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Nodes of knowledge, managing transfer: Shipbuilding and repair during the transformation from sail to steam

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Abstract

The core theme of the special issue in which this article appears is the inherent impossibility of confining the knowledge required to build and sustain the instruments of travel to a single space or institution. This is certainly true for the ships that built empires – the large sailing and later steam ships produced by navies and companies in the process of European expansion. Ships traveled between polities and required repairs overseas, taking the construction knowledge and practices with them. Skilled laborers – experienced shipwrights and increasingly also trained engineers – helped to transfer shipbuilding practices across oceans, and to adapt these practices to local conditions based on forms of "blended know-how." This article explores how the circulation of shipbuilding knowledge and practices within and between maritime empires changed with the increasing pace of industrialization. It does so on the basis of three moments: the Dutch East India Company's shipbuilding activities in Asia in the seventeenth and eighteenth centuries; the interaction between private industry and the Dutch state in advancing machine-manufacturing in both the Netherlands and on Java in the 1830s and 1840s; and the aid provided by Dutch engineers in laying the groundwork for Japanese industrial warship-construction in the second half of the nineteenth century. Such transfers put high demands on the capacities of states and naval administrators in controlling the flows of necessary resources and skilled labor, requiring complex arrangements between states and private capital. Industrialization

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did not change this basic fact, but it did change the nature of these arrangements. Although shipbuilding knowledge always remained practice-driven, highly mobile and susceptible to local adaptation, the increasing technological demands created by the transition from sail to steam and wood to iron, combined with the extension of the power of states and transnationally operating manufacturing companies, considerably changed the institutional embeddings and societal consequences of its circulation.

Keywords
Global history, maritime history, industrialization, shipyards, Netherlands, Dutch East Indies, Meiji period

Introduction

Building ships for building an empire always required not only large investments in terms of resources and time, but also the combination of many different types of labor and the knowledge they implied. These ranged from the highly specialized knowledge involved in ship-drawing and design, increasingly couched in terms of science fostered and protected by corporations and the state, to the shipwrights' deep knowledge of materials required for planking a wooden ship's hull or installing beams, and from the captains' and sailors' knowledge of the conditions of future employment of the ship to state administrators' visions of cost-efficiency and control. Even today, despite the sophistication of (computerized) mathematical modeling in ship design, practical considerations that are privy to shipyard workers, crews, and sailing officers are of crucial importance to shipbuilding projects.[1] Shipbuilding knowledge was thus embedded in practices of production, repair, and management, which were in turn patterned by highly contentious organizational arrangements. This has made both commercial and military shipyards sites of conflict over the intellectual property of designs, the relative weight of practitioners' craftsmanship versus supposedly disembodied theoretical science, and the power to make decisions over the work process and related conditions of labor. These are topics that have long engaged the history of science.[2] As Simon Schaffer noted, these conflicts

1. Hans Solli-Saether and Jan Terje Karlsen, "Knowledge Transfer in Shipbuilding Projects. A Study of Facilitating Mechanisms," *International Journal of Project Organisation and Management* 4:3 (2012): 256–71.
2. E.g. Richard W. Unger, *Dutch Shipbuilding before 1800. Ships and Guilds* (Assen/Amsterdam: Van Gorcum, 1978), pp.84–5; David McGee, "From Craftsmanship to Draftsmanship: Naval Architecture and the Three Traditions of Early Modern Design," *Technology and Culture* 40:2 (1999): 209–36; C. A. Davids, *The Rise and Decline of Dutch Technological Leadership: Technology, Economy and Culture in the Netherlands, 1350–1800*, Vol. 2 (Leiden: Brill, 2008), p.296; and especially Simon Schaffer, "'The Charter'd Thames': Naval Architecture and Experimental Spaces in Georgian Britain," in Lissa Roberts, Simon Schaffer, and Peter Dear (eds.), *The Mindful Hand. Inquiry and Invention from the Late Renaissance to Early Industrialisation* (Amsterdam: Koninklijke Nederlandse Akademie van Wetenschappen, 2007), pp.279–305. For a historiographic overview of the debate over the artisan/practitioner as a key actor in knowledge production, highly relevant to understanding these conflicts

took shape within a marked geography of power on and around the shipyard, comprising "wood sheds and dockyard lofts, city counting houses and drawing offices, or lecture-rooms and academies."[3]

In the case of the large ships built to serve European commercial and imperial expansion in the context of colonial conquest, questions of control over the circulation of knowledge and its application in production immediately touched on state power itself. Even before the industrial revolution, most states therefore attempted to maintain some restrictions on the circulation of knowledge about building and sustaining warships, perhaps the most emblematic pieces of military hardware in projecting the early modern state's power abroad.[4] However, such attempts were always at odds with the realities of extending and intensifying maritime connections. As many historians have pointed out, maritime expansion itself became one of the key drivers for knowledge exchange between continents, including the knowledge required to build and sustain the instruments of expansion, of which the ship itself remained the most costly, complex, and labor-intensive example.[5] The fundamental shift in perspective toward long-distance (re) assembly and repair proposed by Mary Brazelton and Dániel Margócsy in the introduction to this special issue can be of great help for gaining a better understanding of long-distance knowledge transfers in shipbuilding.[6]

As is the case with the other "traveling equipment" discussed in this issue, the very nature of the employment of the fighting ship doomed all attempts to prevent the copying of shipbuilding practices.[7] The act of projecting state power or the power of colonial companies across oceans was in itself antithetical to monopolizing knowledge in contained geographical areas. Knowledge had to travel with the ships because warships needed to be repaired or rebuilt in distant locations, often by members of their own crew; because expanding imperial states chose to erect shipyards in colonial settings; or

surrounding shipbuilding and design, see Pamela O. Long, *Artisan/Practitioners and the Rise of the New Sciences, 1400–1600* (Corvalis, OR: Oregon State University Press, 2011), pp.10–29.

3. Schaffer, "Charter'd Thames," p.280 (note 2).
4. For example, in October 1772 the Amsterdam Admiralty Board decided to put firm restrictions on foreign visits to its shipyard and central storehouse, "considering the frequency of requests to visit them, often coming from unknown people and foreigners, which in other countries are never or only very rarely granted." National Archives, The Hague (NA-Ha), *Collection Pieter van Bleiswijk 1772–1787*, 3.01.25, no. 353.
5. See among others Harold J. Cook, *Matters of Exchange. Commerce, Medicine and Science in the Dutch Golden Age* (New Haven/London: Yale University Press, 2007); C. A. Davids, *Zeewezen en wetenschap: De wetenschap en de ontwikkeling van de navigatietechniek in Nederland tussen 1585 en 1815* (Amsterdam: Bataafsche Leeuw, 1985); Richard Sorrenson, "The Ship as a Scientific Instrument in the Eighteenth Century," *Osiris* 11 (1995): 221–36.
6. Dániel Margócsy and Mary Brazelton, "Techniques of repair, the circulation of knowledge, and environmental 3 transformation: Towards a new history of transportation," *History of Science* 61 (2023): 3–18.
7. Sara Caputo, "Exploration and Mortification: Fragile Infrastructures, Imperial Narratives, and the Self-Sufficiency of British Naval 'Discovery' Vessels, 1760 -1815," *History of Science* 61 (2023): 40-59; Mary Brazelton, "Aviation infrastructures in the Republic of China, 1920–37," *History of Science* 61 (2023): 102–120.

because military competition forced states and colonial companies to emulate or adapt each other's shipbuilding achievements.[8] With the expansion of sea-borne empires from the fifteenth century onward, the mobilization of resources, labor power, and shipbuilding knowledge of necessity expanded from encompassing large coastal regions to encompassing the globe.[9] Furthermore, copying the technological advances made by others in warfare at sea was an inherent part of imperial competition. Often, the objective was to catch up to competitors but not to build identical fleets: differences emerged, among other reasons, out of the different aims for which the fleets were constructed, the varying natural conditions of home ports and foreign harbors, and attachment to local shipbuilding traditions.[10] As Everill's article in this issue highlights, the necessities of ship repair in eighteenth-century West African naval hubs led African shipwrights to selectively adapt local and European designs. Shipyards thus spurred the spread and hybridization of knowledge as their administrators attempted to overcome local limits.

