Inventing Purity in the Atlantic Sugar World, 1860-1930

by
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Abstract

This dissertation illuminates how expert labor makes a complex natural substance into a uniform global commodity. Drawing on both published sources and extensive archival research in the continental United States, in Scotland, and in Puerto Rico, it provides new insight into the workings of the empires of commodities that define modern capitalism. Chapter 1 shows that the notion that sugar has a single valuable molecular essence—sucrose—has been used to explain its history as a commodity. Yet this essentialism is not a natural fact but a product of the political economy of the late nineteenth century itself. From the seventeenth century on, sugar production had relied on the experienced multisensory techniques of enslaved craftsmen. But after 1860, newly sophisticated factories began to appear throughout the Caribbean, producing sugar of unprecedented consistency and quality. Chapter 2 explores how the work of chemists was essential to managing labor within these new factories, whose owners attempted to eliminate the need for artisan work. Yet the more successfully chemists extracted sucrose from sugarcane, the more mechanical and obvious they made that extraction appear, and the more they effaced their own necessity. These efforts to use scientific expertise to de-skill sugar production were made possible, Chapter 3 shows, by the persistence of craft and cooperative production in Glasgow, where those factories' machines were built. Sugar-engineering firms cultivated relationships with distant plantations, ensuring that draftsmen and engineers could design, maintain, and repair machines that would last many decades. It therefore shows how the devices that facilitated sugar's commodification have human histories themselves. Finally, Chapter 4 reveals how the valuation of sugar became a central political issue in the postbellum United States. The Federal government feared its means of enforcing sugar tariffs was being undermined by fraud on the part of Customs officers and by new forms of sugar itself. But supposedly objective chemical techniques were even harder for the state to supervise. In showing how powerful refiners shaped scientific practices to their own advantage, this chapter provides a new framework for historians' analyses of science, commodities, and corruption in the nineteenth century.

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Other teachers have guided me along the crooked highway to becoming a historian. First as a name on a title page, as my MPhil supervisor, and as a friend since, Simon Schaffer has shown me what the history of science can and should be. He also knew just the words a young historian needed to hear at his most bewildered moment. At Columbia, Elizabeth Blackmar, Matthew Jones, Ashli White, and Barbara Fields inspired and then shaped my first attempts at original research. Emma Rothschild has been an unflagging supporter of me and of my project since before we met.

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This dissertation is dedicated to my grandparents, Michael and Anne Roth and Sidney and Molly Singerman. These four warm, kind, generous, and selfless people worked and lived much harder than I ever have or ever will in order that I might get to do something like history for a living.

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Punishing Paul for Peter
Don't ever trust those meters
What you believe is what you see

—Brian Eno

Chapter 1:

Introduction: Sugar, sucrose, and metrological capitalism

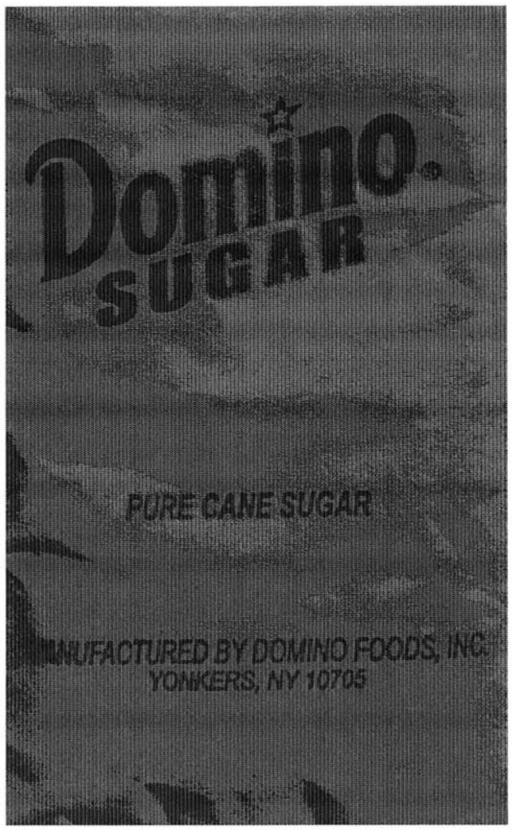


Figure 1.1: What is "pure" about pure cane sugar?

1. Making things the same

What does "pure cane sugar" mean? Whether it comes from the sugar cane or the sugar beet, the anthropologist Sidney Mintz observed, sugar is the only staple food to be consumed in a pure chemical form, as crystals of the sucrose molecule: $C_{12}H_{22}O_{11}$.[1] Why,

1. Sidney Mintz, *Sweetness and Power: The Place of Sugar in Modern History* (New York: W. W. Norton, 1985), 22.

then, should buyers of Domino sugar care that it comes from a particular plant? If what is in the packet and in your coffee is pure sucrose, it shouldn't matter what species first produced it, or indeed whether it was created organically at all (**Figure 1.1**).

Contemporary scholarship on sugar and its history takes this identity of sugar and sucrose for granted. In *Sweetness and Power*, his groundbreaking analysis of the cultural meanings of sugar as a commodity, Mintz axiomatically took sucrose and sugar to be each others' equivalents. He begins his second chapter, on "Production," with the statement that "Sucrose—what we call 'sugar'—is an organic chemical of the carbohydrate family."[2] Earlier in the book, Mintz declares that he will "concentrate in this book on sucrose, though there will be occasion to refer to other sugars."[3] He continues in the same vein. "This focus is dictated by the history of sucrose's consumption in recent centuries, which completely outstripped honey (its principal European competitor before the seventeenth century), and made largely irrelevant such other products as maple sugar and palm sugar."[4] British industrial workers, Mintz writes, are "sucrose consumers."[5] To identify, as the book's subtitle proposes, "the place of sugar in modern history," it holds fixed a single substance from the point of view of late-twentieth-century chemistry.

