ongt'ong," 431–8. Also see Hŏ, "Chosŏn ch'ŏngdongje," 107–21.
34. Hŏ, An, and Yun, "P'yŏngch'ang Sudasa chi," 16–19.
35. Sturges et al., "Digital Radioscopic Examination," 1775–76; Biringuccio, *The Pirotechnia*, 245–48; and Green, "The Carronade Island Guns," 4–5.
36. Hŏ, "Chosŏn ch'ŏngdongje," 107–21.
37. The use of complex chaplet systems was obviated in Europe because cannon makers there began – in the eighteenth century – to cast their bronze artillery solid and drill the bore using water-powered machinery. For more on European practices, see Hoskins, "Sixteenth Century Cast-Bronze Ordnance," 36–40; Keith, Carlin, and De Bry, "Bronze Cannon," 145, 150–54. For Southeast Asia, see Green, "The Carronade Island Guns," 4–5.
38. Swope, "Crouching Tigers, Secret Weapons."
39. Kim provides a useful summary in "Chosŏn hugi choch'ongyŏn'gu." For English works, see Kang, "Big Heads and Buddhist Demons"; and Andrade, Kang, and Cooper, "A Korean Military Revolution?"
40. For more on the introduction of foreign craftsmen, techniques, and tools, see Kang, "Crafting Knowledge," 249–72.
41. *Sŏnjo sillok*, 1593/11/12.
42. *Sŏnjo sillok*, 1593/12/2. The king is unfair in his appraisal of domestic models but if, by "roughly constructed and useless" he meant the liability of bronze replicas to burst, he had

good reason. See contemporary complaints by injured Chosŏn gunners using bronze barrels: *Sŏnjo sillok*, 1595/9/3.

43. Kang, "Crafting Knowledge," 213–33.
44. An almost identical musket – with the same writing in ink – is found in the Kanghwa War Museum, referred to popularly as the 'Kanghwa Musket' (*Kanghwa hwasŭngch'ong*). There is also a Chosŏn sabre there with the same writing. See Kanghwa Chŏnjaeng Pangmulgwan, *2016-yŏn Kanghwa Chŏnjaeng*.
45. The aforementioned Kanghwa musket is dated to 1901, but this is not possible based on new evidence uncovered by Kim Myŏnghun and Pak Sŏnsuk in "Choch'ŏng ŭi tŭngjang," 460. For evidence of reading *sinch'uk*as 1781, see *Ilsŏngnok*, 1781/3/19; *Chŏngjo sillok*, 1781/12/19; *Pibyŏnsa tŭngnok*, 1787/6/26. It so happened that that year, weapons at the Outer Armoury (*Oemugo* 外武庫) in Kanghwa – an extension of the Government Arsenal (*Kun'kisi* 軍器寺, shortened to 武庫) in Seoul – were repaired and marked thus. At the breech end of the gun is another confirmation of its provenance: the character *mu* (military, 武) is inlaid in brass, indicating said arsenal.
46. See notes 2 and 21 above.
47. *Kŭmyŏng tŭngnok*, 1684/10/6; and *Kŭmwiyŏng tŭngnok*, 1701/11/24, 1714/3/3, 1715/1/9. The *Records of the Palace Guards Division* is part of the *Garrison Records* (lit. "Records of the Central Military Garrisons" 軍營謄錄), which was kept by Chosŏn's central armies for almost three centuries (1615–1882).
48. *Sŭngjŏngwŏn ilgi*, 1639/10/14. For more, see Kang, "Crafting Knowledge," 263–67.
49. Existing studies have described Korean musket manufacture in detail, but they were conducted without the same range of material, textual, and experiential evidence consulted here. Pak Chegwang, *Hwayŏm Chosŏn*; Yi, "Kunyŏng ŭi choch'ong chejo". As a result, they misunderstand important details in the manufacturing process, as well as misattribute artisanal skills and identities. For example, both Pak and Yi assume that the only "screwed" component of Korean guns was the breech plug (*nasajŏn* 螺絲轉) and translate terms such as *nasajŏngjang* (螺絲釘匠) as the maker of these plugs. But evidence suggests that breech plugs were made by blacksmiths and their walls carved into female screw threads by borers; and that there is a separate Korean craft for making small brass screws, practiced by *nasajŏngjang*, which I thus translate as "screwed nail maker" or simply "screwsmith." For details on Korean screw manufacture, see Kang, "Crafting Knowledge," 267–72. Consider alsoTable 1 in this essay.
50. *Pibyŏnsa tŭngnok*, 1729/5/25.
51. *Ch'ŏlsik*. Kang, "Crafting Knowledge," 180–184, 278–80.
52. Brass screws are found on an ivory scaphe dial made by Kang Yun (姜潤, 1830–1898) in 1870. History of Science Museum, University of Oxford, inv.47409.
53. See note 4 above.

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