The traveling hardware of the ship was not the only vehicle for transferring shipbuilding knowledge. States frequently offered aid to advance the shipbuilding capacities of strategic allies. In the late seventeenth century, Czar Peter the Great reputedly learned the ropes for building the Russian fleet during a visit to the Netherlands and England, and later on could freely use his connections with naval administrators in Holland to buy ships in Western Europe and train and recruit skilled shipwrights and seamen.[11] Such examples are certainly not confined to the early modern period or to Europe, despite persistent narratives of European exceptionalism in the use of gunpowder technology at sea. During the nineteenth century, the successful copying of naval shipbuilding practices of industrial frontrunners such as Britain became one of the hallmarks of success for the modernization projects of non-European states, from the Tanzimat period in the Ottoman Empire between the 1830s and 1870s to the Meiji reforms in Japan after 1868.[12]

8. Cátia Antunes, "European Shipbuilding and Ship Repairs outside Europe: Problems, Questions and some Hypotheses," *The International Journal of Maritime History* 31:3 (2019): 456–64.
9. For examples of this focused on the Spanish empire, see Ivan Valdez-Bubnov, Segio Solbes-Ferri, and Pepijn Brandon (eds.), *La movilización de recursos militares en el mundo hispánico y la globalización temprana* (Mexico City: UNAM, 2019), and for examples focusing on the Dutch, Portuguese, Spanish, French, and English early modern Empires, see the individual contributions to the special issue of the *International Journal of Maritime History* introduced by Antunes, "European Shipbuilding."
10. Geoffrey Parker, *The Military Revolution. Military Innovation and the Rise of the West, 1500–1800* (Cambridge: Cambridge University Press, 1988), Chapter 3. Also see N. A. M. Rodger, "From the 'Military Revolution' to the 'Fiscal-Naval State,'" *Journal for Maritime Research* 13:2 (2011): 119–28; Gijs A. Rommelse, "An Early Modern Naval Revolution? The Relationship between 'Economic Reason of State' and Maritime Warfare," *Journal for Maritime Research* 13:2 (2011): 138–50.
11. Igor Wladimiroff, "Andries Winius and Nicolaas Witsen, Tsar Peter's Dutch Connection," in Carel Horstmeier, Hans van Koningsbrugge, Ilja Nieuwland, and Emmanuel Waegemans (eds.), *Around Peter the Great. Three Centuries of Russian-Dutch Relations* (Groningen: INOS, 1997), pp.5–23; Tatjana Solovjova, "Die Niederlande und die Schaffung der russischen Flotte im Baltischen Meer," in Carel Horstmeier, Hans van Koningsbrugge, Ilja Nieuwland, and Emmanuel Waegemans (eds.), *Around Peter the Great. Three Centuries of Russian-Dutch Relations* (Groningen: INOS, 1997), pp.35–41.
12. For the Ottoman Empire, see Akin Sefer, "From Class Solidarity to Revolution. The Radicalization of Arsenal Workers in the Late Ottoman Empire," *International Review of*

Key among the global disseminators of shipbuilding techniques and approaches were the sailors, artisans, and industrial workers who formed the highly mobile workforce responsible for building ships and maintaining them abroad. In many ways, these sailing artisans were for the eighteenth and nineteenth century what the tramping journeymen had been for the premodern period: carriers of knowledge beyond the capacities of control of individual companies or states.[13] From the perspective of the state and the colonial companies it backed, the question of organizing long-distance shipbuilding and ship repair was therefore closely connected to managing labor mobility and labor relations onsite. States and colonial companies tried to restrict the migration of skilled personnel, in particular the master shipwrights who, during the early modern period, were "the key persons in naval technology."[14] Especially in the late eighteenth and nineteenth centuries, advancing industrialization went hand in hand with the introduction of more and more elaborate regulations granting state administrators stricter bureaucratic control over ship design, scientific modeling, and technological development, partly to prevent copying by rival nation states, but arguably much more importantly to change the balance of power between managers and skilled artisans on the key sites of shipbuilding themselves.[15]

The central thesis of this article is that the main barriers for transplanting shipbuilding practices across large distances and between polities in the age of European expansion did not reside in the available shipbuilding knowledge in different imperial locations, but in problems pertaining to the management of skilled labor and shipbuilding supplies.[16] Over time, states and colonial companies refined the techniques for long-distance control over shipbuilding practices in faraway locations. This was never simply an issue of administration or managerial techniques: the control over people and things was always a matter of politics and power, involving potential conflicts between metropolitan states and companies, their overseas agents, and local elites, as well as between employers and workers. Large shifts occurred over time in the logistical and technological requirements for harnessing shipbuilding knowledge and applying it in local production processes. These changes will be traced by looking at

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Social History 58:3 (2013): 395–428, 398; Dilara Dal, *The Modernization of the Ottoman Navy during the Reign of Sultan Abdülaziz (1861–1876)*, unpublished dissertation (University of Birmingham, 2015); Akin Sefer, *The Arsenal of Ottoman Modernity. Workers, Industry, and the State in Late Ottoman Istanbul*, unpublished dissertation (Northeastern University, May 2018); For Japan, see Kozo Yamamura, "Success Illgotten? The Role of Meiji Militarism in Japan's Technological Progress," *The Journal of Economic History* 37:1 (1977): 113–35; Yukiko Fukasaku, *Technology and Industrial Development in Pre-war Japan. Mitsubishi Nagasaki Shipyard 1884–1934* (London and New York: Routledge, 1992), pp.28–9.

13. On pre-modern mobility of artisans and their role in knowledge circulation, see Reinhold Reith, "Circulation of Skilled Labour in Late Medieval and Early Modern Central Europe," in S. R. Epstein and Maarten Prak (eds.), *Guilds, Innovation, and the European Economy* (Cambridge/New York: Cambridge University Press, 2008), pp.114–42.
14. Jan Glete, *Swedish Naval Administration, 1521–1721* (Leiden/Boston: Brill, 2010), p.332.
15. Alan Lemmers, *Techniek op schaal. Modellen en technologiebeleid van de Marine, 1725–1885* (Amsterdam: De Bataafsche Leeuw, 1996), pp.98ff; Larrie D. Ferreiro, *Ships and Science: The Birth of Naval Architecture in the Scientific Revolution, 1600–1800* (Cambridge, MA: MIT Press, 2006), p.294; Schaffer, "Charter'd Thames," p.298 (note 2).
16. See the introduction and the other essays in this special issue.

three larger moments of (attempted) long-distance transfer of shipbuilding practices: the creation of hybrid shipbuilding practices through the Dutch and English East India Companies' (VOC and EIC) activities in Asia; the interaction between private industry and the Dutch state to simultaneously advance industrial shipbuilding in the Netherlands and on Java in the first half of the nineteenth century; and the aid provided by Dutch engineers in laying the groundwork for Japanese industrial warship-building in the second half of the nineteenth century. The first involves transfer within the loosely organized, company-directed Dutch Empire in the age of sail; the second looks at transfer in the early stages of industrialization and in the context of rapidly extending metropolitan control over colonial affairs; and the third looks at the transfer of industrialized shipbuilding practices between an imperial state and an independent state. All three examples have previously been discussed by naval historians, and the aim of this article is not details of each individual moment. What is new in our approach is that we take these examples out of their specific national framework, still overwhelmingly the dominant context in which the development of shipbuilding is discussed even when focusing on transfers of shipbuilding knowledge between national states or within empires. Rather, by analyzing shipbuilding knowledge as embedded in practices that were both globally mobile and subject to social conflict at different scales, we will interrogate these Dutch–Asian examples as part of wider shifts in the conditions within which shipbuilding knowledge circulated among European and non-European contexts under the influence of industrialization.