2. Mintz, *Sweetness and Power*, 19.

3. Moreover, these equations of cane and sometimes beet sugar with sucrose, but no others, are especially striking for the passage they bracket. There, Mintz chides other scholars for reading modern sugar backward into history, and observes that the ancient Greek word *saccharon* "is not translatable as some single specific substance." Ibid., 20.

4. Ibid., 17. Three sentences on, the point is reinforced, when "processed sucrose" is again identified as "the refined carbohydrate product we consume and call 'sugar.'" Chemically speaking—it should be said—the sugar content of maple sugar is almost entirely sucrose, too. Abby van den Berg, Timothy Perkins and Mark Isselhardt, "Sugar Profiles of Maple Syrup Grades," *Maple Syrup Digest* (December, 2006). http://www.uvm.edu/~pmrc/sugarprof.pdf.

5. My point is not to nitpick Mintz's semantic choices, but rather to show that even such an astute critic of commodity meanings, who argued how meanings come from uses as much as the other way around, accepts this identity.

Throughout the book, pure cane sugar is purely sucrose, and the objective of the "ancient, complex, and difficult process" of sugar-making is just sucrose's extraction.[6] But if cane sugar—that is, the product made from the juice of the cane—is not the same thing as sucrose, then Mintz's pairings make far less sense.

The problem of making different things look the same is the problem that every market in commodities must attempt to solve, and sugar is the extreme case of an complex natural product that is made to appear uniform. By showing the ways in which certain kinds of expert labor were required to make sugar seem universally chemically pure and thus identical, we can better understand a phenomenon that is common to all commodities, more and more of which come to be measured and valued with the tools, techniques, and language of modern science. Such an understanding, therefore, becomes increasingly important—to historians of science who are interested in the way that scientific knowledge and practices influenced economic activity at every level from the local to the imperial, to historians of capitalism and of labor who are interested in the ways that human effort makes natural objects seem like uniform commodities. More so than any other commodity, sugar's status has always depended on a perception of its uniformity. But the equation of sugar and sucrose is not a natural fact but a social one, and by failing to question the notion that the history of sugar production is simply the history of the application of chemical knowledge, scholars have failed to recognize that

6. Mintz, *Sweetness and Power*, 21-22.

that supposed identity is precisely the product of forces and interests acting during the late nineteenth century itself.

It was only from the middle of the nineteenth century, after all, that sugar's commodified uniformity could be seen in the terms of organic chemistry—terms which had not existed before organic chemistry itself.[7] In the market for sugar in industrial countries, the economic value of sugar has been directly tied to its sucrose content only since the middle of the eighteen-seventies.[8] Until that point, the value of sugar required various forms of tacit knowledge and bodily expertise. Since then, however, the equivalence of "sugar," especially cane sugar, on the one hand, and "sucrose," on the other, has become deeply entrenched.[9] These contemporary categories have then been read back anachronistically into the history of sugar and of the labor, skills, and technologies required to create it.[10] Sugar has not just been sucrose all along: it had to be made that way.

If we ask how sucrose was made the sole standard of value in sugar, and what effects that standardization had, we can see how scientific knowledge and practice were deployed in an attempt to control the production and trade of this commodity, and how they were resisted. The choice of sucrose as a measure is one that reflects configurations

7. William Brock, *Justus von Liebig: The Chemical Gatekeeper* (Cambridge: Cambridge University Press, 1997).

8. Noël Deerr, *The History of Sugar*, vol. 2 (London: Chapman and Hall, 1949), 506.

9. For example, Eric Otremba writes: "In turning the pith of the sugar cane plant into white crystalline sucrose, the ingenios of the Atlantic basin relied upon a series of mechanical and chemical processes which were highly sophisticated for their day." Otremba, Eric. "Inventing Ingenios: Experimental Philosophy and the Secret Sugar-makers of the Seventeenth-century Atlantic." *History and Technology* 28, no. 2 (2012): 122.

10. For the avoidance of "vicious anachronism," see Nick Jardine, "Uses and Abuses of Anachronism in the History of the Sciences," *History of Science* 18 (2000).

of power, influence, and interests, at scales ranging from Caribbean factories and New York docks to the Atlantic world as a whole.

2. The power of sugar's sameness

Hunger for sugar has driven the history of the modern world. Christopher Columbus famously carried cane stalks on his second voyage to the Americas, but, through the sixteenth century, sugar remained a rarity and a luxury. European nations competing to establish, secure, and expand their imperial wealth searched for land on which the sugar cane could be profitably cultivated. From 1600 onwards, however, the empires of Spain, Portugal, France, the Netherlands, and Britain contested control of much of the planet in the name of sugar. One by one, Brazil, Barbados, Jamaica, Louisiana, Saint-Domingue, Cuba, and Puerto Rico were the foci of capital flows, diplomatic intrigue, and outright battle. These struggles, though centered in the New World, were not confined to it. Just as desirable, later on, were Hawaii, Java, Mauritius, and the Philippines, and anywhere else in the tropical zone where the speed with which the sugar cane shoots skyward can sometimes be measured in units of inches per day.

The wealth of Caribbean sugar helped finance the factories of the Industrial Revolution, wealth that was built on the backs of slaves.[11] Of the twenty million Africans brought enslaved to the New World, reckoned the sugar chemist-turned-historian Noël

11. Eric Eustace Williams, *Capitalism & Slavery* (Chapel Hill: University of North Carolina Press, 1944).

Deerr, eighty percent, or sixteen million, owed their perdition to the insatiable Western demand for sugar.[12] It was sugar that made Saint-Domingue one of the wealthiest places on earth, and led to French apoplexy at its loss. After the end of African chattel slavery, hundreds of thousands of people from China and India were indentured in sugar colonies in the Caribbean, South America, and South Africa. Sugar even brought the *Bounty* to Tahiti, from which Captain Bligh had been ordered to bring breadfruit trees to Jamaica to more cheaply feed that island's enslaved. Those slaves, in turn, grew and processed the sugar that provided the calories for the workers toiling in Britain's mills and factories. Psychologically, a sweet cup of hot tea could make the industrial worker's cold meal into one that warmed instead.[13] If the profits from sugar made industrialization possible, so did sugar itself.

All of these stories about the historical power of sugar as a commodity relate that power to sugar's substance itself. In the sixteenth and seventeenth centuries, that substance was novel: sugar was a modern marvel, like gunpowder, coffee, or strange stones that seemed always to point north.[14] Observers described it in various ways. In his questionably *True & Exact History of the Island of Barbadoes* of 1657 and 1673, famous for its detailed description of sugar-making practices, the Englishman Richard Ligon wrote that the sugar cane has "but one single taste," a taste that could come from the cane

12. Deerr, *History of Sugar*, vol. 2, 284.

13. Mintz, *Sweetness and Power*, 117.

14. Otremba, "Inventing Ingenios," shows how credit for this marvel was systematically stripped from the enslaved artisans who made it and reassigned to planters allied with the Royal Society in order to bolster the prestige of experimental philosophy. For disputes about the novel properties of coffee, see *The Women's Petition against Coffee Representing to Publick Consideration the Grand Inconveniencies Accruing to Their Sex from the Excessive Use of That Drying, Enfeebling Liquor: Presented to the Right Honorable the Keepers of the Liberty of Venus* (London, 1674).

and nowhere else. Yet he did not speak of sugar that was "pure," but of sugar that was "white," or "well cur'd," or "of a bright colour, dry and sweet," and "of a kind of Sugar somewhat inferiour to the Muscavado; but yet will sweeten indifferently well, and some of it very well coloured."[15] Three decades later, as Barbados rose to its greatest wealth and prominence as the most sophisticated and productive sugar-growing region on the earth, no less than John Locke used sugar as an exemplar of a substance that had a nearly universally similar effect on all human beings. Our ideas of sugar "perfectly represent those archetypes which the mind supposes them taken from," Locke wrote in his *Essay Concerning Human Understanding*. "For, if sugar produce in us the ideas which we call whiteness and sweetness, we are sure there is a power in sugar to produce those ideas in our mind."[16] There was some essence within sugar that affected all humans, Locke claimed, even if the nature of that essence was as yet undefined. Viewed through the instruments of the modern natural sciences, Locke's "power in sugar" would seem obviously to be the sucrose molecule. Yet before the development of organic analysis in the early years of the nineteenth century, and before the ideology and rhetoric of precise chemical measurement championed by Antoine Lavoisier, no one described sugar as sucrose. Instead, they described sugar in terms of its means of production and, above all,

15. Richard Ligon, *A True & Exact History of the Island of Barbadoes*, (London: Peter Parker, 1673), 84, 89-90.

16. John Locke, *An Essay Concerning Humane Understanding. In Four Books* (London, 1694), Book II, Chapter XXXI: Of Adequate and Inadequate Ideas.

with the results of what Lissa Roberts called their "sensuous" techniques of bodily experience.[17]

In his chemistry lectures at Princeton, for instance, in 1796 and 1797, the student Louis Hasbrouck recorded the instructor's admonition that "Vegetables furnish many substances which are applied to various uses, but which require the art of the Chemist to fit them for these purposes." Hasbrouck's lecturer's description of his "art" included, rather than an analysis of "sugar" as a distinct component of the juice, a discussion instead of how to separate sugar from the "mucilage and perhaps some filth and impurities of different kinds," which would impede its crystallization and "the white colour which is so agreeable in sugar." But in general the Princeton chemist was uncertain about why sugar interacted with the means and other substances needed in its production and refinement, such as bullock's blood or bone charcoal, in precisely the way that it did.[18] Three decades later, Frederick Mills, a student in Benjamin Silliman's chemistry lectures at Yale in the late eighteen-twenties, recorded that Silliman described sugar as what "may be extracted from the juice of a number of vegitables [sic], & is contained in all those having a sweet taste," and rather than identifying it by its elemental constituents depicted the process "which sugar undergoes, with the view of bringing it to the white and beautiful form."[19]

17. Lissa Roberts, "The Death of the Sensuous Chemist: The 'New' Chemistry and the Transformation of Sensuous Technology," *Studies in the History and Philosophy of Science* 26, no. 4 (1995).

18. Louis Hasbrouck, "Notes from Lectures on Chemistry delivered by Doctor John Maclean, Princeton College, in 1796 & 1797," 67-85. Mss.540.H27, American Philosophical Society, Philadelphia, Pennsylvania (hereafter APS).

19. Frederick Ira Mills, "Lecture 57th, February 17th 1827, in Book 2d. Notes to Proffessor [sic] Benjamin Siliman's [sic] Lectures on Chemistry and Pharmacy. Yale College, 1826 & 7." APS Mss.B.M622.