Early modern fighting ships and the problem of leverage over resources and skilled labor: The case of the Dutch East India Company

Recent literature on the extent of circulation of shipbuilding knowledge and practices within and between empires rightly challenges the idea that Europeans owed their advantage in seapower to their monopolization of a particular kind of shipbuilding knowledge. In fact, as Cátia Antunes recently noted, imperial shipbuilding should always be regarded as the result of "blended know-how": "Although European knowledge and geo-political needs may have dictated the number, design and build of the ships, specific challenges meant that local techniques, inputs and solutions were also needed. In practice, it was a mostly non-European specialized labor force that developed the projects and delivered the final ships."[17] The extent to which copying shipbuilding practices across political and cultural borders was possible can be illustrated by an early seventeenth-century example. In 1633, faced with attempts by the Dutch East India Company to make incursions into the Chinese Empire, the warlord Zheng Zhilong managed to build in the port city of Xiamen a fleet of "sturdy, multidecked vessels" following "the Dutch style," carrying thirty to thirty-six large guns.[18] The feat was never replicated. The reason for this,

17. Antunes, "European Shipbuilding and Ship Repairs," 460 (note 8).
18. Tonio Andrade, *The Gunpowder Age. China, Military Innovation, and the Rise of the West in World History* (Princeton and Oxford: Princeton University Press, 2016), pp.203–4.

however, seems not to have been any particular lack of capacity in shipbuilding, but the simple fact that in the end traditional Asian warships proved to be perfectly capable of keeping the Dutch at bay.[19] Likewise, the failure of the early modern Japanese state to match European warship manufacturing has been ascribed to political more to political choices than to a lack of technological capacity to adapt Dutch examples.[20]

Consciously erected political barriers to knowledge transfers, whether part of the mercantilist policies of early modern states to protect domestic industries, pragmatic reasons to stick to pre-existing shipbuilding techniques, or the xenophobic suspicions of rulers, overall proved rather porous. This does not mean that there were no formidable barriers to overcome when transplanting shipbuilding practices between states or empires, or across large distances. However, the many examples of attempts at copying or improving on competitors' designs suggests that such obstacles did not primarily reside in the inability to acquire theoretical insights into the manner of building particular types of ships. More important obstacles in this period resided in problems concerning the practical application of such knowledge, and were connected to states' control over flows of skilled labor, money, and materials.[21] A key role in this was reserved for master shipwrights, who were coveted for the knowledge and experience they embodied. Especially the construction of large hulls required a trained eye for overseeing the selection of materials and delicately arranging particular pieces of timber into the general shape called for by the design specifications. These skills were so important to founding shipbuilding programs that early modern states acquired a lively interest in stimulating rival shipwrights' migration. Despite states and naval authorities' occasional efforts to prevent emigration, it proved difficult to constrain shipwrights' movements. The Dutch shipwright Henrik Hybertsson was recruited to the post of Master Shipwright at Stockholm navy yard in 1621. Similar processes took place in Asia: when, in the middle of the seventeenth century, the king of Siam wanted to build up his naval presence, he did so by employing the Dutch master shipwright Abram Jansen, and by hiring a Dutch helmsman and ten Dutch gunners to man his Dutch-design yacht, to the great dismay of the VOC.[22]

European merchant companies such as the VOC faced similar problems to states in maintaining their fleets overseas, having to mobilize labor and resources. In Amsterdam

19. Ibid., p.206. For more detail on the organization of naval shipbuilding in the later Ming and Qing period, see Christine Moll-Murata, *State and Crafts in the Qing Dynasty (1644–1911)* (Amsterdam: Amsterdam University Press, 2018), Chapter 4.
20. Leonard Blussé, "Towards a Hybrid Seagoing Ship: The Transfer and Exchange of Maritime Know-How and Shipbuilding Technology Between Holland and Japan before the Opening of Japan (1853)," in Angela Schottenhammer (ed.), *Early Global Interconnectivity across the Indian Ocean World*, Vol. II (Cham: Palgrave Macmillan, 2019), pp.227–48.
21. This claim draws on the collaborative work on military and naval state (sub-)contracting presented in H. V. Bowen, "The Contractor State, c. 1650–1815," *International Journal of Maritime History* 25:1 (2013): 239–74, as well as the more recent special issue on the "Business of War" edited by Rafael Torres-Sánchez, Marjolein 't Hart and Pepijn Brandon, *Business History* 60:1 (2018).
22. Blussé, "Towards a Hybrid Seagoing Ship," pp.239–40 (note 20).

and other Company towns in the Netherlands, the VOC acquired shipyards that rivaled those of the navy in size and building capacity.[23] These shipyards churned out large ships that combined two functions: carrying out intercontinental trade and mustering firepower. Throughout the seventeenth century, the directors of the VOC repeatedly attempted to ban the construction of ships outside of the Netherlands, both for reasons of bureaucratic control and with the explicit aim of making sure that "the indigenous did not acquire experience in shipbuilding."[24] VOC directors residing in *patria* strongly favored sticking to a unitary model for shipbuilding, and instituted forms of control as part of the production process to ensure this.[25] However, as Matthias van Rossum has argued, the exigencies of running shipyards to repair ships overseas meant that such a ban on knowledge-diffusion was untenable for local colonial administrators, who often did not enforce it. Instead, the Company relied on hybrid Dutch–Asiatic shipbuilding practices, spawning new repair yards throughout its realm, which often also engaged in shipbuilding, albeit on a more modest scale than that of the major yards in the Dutch Republic.[26] The VOC's main shipyards in the East Indies were located in Batavia and the nearby island of Onrust. Although primarily intended to repair European ships, the shipyards were also utilized for the construction of new ships, such as the brigantine *Achilles* in 1713.[27] Since organizational and infrastructural limits formed the main bottleneck for both repair and construction, once these limits were overcome it was tempting to repurpose repair yards as construction yards in times of need.