Early the following decade, Silliman was commissioned by Louis McLane, the Secretary of the Treasury, to deliver a report on sugar's agriculture and production. The Treasury had been instructed by Congress, in 1830, to produce "a well digested Manual" of sugar as a crop, "including the most modern improvements."[20] Silliman's 1832 pamphlet included a section on the "chemical history of cane juice." Yet it nonetheless described sugar in terms of its observable properties first and its definition as a compound last. Sugar was a substance which, "when in loaf, consists of an aggregate of little crystalline grains, is white, inodorous and of a well known sweet taste," he wrote. "It is hard, brittle, and emits a phosphorescent light, when two pieces are rubbed together in the dark." He described how a saturated sugar solution would crystallize, through evaporation, into "very perfect oblique rhombic prisms," how it could be cooked to form caramel, and how a dilute solution would become "sour and mouldy" in a short time. Only at the end did he describe the analysis of completely water-free sugar, and of "Common sugar, or Sugar not perfectly anhydrous." But its analytic constituents were not used, as they would be in later works, as the definition of sugar from which all else followed.[21]

The idea that there was a form of pure sugar, however, one that could be abstracted from the cane and derived from another plant, arose at the same time as the beginnings of the claim that there was a set of practitioners called chemists and a distinct

20. "Letter from Secretary of the Treasury Louis McLane to Professor Benjamin Silliman, New Haven, Connecticut, 18 October 1832." APS MSS.B.Si4.

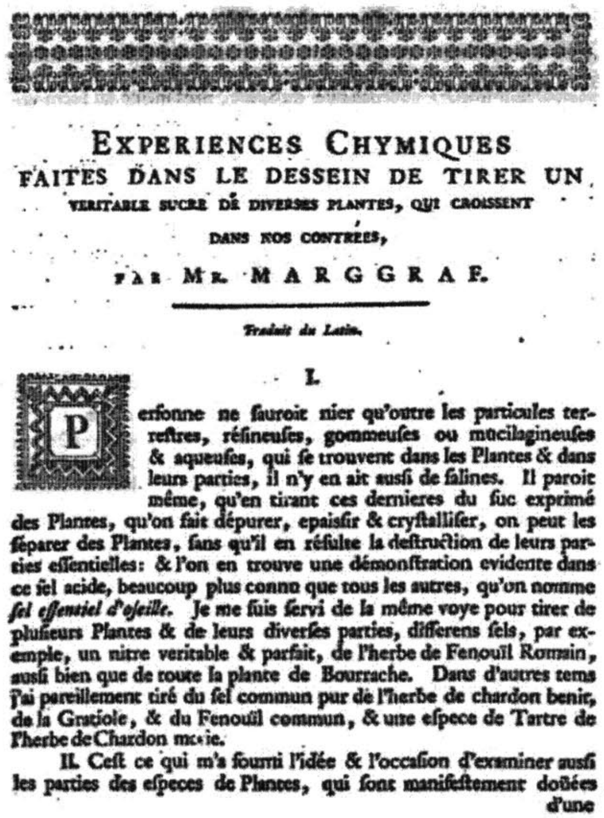
21. *Manual on the Cultivation of the Sugar Cane, and the Fabrication and Refinement of Sugar. Prepared under the direction of the Hon. Secretary of the Treasury, in compliance with a resolution of the House of Representatives of Jan. 25, 1830* (Washington: Francis Preston Blair, 1833), 21-24.

activity called chemistry. In 1747, the German apothecary Andreas Marggraf had concluded, by microscopic observation and a "strong sweet taste," that the substance he had crystallized from the roots of several European plants was the same as what was extracted from the cane: "not merely a substance approaching sugar, but in fact a true and perfect sugar, which has a complete resemblance with *common sugar, which is extracted from the sugar cane*." He published his findings as "Chemical experiments made in order to extract *a true sugar from diverse plants* that grow in our countries" **(Figure 1.2)**.[22] By the beginning of the nineteenth century, those countries that lacked reliable access to a supply of cane sugar, such as the German lands or France sans Saint-Domingue, began a desperate search for alternative sources of sweetness. Marggraf's work, commercialized with Prussian state sponsorship by his pupil Franz Carl Achard, brought into being an industry based on a new crop called the "sugar beet," capable of producing masses of sweet crystals, and which could be cultivated in temperate rather than tropical climates.[23] In 1843 even Justus von Liebig, the pioneer of organic chemistry and himself a beet-sugar skeptic, felt comfortable saying that "This branch of industry seems at length, as to its processes, to be perfected. The most beautiful white sugar is now manufactured from the beet-root, in the place of the treacle-like sugar, having the taste of the root, which was

22. Translation my own, emphasis added. "Un gout fort doux," and "Non seulement une matiere approchant du Sucre, mais meme un sucre veritable & parfait, qui a un entire ressemblance avec le sucre connu, qu'on tire de la Canne à Sucre." See "Experiences chymiques faites dans le dessein de tirer un veritable sucre de diverses plantes, qui croissent dans nos contrées, par Mr. Marggraf. Traduit du Latin.» *Histoire de l'academie royale des sciences et belles lettres 1769* (Berlin: Haude & Spener, Libraires de la Cour & de L'Academie Royale, 1769).

23. Ursula Klein, *Materials in Eighteenth-Century Science: A Historical Ontology* (Cambridge, Mass: MIT Press, 2007), 200.

first obtained."[24] The nature of cane sugar was intimately tied to its agricultural origins, but the possibility of a consumable "beet sugar" was Frankenstein's monster, inescapably the product of early-nineteenth-century German chemical laboratory.



EXPERIENCES CHYMIQUES FAITES DANS LE DESSEIN DE TIRER UN VERITABLE SUCRE DE DIVERSES PLANTES, QUI CROISSENT DANS NOS CONTRÉES,

PAR MR. MARGGRAF.

Traduit du Latin.

I.

Personne ne fauroit nier qu'outre les particules terreftres, réfineufes, gommeufes ou mucilagineufes & aqueufes, qui fe trouvent dans les Plantes & dans leurs parties, il n'y en ait auffi de falines. Il paroit même, qu'en tirant ces dernieres du fuc exprimé des Plantes, qu'on fait dépurer, epaisfir & cryftallifer, on peut les féparer des Plantes, fans qu'il en réfulte la deftruction de leurs parties effentielles: & l'on en trouve une démonftration evidente dans ce fel acide, beaucoup plus connu que tous les autres, qu'on nomme *fel effentiel d'ofeille*. Je me fuis fervi de la même voye pour tirer de plufieurs Plantes & de leurs diverfes parties, differens fels, par exemple, un nitre veritable & parfait, de l'herbe de Fenouïl Romain, auffi bien que de toute la plante de Bourrache. Dans d'autres tems j'ai pareillement tiré du fel commun pur de l'herbe de chardon benit, de la Gratiole, & du Fenouïl commun, & une efpece de Tartre de l'herbe de Chardon marie.

II. C'eft ce qui m'a fourni l'idée & l'occafion d'examiner auffi les parties des efpeces de Plantes, qui font manifeftement doüées d'une

Figure 1.2: Andreas Marggraf's "Chemical experiments made in order to extract a true sugar from diverse plants that grow in our countries" (1747)

The Irish-Virginian chemist John William Mallet, author of an official judges' report at the 1876 Centennial Exposition in Philadelphia, described the substance of sugar in ways notably different from Silliman's. As part of a composite noun, he began, "the

24. Justus Liebig, *Familiar Letters on Chemistry and Its Relation to Commerce, Physiology and Agriculture* (New York: D. Appleton & Co., 1843), no. 4. Liebig himself invested in a beet sugar factory in the late 1820s, but lost much money due to what he felt was its poor administration. See Brock, *Chemical Gatekeeper*, 118-119.

term sugar applies not merely to a single substance, but to a class, no longer a very small one, of substances related to each other by like chemical and physical properties." Under the commercially-important varieties, he listed "Cane-sugar (in the restricted sense, as produced from the sweet cane of the tropics); Beet sugar; Maple-sugar; Palm-sugar; Sorghum-sugar." Cane sugar had an unrestricted sense, too. "When pure," Mallet wrote, "*all of these are cane-sugar in the chemical meaning of the term*; all are one and the same substance, though derived from different sources." Though chemical cane sugar might be procured by "more or less special methods" from different flora, it was mere convenience "to distinguish by different names the sucrose obtained from special plants."[25] Marggraf's "diverse plants" could all produce the substance whose colloquial name still linked it to the sugar cane. But if "pure beet sugar" and "pure sorghum sugar" are just the same as "pure cane sugar," then there would seem to be at least an inherent tension in what is meant by "purity" itself.

By the beginning of the twentieth century, popular (or at least popularly-directed) histories of and introductions to the sugar industry reiterated sugar's essential chemical purity.[26] Harvey Washington Wiley, who began his career as a chemist working for the United States Department of Agriculture in its efforts to develop sugar autarky through

25. Francis Amasa Walker, ed., *International Exhibition, 1876: Reports & Awards: Groups 1- 36* (Philadelphia: Lippincott, 1878), 2.

26. For two examples from popularly-aimed sugar literature of the early twentieth century: "Among the many varieties of sugar the most important are the sucroses and the glucoses....Chemically considered, all sugars are carbohydrates, that is to say, bodies composed of three elements: carbon, hydrogen, and oxygen;" and "But in order to pass the chemical test of purity, all sugar, no matter whether its origin be the cane or beet, must be refined. This most searching process of purification is capable of converting good quality raw sugar into an article that is absolutely pure sugar to the extent of 99.95 per cent.; the remaining 0.06 per cent. is water." George M. Rolph, *Something about Sugar: Its History, Growth, Manufacture and Distribution* (San Francisco: J.J. Newbegin, 1917), 3; Edith A. Browne, *Peeps at Industries: Sugar* (London: A. & C. Black, 1911), 82-3.

beet and sorghum, later became a crusader for the pure food and drug movement, and the first director of Hearst's *Good Housekeeping* magazine Bureau of Foods, Sanitation, and Health. "The principal sugar of commerce is sucrose," he began his chapter on "Sugars and Saccharine Products." Summoning his own memories of "old fashioned New Orleans molasses," Wiley noted that raw cane sugars were "aromatic, good tasting, good smelling and delicious," while those from the beet were "soapy, bad smelling, bad tasting, and unedible." But "when both are pure," he said, they became indistinguishable.[27]

The polariscope was the primary instrument through which chemists claimed to be able to know the sucrose content of a sample of sugar.[28] This device, developed in the first half of the century by the French physicist Jean-Baptiste Biôt, was capable of measuring the degree to which certain substances rotated the direction of polarization of light.[29] Sucrose was such a substance. Despite Biôt's own misgivings as to the instrument's fragility and delicacy, it became a key tool for beet-sugar manufacturers in Europe **(Figure 1.3)**.

27. Harvey Washington Wiley, *1001 Tests of Foods, Beverages, and Toilet Accessories, Good and Otherwise: Why They Are So* (New York: Hearst's International Library Co., 1914), 163, 166.

28. See, among countless others, Charles Albert Browne, *A Handbook of Sugar Analysis: A Practical and Descriptive Treatise for Use in Research, Technical and Control Laboratories* (New York: John Wiley and Sons, 1912); Guilford Lawson Spencer, *General Instructions and Methods of Analysis and Chemical Control: For Use in the Factories of the Cuban-American Sugar Company* (New York: The Cuban-American Sugar Company, 1916). The experience of using the polariscope is explored in more detail in Chapter 4.