Overcoming these organizational limits required ship-repair and ship-construction knowledge to be integrated into infrastructural knowledge concerning resource flows and labor management. In 1681, the Governor-General of the Dutch East Indies reported that the repair of ships at Onrust was stalling:

> The scarcity of carpenters and lack of space to careen [turn a ship on its side to repair its hull] more than one ship at a time has caused much hindrance, and the wood is also running out, although our provisions would be refilled soon, were it not for the lack of strong knees [curved hardwood used in ship frames].[28]

23. As detailed in Pepijn Brandon, *War, Capital, and the Dutch State (1588–1795)* (Leiden and Boston: Brill, 2015), Chapter 3. Also see Johan de Jong, "Drawings, Ships and Spices: Accumulation at the Dutch East India Company," in Lissa Roberts (ed.), *Centres and Cycles of Accumulation in and Around the Netherlands during the Early Modern Period* (Zürich/Berlin: Lit Verlag, 2011), pp.177–204.
24. Matthias van Rossum, "Building Maritime Empire: Shipbuilding and Networks of Coercion under the Verenigde Oost-Indische Compagnie (VOC) in South and Southeast Asia," *The International Journal of Maritime History* 31:3 (2019): 465–80, 471.
25. De Jong, "Drawings, Ships and Spices," p.184 (note 23).
26. Van Rossum, "Building Maritime Empire," 471–2 (note 24).
27. Ibid., 470.
28. "Report to the Gentlemen XVII of the VOC by Rijckloff van Goens, Cornelis Speelman, Balthasar Bort, Anthonio Hurdt, Willem van Outhoorn, Joannes Camphuys and Frederik Bent, Batavia, 25 July 1681, in *Generale Missiven van Gouverneurs-Generaal en Raden aan Heren XVII der Verenigde Oostindische Compagnie*. Volume IV, edited by W. Ph. Coolhaas (The Hague: Nijhoff, 1960), p. 477.

The Governor-General thus highlighted three major bottlenecks that confronted naval administrators everywhere: the mobilization of sufficient labor power, the quality of the local shipyard facilities and infrastructure, and the adequacy of local supplies of wood and other strategic goods. Experiments were carried out with the outsourcing of ship-construction to other places, but the set of barriers encountered remained quite consistent between shipyards in different locations. For instance, in 1652 the VOC ordered ships from a merchant in Siam, but two years later it was decided no more orders would be placed with her due to a lack of shipwrights under her command.[29] As described by Van Rossum, a number of other strategies were tried out by the VOC: to overcome the dearth of suitable materials, the company made deals with the sultanate of Mataram to deliver timber from its rainforests; to overcome the lack of laborers, enslaved and convicted laborers were employed alongside waged workers, both to deliver wood and to construct infrastructure.

In this manner, shipyards and ships formed integrated worlds of labor where various forms of knowledge were produced, combined, embodied, and redistributed. The movement of sailors and artisans from shore to sea and back, and their circulation between different empires, not only formed a pathway for the rapid international movement of ideas but also of artisanal knowledge and experience.[30] Beyond skilled shipwrights, many members of ships' crews in the course of their careers gained hands-on experience in building and repairing ships onsite. This is explored in more detail in Caputo's contribution to this special issue, where she discusses the almost permanent need for "voyage repairs" or "unscheduled ship maintenance" that had to be undertaken before ships could reach the far-apart repair stations established by the British state in Asian waters.[31] Even when a ship managed to reach a repair station, sailors might be called upon to work side by side with ship carpenters or the shipwrights employed on these yards.[32] Indeed, the dependency of early modern shipping on the daily availability of ordinary sailors to keep their vessels afloat helped to turn the individual sailor into a "collective worker," as Marcus Rediker described it, greatly enhancing the workforce's collective power during the voyage.[33] The wish to maintain skilled crews for company or state led to the creation of elaborate schemes – sometimes voluntary and to the benefit of workers, sometimes underpinned by forms of impressment driven solely by the desires of naval authorities – to secure unemployed sailors to work in shipyards.[34]

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29. Van Rossum, "Building Maritime Empire," 468 (note 24).
30. Peter Linebaugh and Marcus Rediker, *The Many-Headed Hydra. Sailors, Slaves, Commoners, and the Hidden History of the Revolutionary Atlantic* (Boston: Beacon Press, 2000).
31. See Caputo, "Exploration and Mortification" (note 7).
32. Good examples of the practice of recruiting sailors on the spot to assist in ship repairs, either onboard or on shore, though in this case in a Caribbean context, can be found in Karwan Fatah-Black, "Shipbuilding and Repair in Eighteenth-Century Suriname," *The International Journal of Maritime History* 31:3 (2019): 521–38, 536.
33. Marcus Rediker, *Between the Devil and the Deep Blue Sea. Merchant Seamen, Pirates, and the Anglo-American Maritime World, 1700–1750* (Cambridge/New York: Cambridge University Press, 1987), Chapter 2.
34. E.g. the *matricula de mar* in the Spanish Empire. Javier de Salas, *Historia de la matrícula de mar y exámen de varios sistemas de reclutamiento marítimo* (Madrid: T. Fortanet, 1870).

The necessity of developing infrastructure, access to resources, and a stable local workforce capable of adapting designs to local conditions was certainly not unique to the VOC. These necessities posed similar challenges for all states and company directors attempting to dictate the limits for local engagement in shipbuilding from the metropoles. Here, attempts by the British East India Company to develop its overseas naval capacities can provide a point of comparison, as hybrid nautical knowledge in India was embedded in a similar context of infrastructural limits and organizational conflicts. Frank Broeze writes that until the nineteenth century, "no marked dualism existed between the technology and organization of Indian and British shipowners."[35] Inspired by Portuguese vessels, Indian shipwrights incorporated iron nails and European cannons into Indian teak designs. These shipwrights were skilled in the creation of rabbeted hulls, which dispensed with European caulking techniques. As early as 1526, a Chittagong-based merchant locally commissioned a Portuguese-style galliot, against the wishes of the Portuguese themselves.[36] By the sixteenth century, the Coromandel Coast had developed into a hub for Indian shipbuilding, and European merchants were not averse to purchasing locally built ships.[37] The Coromandel Coast was especially well placed for the social infrastructures mobilizing labor, iron, and teak, but competitors soon emerged on the Malabar Coast, and eventually Bombay, where shipyards had ready access to the teak supplies of the western Ghats.[38]

The EIC's shipbuilding and repair facilities were developed in this contentious context, embedded in conflicts over timber, iron, and labor. As with the VOC, metropolitan shipbuilders in London attempted to monopolize the provision of ships for the interoceanic trade.[39] However, the realities of long-distance trade drove the Company to develop overseas repair facilities, and to buy Indian-built ships for the intra-Asian trade. The step to outright ship-construction overseas was much smaller after the EIC had inserted itself into the mobilization networks necessary to carry out repairs and purchases. In 1686 the Bombay council wrote to the Company directors in London:

> A dry dock for the refitting of shipps will be of great use here and may be easily made. This your Deputy Governor Sir John Wyborne does believe may be of great use and profit to your Honours and indeed so it must for all shipps in these seas, when they know of a Dock where they may lye dry securely, will come to clean and repair their shipps.[40]

35. Frank Broeze, "Underdevelopment and Dependency: Maritime India during the Raj," *Modern Asian Studies* 18:3 (1984): 429–57, 433.
36. Sanjay Subrahmanyam, "A Note on Narsapur Peta – A 'Syncretic' Shipbuilding Centre in South India, 1570–1700," *Journal of the Social and Economic History of the Orient* 16 (1988): 305–11, 308.
37. Sanjay Subrahmanyam, "A Note on Narsapur Peta – A 'Syncretic' Shipbuilding Centre in South India, 1570–1700," *Journal of the Social and Economic History of the Orient* 16 (1988): 305–11.
38. K. N. Chaudhuri, *The Trading World of the English East India Company, 1660-1760* (Cambridge: Cambridge University Press, 2006), p.202.
39. Ibid.
40. Quoted in Ruttonjee Ardeshir Wadia, *Bombay Dockyard and the Wadia Master Builders* (Mumbai: Memorial Printing Press, 1955), p.31.

The dock became a central node of control, also hosting a jail and offices of various EIC officials. Once infrastructure and resource networks were developed, repair yards could be repurposed as construction yards for oceanic vessels, especially in times of heightened tensions in the "fraught relationship between commercial and military demands for scarce naval resources that [pervaded] British political discourse."[41] The shipyard not only produced vessels for the EIC, but also for Indian merchants, to the extent that the Bombay council felt compelled to intervene by forbidding the sale of ships to military and mercantile competitors.[42]

The yard steadily expanded throughout the eighteenth century, driven by competition over labor and timber amid rising military demands. In 1735, Lowjee Nusserwanjee, a Parsi carpenter working for the English at Surat, informed the Company that twenty-eight English workmen had defected to the French.[43] The following year, Lowjee was offered a large raise to move to Bombay with his team, where he eventually replaced the English master shipwright and oversaw the construction of a large drydock in 1750.[44] Under the pressure of the Carnatic Wars, the Bombay council had managed to convince the EIC's London office that an expansion of the yard was desirable, despite the latter's protectionist inclinations when it came to transoceanic shipbuilding. The EIC spared no expense in retaining Lowjee, providing him the funds to build a house for his family to move to from Surat.[45] There are indications that Lowjee was held on to not just for his technical prowess, but also for his managerial knowledge, mediating in conflicts between EIC captains and Parsi workers.[46]

As with the VOC's East Indies facilities, the provision of timber for the Bombay shipyard became a major bottleneck. Unlike the VOC, however, this was driven in large part by a conflict over *metropolitan* sources of timber. Toward the end of the eighteenth century, tracts by public figures warned of the impending exhaustion of timber supplies from English forests. In 1772, scarcity prompted a construction ban for large ocean-going EIC vessels in London, under the concerted lobbying efforts of the admiralty and London shipyard owners.[47] However, the EIC's overseas yards were incapable of replacing the London yards at short notice. In 1778, Admiral Edward Hughes wrote to London: "The extent of the Marine Yard, as it is at this time, is much too small to give room for the necessary quantities of timber and workmen and I earnestly recommend to you that you will extend it."[48] Renewed war with France in the 1790s again squeezed the supply of metropolitan timber, and the EIC's directors decided to charter Indian shipping and

41. Edmond Smith, "Corporate Naval Supply in England's Commercial Empire," *Journal of Maritime History* 31:3 (2019): 574–83, 576.
42. Wadia, *Bombay Dockyard*, p.131 (note 40).
43. Ibid.
44. Ibid., p.40
45. Ibid., p.134
46. Ibid., p.159
47. Michael Mann, "Timber Trade on the Malabar Coast, c. 1780–1840," *Environmental History* 7 (2001): 403–25, 404.
48. Wadia, *Bombay Dockyard*, p.40 (note 40).

further scale up their Bombay construction operations, aiming to construct at least one teak ship of the line and a frigate there annually. This required them to redirect the Malabar teak trade more substantially, which they attempted to do with a form of forest management that monopolized the felling of certain trees. However, they ultimately lacked the ability to enforce this monopoly, and local merchants maintained their power to direct the flows of teak well into the nineteenth century.[49] After the Napoleonic Wars, London shipbuilders reasserted their interests, with the Registry Act of 1815, commonly known as the Lascar Act, prohibiting the registration of India-built ships in England.[50]

What emerges clearly from these examples is that despite states' and chartered companies' occasional attempts to restrict the movement of this vital form of production and the knowledge embedded in it, the transfer and adaptation of shipbuilding practices did take place time and time again. Barriers to such transfers did not primarily arise from technological incapacity, especially because so much knowledge about the shipbuilding process resided with skilled craftsmen who moved across imperial, jurisdictional, and cultural boundaries. Additionally, the maintenance of company activity in Asian waters required a constant supply of ships and repair-work on the spot that could only be met locally. However, important bottlenecks for long-distance shipbuilding and ship repair continued to arise from the difficulty of mobilizing labor power and strategic goods far away from the state's main seat of power, creating tensions between metropolitan states or company directors and their local agents in the process.

Steam power and state power

During the first half of the nineteenth century, the increasing use of steam-powered machinery changed the aspect of shipyards throughout the world. Much, however, remained the same. Despite the slow rise of the steamship in commercial transport and in auxiliary functions for state navies, wooden sailing ships were not replaced by iron-clad steamships in naval warfare or on transoceanic commercial routes until the second half of the nineteenth century.[51] Well into the nineteenth century, therefore, shipyards continued to combine many of the features of preindustrial manufacturing, including the central position of skilled shipwrights in the work process, with the increasing use of steam-driven cranes, pumps, and other machinery bringing in new types of workers and knowledge. However, as in the preceding period, problem-solving on the road to industrial transformation almost always took place in the context of attempts to overcome resource constraints amid fast-paced international knowledge-circuits. When it came to transforming labor management in a setting of large-scale production employing hierarchically differentiated labor forces consisting of highly trained engineers, skilled and unskilled wage workers, and unpaid convict workers, shipyard managers across Western

49. Mann, "Timber Trade," 405 (note 47).
50. Broeze, "Underdevelopment and Dependency," 435 (note 35).
51. As was the case in commercial shipping. David M. Williams and John Armstrong, "An Appraisal of the Progress of the Steamship in the Nineteenth Century," in Gelina Harlaftis, Stig Tenold, and Jesús M. Valdaliso (eds.), *The World's Key Industry. History and Economics of International Shipping* (Basingstoke: Palgrave Macmillan, 2012), pp.43–63.

Europe and the United States actively drew on knowledge acquired in colonial contexts.

What is remarkable when comparing the timeline of industrial change in naval shipyards of the so-called industrial frontrunners and those within the global periphery is their synchronicity. The same period that saw the introduction of steam-powered cranes and pumps at Chatham or in Toulon also saw the introduction of similar instruments at the *Astillero* (shipyard) at Havana, which by that time had been consigned to the margins of Spanish naval renewal for several decades.[52] In 1827, the crushing defeat of the Turkish navy at the Battle of Navarino against the far superior British, French, and Russian navies had laid bare the inadequacy of the old infrastructure of naval power of the Ottoman Empire, as well as the general weakness of the Ottoman state. In the Tanzimat period of state-led attempts at administrative and economic modernization introduced in 1839, the imperial shipyard in Istanbul became one of the focal points for industrial reform by the Ottoman state.[53] In 1831, engineers had already been brought in from the United States to advise the sultan on the conditions of Ottoman shipbuilding and to launch a program to start manufacturing steam ships in Turkey. In 1837, under their direction, the first steamship was built on *Tersane-i Amire* itself, although at this point the engine still had to be imported from Britain. This rapid process of emulation was partly the result of the activities of states, but as in the early modern period it also depended substantially on the mobility of non-state actors, from skilled machine workers to the "entrepreneurial engineers" whose importance as go-betweens in the early industrial revolution has been stressed by Lissa Roberts.[54]

Preventing the spread of machine technology from ostensible frontrunners to peripheries was at this stage near-impossible, as production facilities did not yet require highly complex fixed capital. In this context, shipyards could function as important nodes for the transfer of knowledge between the state and private industry, as well as between different national and imperial settings. As before, political attempts to limit the spread of knowledge were relatively easily overcome. The British state tried to control the export of steam-power machinery through an ineffectual emigration ban for "skilled artisans" that lasted until 1824, and an export ban for complex machinery that lasted until 1842.[55] However, foreign competitors could easily circumvent these British protections, as the development of both metropolitan and colonial shipyards-cum-machine-workshops in the Dutch empire shows. In the early 1820s, the Dutch navy employed

52. Ovido Ortega Pereyra, *El Real Arsenal de La Habana. La construcción naval en La Habana bajo la dominación colonial española* (La Habana: Editorial Letras Cubanas, 1998).
53. Akin Sefer, *The Arsenal of Ottoman Modernity. Workers, Industry and the State in Late Ottoman Istanbul*. PhD Thesis (Northeastern University, 2018).
54. Lissa Roberts, "Full Steam Ahead. Entrepreneurial Engineers as Go-betweens during the Late Eighteenth Century," in Simon Schaffer, Lissa Roberts, Kapil Raj, and James Delbourgo (eds.), *The Brokered World. Go-Betweens and Global Intelligence, 1770–1820* (Sagamore Beach: Science History Publications, U.S.A., 2009), pp.193–238.
55. M. S. C. Bakker, W. H. P. M. van Hooff, and H. Schippers, "Machine-bouw," in H. W. Lintsen (ed.), *Geschiedenis van de techniek in Nederland. De wording van een moderne samenleving 1800–1890. Deel IV* (Zutphen: Walberg Pers, 1993), pp.36–65, 39.