29. Sean F. Johnston, "Polarimeter, Chemical," and Paolo Brenni, "Polarimeter and Polariscope," in Robert Bud and Deborah Jean Warner, eds., *Instruments of Science: An Historical Encyclopedia*, Garland Encyclopedias in the History of Science vol. 2 (New York: Science Museum, London, and National Museum of American History, Smithsonian Institution, in association with Garland Publishing, 1998). See also R. Ward, "The Development of the Polarimeter in Relation to Problems in Pure and Applied Chemistry : An Aspect of Nineteenth Century Scientific Instrumentation." (Ph.D., University of London, 1980).

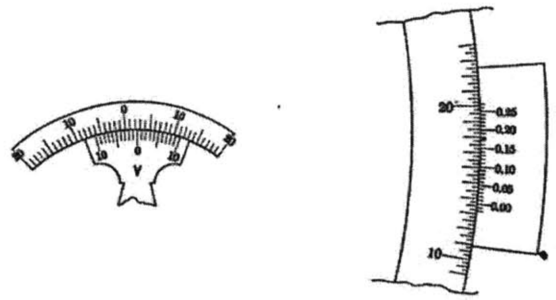


Fig. 53 Fig. 54

Sections of circular scales of polariscopes.

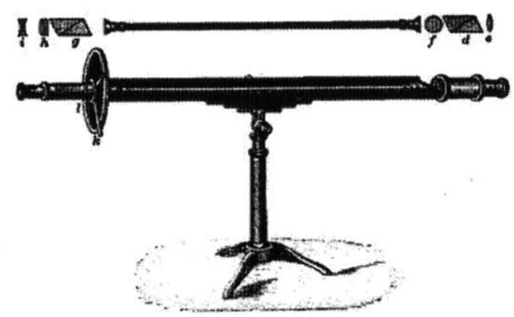


Fig. 55. — Robiquet's polariscope.

d = polarizer
e = condensing lens
f = Soleil double quartz plate
g = analyzer
h–i = telescope
k = lever for rotating analyzer.

Figure 1.3: Mid-nineteenth-century polariscope
(C. A. Browne, *A Handbook of Sugar Analysis*, 1912, p. 87)

Although the polariscope would become the means by which chemists publicly asserted they could straightforwardly measure the presence of sucrose, whether in industrial sugar factories or in customs houses, in their own handbooks chemists acknowledged finer distinctions. "It is customary to use the word 'sucrose' to indicate the apparent or approximate sucrose as ascertained by a direct polarization," read the official handbook of the Cuban-American Sugar Company in 1916.[30] Knowing "the true sucrose content of

30. Guilford Lawson Spencer, *General Instructions and Methods of Analysis and Chemical Control: For Use in the Factories of the Cuban-American Sugar Company* (New York: The Cuban-American Sugar Company, 1916), 4.

a material" required additional steps to account for the presence of invert sugar, which rotated polarized light differently. The ambiguity in everyday use of the distinction between the words "sucrose" and "polarization," the latter meaning specifically the reading on the polariscope's scale, points to the (always already) artifactual and laborious nature of any measurement of a value called purity.[31]

The properties of sugar itself have been taken to have strongly determined everything about the world built around it: the planting of cane, the organization of plantations, work in the mill, trade and commerce, and the use and impact of sugar as consumer good. Furthermore, the supposedly revolutionary nature of new industrial sugar production that took place in the late nineteenth century was predicated on new forms of control over the chemical consistency and makeup of the sugar itself. To a significant degree, the historical analysis of sugar as an Atlantic commodity has been dominated by the notion of a "sugar revolution," and much ink and effort has been expended to define such a revolution and determine precisely where and when it took place.[32] Everywhere in

31. This was the Clerget method of "double polarization." To account for the possibility that some of the sucrose had decomposed into glucose and fructose, each of which rotated polarized light at different rates and in different directions, the Clerget method called for a more elaborate laboratory procedure. Following an initial use of the polariscope, the operator or an assistant added a catalytic acid to the solution to fully split sucrose into its two constituents. A second measurement would allow for the calculation of the change in polarization, and thereby what fraction of the original solution had been sucrose and what had been invert sugars. Such sugars could not be crystallized; indeed, it was precisely their concentration in the molasses which rendered molasses the byproduct of the manufacture of sugar crystals, rather than another intermediate factory product from which further sucrose could be coaxed. The inbuilt checks of the Clerget method led every sugar treatise to acclaim its precision. The question was whether the increase in that precision justified such a laborious process. See George William Rolfe, *The Polariscope in the Chemical Laboratory: An Introduction to Polarimetry and Related Methods* (New York: The Macmillan Company, 1905), 106.

32. Barry W. Higman, "The Sugar Revolution," *Economic History Review* LIII, no. 2 (2000); Philip D. Curtin, *The Rise and Fall of the Plantation Complex: Essays in Atlantic History*, 2nd ed. (New York: Cambridge University Press, 1998), 81-85.

the early modern Atlantic, that revolution is supposed to have encompassed the replacement of small farms by large plantations for sugar monoculture, the supplanting of free labor by enslaved, and a striking increase in population density—the last brought about by an increase in output per capita that itself is attributed to new techniques of planting, grinding, and boiling in the fields and in the sugar-house itself. In writing the history of sugar production in the Atlantic, enormous agency has been assigned to the biology and agricultural demands of the sugar cane itself and the steps that are allegedly necessary to turn it into a transportable, salable commodity.[33] Yet it was not biological or "crop determinism" that led to certain modes of production. Rather it was the linkage of biological requirements, and their effect on the cost of production, with other factors, including the price that consumers would pay for sugar, the taxation policies of the state (set to protect domestic refiners and overseas planters as well as to raise revenue), and what those planters themselves considered a desirable and sustainable rate of profit.[34]