Gerhard Roentgen to investigate English naval construction facilities. In a common pattern of transfer between state and private industry, Roentgen would use the knowledge acquired to buy his own shipyard at Feyenoord and convert it to the production of steam engines in 1827. That same year, his competitor Paul van Vlissingen likewise converted a major shipyard to machine-manufacturing, hiring the English engineer William Jackson to convert the former VOC yard on Oostenburg in Amsterdam into the *Fabriek voor Stoom- en andere Werktuigen*. Jackson became one of 2,000 English steam-workers drawn to mainland Europe in the 1820s to circumvent the British export ban. The plants developed onsite schooling facilities to train a new generation of cheaper local engineers, and they mobilized large workforces to build the necessary infrastructure for large construction projects: in 1847 at least 700 worked at Feyenoord and 1,200 worked at the Oostenburg factory.[56]

These machine-manufacturing firms also played a role in a wider infrastructural transformation. Having given the impetus to the creation of these two concentrated machine-manufacturing plants, the Dutch state in turn became dependent on them for carrying out two aspects of its project of colonial consolidation: shipbuilding and the extension of sugar production in the East Indies. In a time of rapid changes in shipbuilding practices, the Dutch state looked to the expertise of the Feyenoord and Oostenburg workforces to solve problems of power-projection. Some of Roentgen's earliest contracts in 1824 were for fast wooden steamships that the navy intended to use to patrol the East Indies against piracy.[57] A decade later, the navy again ordered such "bandit ships," this time made of iron, for which both Roentgen and Van Vlissingen delivered steam engines. Knowledge that circulated through the plants became instrumental in overcoming infrastructural bottlenecks elsewhere. In 1844, Van Vlissingen ordered the construction of a drydock for steel ships on Oostenburg, which was immediately put to use building a barge for the Dutch colonial administration of Surinam. Many of these ships were assembled in the Netherlands, disassembled for transport, and then reassembled overseas.[58] Reassembly and repair required adequate facilities in the colonies, and the 1840s therefore saw the transformation of colonial shipyards, a task for which the state again turned to Oostenburg. In 1847, the Oostenburg factory constructed a steam-powered drainage pump for the shipyard at Onrust; a floating drydock for the repair of iron ships was sent to Surabaya from Oostenburg in 1863.[59] In turn, these colonial shipyards became sites of machine-manufacturing in their own right.

Overall, the relationship between private capital and colonial state in advancing transnational production processes and knowledge transfers is thus best considered as

56. G. Roger Knight, *Sugar, Steam and Steel: The Industrial Project in Colonial Java, 1830–1885* (Adelaide: University of Adelaide Press, 2014), p.56; J. L. van Zanden, *De industrialisatie in Amsterdam, 1825–1914* (Bergen: Octavo, 1987), p.25.
57. J. M. Dirkzwager, "Scheepsbouw," in H. W. Lintsen (ed.), *Geschiedenis van de techniek in Nederland. De wording van een moderne samenleving 1800–1890. Deel IV* (Zutphen: Walberg Pers, 1993), pp.66–102, 77.
58. Ibid.
59. Paul van Vlissingen and Abraham Dudok van Heel, Letter to the Minister of Colonial Affairs (January 9, 1847), NA-Ha, Collection *Ministerie van Koloniën 1814–1849*, 2.10.01, no. 1756; Bakker, Hooff, and Schippers, "Machine-bouw," p.63 (note 55).

symbiotic. This symbiosis was reinforced by the infrastructural and managerial knowledge developed in shipyards. Advances pioneered in naval shipbuilding could be applied to other, commercial purposes. A key intersection of naval machine-industry and colonial policy in the mid-nineteenth century was sugar. On Java (as in other places, such as Cuba under Spanish colonial rule), there was a direct connection between the creation of industrialized shipyards and capital-intensive sugar refining. The Oostenburg factory smoothed over dips in naval orders with orders from the sugar industry to such an extent that the latter became its main customer. Paul van Vlissingen sent William Jackson as an agent to Surinam; another agent, Jacob Bayer, was employed on Java.[60] Fusing the exigencies of machine production for shipping and sugar, government shipyards in the Indies played a key role in the creation of machine-manufacturing firms that adapted technologies to conditions on the sugar frontier. The government shipyard at Surabaya, employing 800 workers by 1853, spent the sugar season repairing sugar machinery, and even delivered an entire sugar installation.[61] Private offshoots sprang up around Surabaya: Alexander Lawson, a former Feyenoord engineer who had started as an apprentice in the shipyard-foundries of Dundee, set up a machine-plant; Van Vlissingen's former agent Bayer quit his stint as engineer at the government shipyard in 1841 and started his own machine-manufacturing firm close by.[62] Within two decades it had grown to a size rivaling Feyenoord, with 750 workers carrying out assemblies and repairs on steam engines for sugar plantations.

The extension of colonial industry and the increasingly international operations of machine manufacturers, combined with the increasing efficiency of colonial bureaucracies, enhanced the advantages of transplanting production wholesale to the colonies. Just like ships, steel mills and vacuum pans were initially manufactured in the metropole, disassembled for shipping, and reassembled onsite. However, buyers in the colonies were often unhappy with the machinery they had acquired, finding it unsuited to local conditions, and encountering transportation damage such as rust and assemblage problems such as leaks.[63] They therefore looked to more local solutions to their machinery issues, bypassing the control of their metropolitan suppliers. Both Van Vlissingen and Roentgen undertook ill-fated attempts to reassert control over the supply of machinery to the colonies. Van Vlissingen repeatedly requested that the Ministry of Colonial Affairs set up a depot in Batavia and fund one of his own engineers to carry out the reassembly in Surinam and Java.[64] With the reputation of Oostenburg machinery in jeopardy, he

60. Paul van Vlissigen and Abraham Dudok van Heel, "Fabrijk van Stoom- en andere Werktuigen te Amsterdam," *Algemeen Handelsblad*, August 10, 1832; J. L. Meijer, "Industriele ontwikkleingen op Oostenburg na 1800," in J. B. Kist et al. (eds.), *Van VOC tot werkspoor: het Amsterdamse industrieterrein Oostenburg* (Utrecht: Stichting Matrijs, 1986), p.187; M. G. de Boer, *Honderd jaar machine-industrie op Oostenburg, Amsterdam, 1827–1927* (Amsterdam: De Bussy, 1927), p.109.
61. Knight, *Sugar, Steam and Steel*, pp.41, 55 (note 56).
62. Ibid., p.56.
63. Margaret Leidelmeijer, *Van suikermolen tot grootbedrijf : technische vernieuwing in de Java-suikerindustrie in de negentiende eeuw* (Eindhoven: Technische Universiteit Eindhoven, 1997), p.122.
64. De Boer, *Honderd jaar machine-industrie*, pp.107, 111, 120 (note 60).

attempted to set up a sugar factory in the mid 1840s that would showcase his products close to Surabaya in Java's eastern salient.[65] Although European firms continued to be the main suppliers of machinery, Javan firms soon began carrying out repairs and assembling steam-machinery of their own. In a bid to save the protected status of metropolitan firms, Roentgen proposed to the Minister of Colonial Affairs that iron from the East Indies should not be used for machine-construction there, but should instead be transported to the Netherlands for processing.[66] The expensive proposal was rejected.