The pioneering Cuban sugar historian Manuel Moreno Fraginals, most famous for his magisterial 1964 study *El Ingenio* (*The Sugarmill*), helped establish the prevailing narrative of a second, industrial revolution in sugar production.[35] He wrote that "starting

33. Higman, "Sugar Revolution," 214. For an example of a recent work that argues that "the basic natural processes" of sugar "were in many ways 'actors' in the drama of industrialization," see Mark J. Smith, "Creating an Industrial Plant: The Biotechnology of Sugar Production in Cuba," in *Industrializing Organisms: Introducing Evolutionary History*, ed. Philip Scranton and Susan R. Schrepfer, Hagley Perspectives on Business and Culture v. 5 (New York: Routledge, 2004), 85–106.

34. Higman, 228-9.

35. Manuel Moreno Fraginals, *The Sugarmill*, trans. Cedric Belfrage (New York: Monthly Review Press, 1976). For more recent analyses on the revolutionary nature of industrialization in sugar, see, e.g. Alan Dye, *Cuban Sugar in the Age of Mass Production: Technology and the Economics of the Sugar Central, 1899-1929* (Stanford, CA: Stanford University Press, 1998); Fe Iglesias García, *Del Ingenio Al Central*, 1. ed. (San Juan, Puerto Rico: Editorial de la Universidad de Puerto Rico, 1998); John Alfred Heitmann, *The Modernization of the Louisiana Sugar Industry*, 1830-1910 (Baton Rouge: Louisiana State

about 1860 and within not more than thirty years, the centuries-old structure of the sugar industry was shattered, to be replaced by completely new forms of production and commerce." The product of sugar itself even took on a "new form," one "produced to different standards and shipped in different packaging." He concludes that "it is no exaggeration to say that as regards sugar in the Caribbean, in the nineties everything was completely different from what existed in the sixties."[36] In Moreno Fraginals's influential analysis, the development of new industrial technologies brought about a crisis in plantation slavery, as "radical innovation" in the devices and chemical techniques of sugar-making "caus[ed] the old manual machines (run by untrained workers) to be junked and replaced by highly sophisticated machinery that required skilled operators and efficient technical supervision."[37] But Moreno Fraginals tied the quality and qualities of sugar itself directly to the changing organization of the factory and labor. The sugar that emerged from these new, more mechanized factories "was as different from the previous product as the central was different from the old slave-run ingenio." In the early

University Press, 1987), Andrés Ramos Mattei, *La Hacienda Azucarera: Su Crecimiento Y Crisis En Puerto Rico (siglo XIX)* (San Juan, Puerto Rico: Cerep, 1981); Humberto García Muñiz, *Sugar and Power in the Caribbean: The South Porto Rico Sugar Company in Puerto Rico and the Dominican Republic, 1900-1921* (San Juan, Puerto Rico: La Editorial Universidad de Puerto Rico, 2010).

36. Moreno Fraginals, "Plantations in the Caribbean: Cuba, Puerto Rico, and the Dominican Republic in the Late Nineteenth Century," in in "Between Slavery and Free Labor: The Spanish-Speaking Caribbean in the Nineteenth Century," ed. Manuel Moreno Fraginals, Frank Moya Pons, and Stanley L. Engerman, 3.

37. Moreno Fraginals, "Plantations in the Caribbean," 4-5. More recently, however, Rebecca Scott has argued for a less deterministic understanding of the end of Caribbean slavery, showing instead that new technologies coexisted perfectly well with human bondage and even, by reducing the demand for certain kinds of labor, helped to sustain it. See Rebecca J. Scott, *Slave Emancipation in Cuba: The Transition to Free Labor, 1860-1899* (Pittsburgh, PA: University of Pittsburgh Press, 2000). For an insightful recent analysis on the lack of contradiction between technical sophistication and enslaved labor, see Daniel Rood, "Plantation Technocrats: A Social History of Knowledge in the Slaveholding Atlantic World, 1830-1865" (PhD dissertation, University of California, Irvine, 2010).

nineteenth century, he observed, prices for sixteen different sugars were posted daily near Havana's wharves.[38]

Such a multiplicity of kinds of sugar was, Moreno Fraginals wrote, "the logical consequence of sugar's being manufactured with primitive equipment, set up in different ways in hundreds of small factories throughout the Caribbean." In each place, "the quality of sugar" changed based on variation in what Moreno Fraginals called "natural factors" like the purity of the juice, and most of all, by the sugarmaster himself, "guided only by his senses (smell, taste, touch, hearing), by his long experience, and by orally transmitted tradition." The sugarmaster was "generally illiterate," Moreno Fraginals noted (in contrast to the warmth of his writing about the same figure elsewhere), while the central factories of the end of the century were instead "supervised by technically trained professionals," connected to international networks of standardized scientific practice, including both their methods of analysis and their "modern laboratory equipment." By the end of the century, he asserts, all Caribbean mills produced to the same standard, 95% [*sic*—actually 96%] sucrose as measured by the polariscope, and this sugar "was a standardized product, where source (cane or beet) or region of origin...was impossible to determine." That standardization was in large part the result of the United States government's decision to set the tariff boundary between raw and refined sugar at 96° by the polariscope in the early 1890s. The undifferentiated nature of sugar as an industrial product allowed for the consolidation of foreign capital's control over the

38. Moreno Fraginals, The Sugarmill, 119.

means of its production.[39]

But the perception of that nature as undifferentiated in the first place was equally the product of that consolidation. Indeed, confusing the distinction between sugar and sucrose renders these changes that Moreno outlined simultaneously revolutionary and evolutionary. On the one hand, factories are supposed to be under scientific control at last, and producers can finally bid adieu to the persistence of old-fashioned craft knowledge. But on the other, if pure sugar really is just sucrose, then the purification of sugar is the same thing as the production of sucrose, which had been the goal all along. In this view, the new industrial factory becomes just the culmination of centuries of development towards efficient technical perfection. Chemists exist merely to ratify this perfection, and once they do, they become invisible.