As before, the key challenge to the spread of industrial sites was not technological in a disembodied theoretical sense, but lay in the long-distance management of labor and resources, as well as the potential friction this created between metropolitan companies and their local agents. Javan production sites had an advantage over their European counterparts in their close access to the point of machinery's application, as well as to sources of iron and wood. Once issues with labor acquisition were overcome, the way was cleared for machine-industry on Java. The spread of industrial shipbuilding practices brought along other industries in its wake. In sugar factories and at the government shipyard in Surabaya, waged Javan and Chinese engineers were trained.[67] However, alongside the creation of new groups of skilled laborers, these facilities also remained deeply steeped in colonial forced labor practices. The shipyard at Onrust had convict quarters dating from the seventeenth century, and it continued to make use of convict labor throughout the nineteenth century.[68] Large construction projects, such as the expansion of the Surabaya shipyard and the construction of Van Vlissingen's model factory, enlisted corvée laborers. Conflicts between the state and private industry over the implementation of corvée labor reveal its indispensability for such projects: when Van Vlissingen constructed his factory in Java, the military authorities of Surabaya protested that they required the laborers for the construction of naval defenses.[69] Overall, the interplay between state and private capital surpassed attempts at monopolizing knowledge in "advanced" metropolitan industries. Rather, the capacity to mobilize resources and control workers was in crucial ways refined in the transfer of technological knowledge and managerial practices between private industries and the state, and between colonial and metropolitan contexts.

Machines to build machines: Naval shipyards as part of a wider industrial landscape

As is clear from the previous section, early industrialization saw the continuation of a multidirectional pattern of knowledge transfer at the levels of states and private companies, involving not just theoretical shipbuilding models but also transfers in managerial

65. Ibid., pp.113–16.
66. Ibid., p.109.
67. Knight, *Sugar, Steam and Steel*, pp.56–8 (note 56).
68. Van Rossum, "Building Maritime Empire" (note 24); for evidence of convict labor at Onrust in the mid-nineteenth century, see for instance the reference to "bannelingen" (exiles) in *Java-bode* (July 23, 1856).
69. Governor of the East Indies to the Minister for Colonial Affairs (May 19, 1846), NA-Ha, Collection *Ministerie van Koloniën 1814–1849*, 2.10.01, no. 1709.

techniques and adjustments to the long-distance mobilization of resources. Older practices of the manufacture of wooden sailing warships were mixed with new technologies such as the application of steam-driven machinery on shipyards. "Blended know-how" continued to be crucial in the organization of production and repair outside the metropoles, contradicting the kind of one-directional diffusionist model between industrial frontrunners and followers assumed by traditional modernization narratives. The advent of industrialized shipbuilding in the first half of the nineteenth century did push to the fore new transnational actors and sets of interests in stimulating the circulation of these varied forms of practical knowledge, from machine operators and transnationally active manufacturers to colonial state officials. The importance of this grew by the second half of the nineteenth century, when the superiority of the steam-propelled, ironclad battleship over wooden sailing ships for the first time created a decisive connection between military advantage and technological advances.

The proliferation of the iron, steam-propelled battleship can illustrate the accelerated speed at which technologies traveled from this time onward. In 1862, the U.S. Civil War saw the first sea battle between ironclads, pitting the USS Monitor against the CSS Virginia near the major Confederacy shipyard in Norfolk, Virginia. Just a month after this battle, the Dutch navy decided to put a halt to the then ongoing refurbishing of the wooden steam frigate De Ruyter, which in 1863 was transformed into an ironclad with reference to "the important events, which have occurred in March of last year off the coast of Norfolk in North-America."[70] In September 1864, the Royal Dockyard at Chatham completed the *Achilles*, a much more sophisticated iron battleship with a steam engine, the first of its kind to be built at one of the British navy's own yards.[71] Japan built its first steam-propelled gunboat in 1866, and within a decade, building on U.S., British, French, and Dutch experience, both China and Japan had naval shipyards that produced ironclad, steam-propelled ships of considerable quality.[72]

Important factors inducing this acceleration in international transfers, apart from improved means of communication and transport, were the increasing reach of state power both within societies and between metropoles and colonies, more intense cooperation between states and internationally operating private industry, and advances in the ways of spreading scientific and managerial knowledge through the proliferation of naval and engineering schools. However, alongside these factors benefiting international transfers of shipbuilding practices, the growing technological requirements of military production and the acceleration of research and development produced by the deepening of the industrial revolution also led to an exponential increase in the challenges of transplanting shipbuilding practices between societies. The great power advantages presented by ironclads over traditional wooden ships by the mid-nineteenth century forced the hand of states in updating their naval facilities. Apart from the ongoing issues of state

70. Cited in A. van Dijk, *Voor Pampus. De ontwikkeling van de scheepsbouw bij de Koninklijke Marine omstreeks 1860* (Amsterdam: De Bataafsche Leeuw, 1987), p.104.
71. Philip Macdougall, *Chatham Dockyard, 1815–1865. The Industrial Transformation* (Ashgate: The Navy Records Society, 2009), p.xv.
72. Andrade, *Gunpowder Age*, pp. 279–81 (note 18); Fukasaku, *Technology and Industrial Development*, pp.28–9 (note 12).

control over resource mobilization and skilled labor across large distances, builders of warships now to a far greater extent grappled with the difficulty of replicating integrated industrial production processes. In 1843, the Qing naval official Ding Gongzhen aptly summarized the reason why the Chinese state was not capable of producing its own full-sized steamships as the lack of "machines for making machines." Twenty years later, when asked by a state official what China at that point needed most, the first Chinese graduate from an American university, Yung Wing, replied, "a mother machine shop, capable of reproducing other machine shops."[73]

The example of the Surabaya shipyard, which already produced both ships and machinery, hinted at the way in which industrializing shipbuilding partly depended on, but also partly provided the solution for the problem of, integrating machine-manufacturing processes. The history of Japanese industrialization provides a classic example of the way in which this bottleneck could be overcome, as well as the crucial role that international knowledge circulation played even in the most nationally oriented naval construction programs. The threat posed by European and U.S. naval power to Japan's traditional policy of isolation in the mid-1850s led to the first attempts to replicate European shipbuilding practices by reverse-engineering a stranded Russian schooner. This paved the way for the wholesale importation of foreign shipbuilding practices. In 1856, the shogun asked the Dutch state for a team of engineers to set up an iron foundry and naval training facility in Nagasaki. The ministerial salary paid to the leading engineer, W. J. C. Huyssen van Kattendyke, reflects the importance the Japanese state accorded to this project of knowledge transfer.[74]

Once in Nagasaki, the engineers came across the by now familiar problems of resource leverage and skilled labor acquisition. These problems were compounded by the necessities of manufacturing in an industrial era, with complex machinery requiring a wider landscape of manufacturing facilities, such as brickworks. The enterprise found itself having to manage these different components of the industrial process, which in Europe fell under "separate masters."[75] According to Huyssen van Kattendyke's memoire of the period, "the engineer [in charge of constructing the foundry] encountered many impediments, with the limited tools and total lack of brick makers, masons, and masters in other crafts."[76] The engineers realized that even if they found the necessary skilled laborers, they could not always control them, and (undoubtedly reflecting the spread of the trope of "the lazy native") the Dutch complained that "The Japanese are so slow."[77] When a master smith was brought to the workshop, he disappeared after one day. Huyssen van Kattendyke suggested that the skilled laborer had too much power in the local political structure: When he asked the governor of Nagasaki whether there was a way to "coerce"

73. Andrade, *Gunpowder Age*, p.278 (note 18).
74. Herman Stapelkamp, "Hendrik Hardes (1815–1871): grondlegger moderne Japanse scheepsbouw en industrie," *Tijdschrift voor zeegeschiedenis* 10:1 (1992): 29–40, 32.
75. W. J. C. Huyssen van Kattendyke, *Uittreksel uit het dagboek van W.J.C. ridder Huyssen van Kattendyke, kapitein-luit ter zee, gedurende zijn verblijf in Japan* (The Hague: W.P. van Stockum, 1860), p.72.
76. Ibid., p.56.
77. Ibid., p.64.

the smith, either through "imprisonment or by withholding his considerable salary," the governor replied that this would be "very difficult" as it was not "the Japanese way." Huyssen van Kattendyke was disappointed in the state's general lack of disciplining power, writing that "The police in this country is terrible! One could almost say there is none."[78] As a side-note, he added that he had advised the Japanese government about the European army-conscription policies. For these Dutch engineers, the creation of an industrial foundry for the purposes of shipbuilding was thus inseparable from an expansion of state power as an auxiliary to extending managerial control over the workforce – a conviction that had strong parallels to the experience of colonial labor management in the context of the expansion of industry in the Dutch East Indies.

Huyssen van Kattendyke also had other criticisms of the institutions that he encountered in his attempt to apply naval steam technology to a new setting. The naval academy that was established alongside the shipyard and machine workshop taught a broad curriculum including geography, medicine, Dutch, and mathematics, aiming to train administrators skilled in both managerial and technical tasks.[79] In Huyssen van Kattendyke's assessment, this venture also clashed with the local political structure, as the students were picked by lords based on political expediency rather than their interest in naval industrialization. He suspected that "the majority of our students only came to Nagasaki to obtain a general education, which will later recommend them to be placed in high positions, and that only very few of them have set their sights on the navy."[80] He complained that they were too old to be disciplined, and were generally uninterested in the education that the Dutch officers deemed necessary. The social conflicts involved in creating a class of technically schooled administrators eventually felled the academy itself: amid intensifying struggles over Japan's foreign treaties and rising suspicions of the local daimyo's officials, the Edo government suddenly withdrew its students in 1859.[81]

Throughout the 1850s and 1860s, the shogunate continued working on developing its industrial landscape for the purposes of steamship construction by sending inspectors overseas. One team visited the Netherlands in 1862; another visited Bayer's Surabaya machine-factory in 1866.[82] Dutch books on shipbuilding were translated and taught at Nagasaki. Despite the Nagasaki naval academy's prompt closure, some of the Japanese administrators connected to it would go on to occupy influential positions in training a class of modernizing officials.[83] Under the Meiji Restoration, the shipbuilding and iron complex became the center of the country's industrial transformation. As in the sugar machinery workshops developed in East Indies shipyards in the preceding decades, or in the naval facilities developed by charter companies in the preceding centuries, private

78. Ibid.
79. Ibid., pp.23–4.
80. Ibid., p.201.
81. Stapelkamp, "Hendrik Hardes," 33 (note 74); Marius B. Jansen, *Sakamato Ryoma and the Meiji Restoration* (Princeton, NJ: Princeton University Press, 1961), p.63
82. Fukasaku, *Technology and Industrial Development*, p.19 (note 12); Knight, *Sugar, Steam and Steel*, p.53 (note 56).
83. Jansen, *Sakamato Ryoma*, p.76 (note 81).

industry and state power fed off one another in the transfer of technologies through shipyards. Even before the Japanese state privatized its Nagasaki shipyard by leasing it to Mitsubishi in 1884, these state facilities played a large role in assisting private industry by acting as a "mother machine shop" in the sense indicated by Yung Wing. According to historian Kozo Yamamura,

> The Yokosuka arsenal . . . is known to have produced mining and other machinery as well as repaired twice as many foreign and privately-owned Japanese ships as navy ships. With its heavy machinery the arsenal constructed lighthouses and participated in the construction of government buildings, private factories, roads, and harbors. Though rarely noted by economic historians, six of the ten private cotton textile firms, which began operation in the early 1880s using spindles imported by the government, relied on steam engines produced at the arsenal.[84]

Not only did shipyards continue to function as nodes of transnational shipbuilding knowledge-transfer, but they became sites of all-round industrial development, mobilizing labor and resources for shipbuilding, and thereby expanding their countries' wider industrial potential. To a much greater extent than in the early modern period, this ability to transform local conditions depended on cooperation between engineers, companies, and the imperial state in the management of production and resource mobilization.

Conclusions

This survey has discussed a wide variety of examples where large-scale shipbuilding in the service of imperial expansion was transferred across large distances to meet the exigencies of naval competition, transoceanic shipping, and the need to build and repair ships far outside the metropoles. The construction of ships for empire, either by navies or by private companies, lends itself well to comparing processes of technological transfer before, during, and after the Industrial Revolution, and on an international scale. Unlike many other branches of manufacturing, both before and after the Industrial Revolution, the building of such ships involved large-scale integrated production processes on yards that often employed many hundreds, if not thousands, of workers at the same time. Navies and colonial companies inherently operated in an environment of international competition, and technologies and work-practices were transferred over large distances, both accompanying the movement of the ships themselves and reflecting wider patterns of imperial expansion.

Historians of science and technology in the past have often privileged the importance of abstract thought or laboratory inventions as drivers of industrial progress. Such approaches, however, have come under sustained criticism from those emphasizing the practice-oriented, socially embedded nature of scientific and technological change, in the process reinforcing the role of the joint efforts of artisans and practitioners against that of the pure scientist acting as an individual, separate from the world.[85] The examples of the attempts to transplant

84. Yamamura, "Success Illgotten?", p.117 (note 12).
85. See the overview of the debates emanating from Steven Shapin and Simon Schaffer, *Leviathan and the Air-Pump. Hobbes, Boyle, and the Experimental Life* in the authors' introduction to the second edition (Princeton and Oxford: Princeton University Press, 2011 [1985]), xi–l.

machine production over large distances show that the application of new scientific insights not only depended on the continuous interaction between scientists and practitioners but also involved the development of new techniques of managerial control over labor and resources within the production process. Shifts in the power nexus between (private or semi-private) companies and the state accompanied this development of managerial practices.

More important determinants in the circulation of shipbuilding practices than unequal access to theoretical knowledge were the capacities of states, naval administrators, and colonial companies in controlling the flows of necessary resources and the spread of managerial practices over skilled and unskilled, waged and coerced shipyard labor, depending on complex arrangements between states and private capital. Industrialization did not change this basic fact, but it did change the nature of these arrangements. Although shipbuilding knowledge always remained practice-driven, highly mobile and susceptible to local adaptation, the heightened technological demands entailed by the transition from sail to steam and wood to iron, combined with the extension of the power of states and transnationally operating manufacturing companies, considerably changed the institutional embeddings and societal consequences of its circulation.

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