The homogeneity of sugar was what the Cuban sociologist Fernando Ortiz, looking back from 1940, chose to juxtapose against the uniqueness of each leaf of tobacco. Poetically and mischievously, Ortiz explicitly connected the natural origins, material properties, and means of production of each commodity to what he suggested were their strongly divergent personalities as historical actors. The interplay between "radical" tobacco and "conformist" sugar, he argued, defined Cuban history. By drawing on his own proprietary skill, ingenuity, and knowledge, which were impossible to

39. Moreno Fraginals, "Plantations in the Caribbean," 7-8. He suggests, for instance, that the shelf-stability of centrifugal sugar, because of its low moisture content, allowed stocks to rise from 10 to 50 percent of annual United States consumption, keeping downward pressure on prices. The old commerce, "physical and tangible," required the sugar trade to be a personal one, but "Just as the old slave-operated sugar factories were swept away by the modern industry, this type of trading (and consequently this type of trader) would be replaced by new firms, using new methods, in the last thirty years of the nineteenth century" (10).

mechanize, the tobacco farmer drew out the plant's own sinful, intoxicating power.[40] But while the tobacco leaf was rolled and smoked intact, "sugar is made by man and power."[41] Sugar was the crop of world capitalism, of international corporations that owned huge factories filled with great machines and through those controlled the Caribbean's destiny.[42] Sugar was fundamentally a commodity of social conformity, of satiation rather than inspiration. Cigar-rollers' famous radicalism, spurred by the political tracts read aloud during their workday, was inverted in the subservience of sugar-mill workers, who toiled at their specialized tasks in the noise and heat. And these conforming, accommodating properties of the sugar world emerged because, fundamentally, all sugar was itself the same. "For both sugar-grower and refiner the aim is the most," Ortiz wrote, in one particularly evocative passage:

> the most cane, the most juice, the most bagasse, the most evaporating-pans, the most centrifugals, the highest crystallization, the most sacks, and the most indifference as to quality for the sake of coming close as possible in the refineries to a symbolic hundred

40. Tobacco expressed the political and spiritual independence of the peoples of the Caribbean. It was tobacco that brought inspiration, criticism, and rebellion to Europe, "the breath of a new spirit through the Old World" and its rationalist Enlightenment. Likewise, the tobacco plant itself was, Ortiz wrote, "individualistic to the point of anarchy." Farmers paid attention to each leaf's unique characteristics in picking and drying it.

41. Fernando Ortiz, *Cuban Counterpoint: Tobacco and Sugar*, trans. Harriet de Onis (Durham: Duke University Press, 1995), 9, 49.

42. In writing of the people who cultivated tobacco, but of the machines that made sugar, Ortiz drew his readers' attention to the location of ownership of those machines themselves. Fernando Coronil's introduction to the 1994 edition of Cuban Counterpoint provides an illuminating analysis. "Ortiz treats tobacco and sugar as highly complex metaphorical constructs that represent at once material things and human actors [and] uses the fetish power of commodities as a poetic means to understand the society that produces them," Coronil writes. "At the end of the book, the owners of the machines emerge as the leading actors, for they dominate the structure and aims of production." Fundamentally, Coronil writes, "Ortiz's counterfetishism questions both conservative interpretations that reduce history to the actions of external forces, and humanist and liberal conceptions that ascribe historical agency exclusively to people" (Coronil, in Ortiz, xxvii-xxx). All this makes it perhaps still more startling that Ortiz assumed the truth of the definition of sugar, a definition whose construction he was revealing to be a product of capitalist interests.

> per cent chemical purity where all difference of class and origin is obliterated, and where the mother beet and the mother cane are forgotten in the equal whiteness of their offspring because of the equal chemical and economic standing of all the sugars of the world, which, if they are pure, sweeten, nourish, and are worth the same.[43]

To Ortiz, pure sugar was just a chemical, and the function of a sugar factory was not even to transform sugar, but to restore it to that essential form. The factory facilitated sugar's "pass[ing] from the botanical mass to the chemical product," and in this way, those hulking silhouettes over Caribbean landscapes were read back into the sugar cane plant itself. They were, he wrote, simply extensions of the "little natural sugar mills of the cane stalks" themselves. Thus Ortiz presented as natural and even inevitable the reduction of the "botanical mass" of the fibrous and juicy sugar cane, composed of a variety of substances and flavors, into crystals of sucrose.[44] And it was this identical crystalline form that gave sugar its fetishistic status as a commodity. Through its reduction to sucrose, sugar was allowed, in his provocative phrase, to "pass for white, travel all over the world, reach all mouths, and bring a better price," having become as close to an ideal universal commodity as any actual object could be.[45]

43. Ortiz, 24-25.

44. Harriet de Onis translated Ortiz's "sacarosa," the Spanish term for "sucrose," as "saccharose," an English nomenclature no longer in use.

45. "A long series of complicated physiochemical operations are required merely to eliminate impurities—bagasse, scum, sediment, and obstacles in the way of crystallization." Sugar "is born brown and whitens itself; at first it is a syrupy mulatto and in this state pleases the common taste; then it is bleached and refined until it can pass for white, travel all over the world, reach all mouths, and bring a better price, climbing to the top of the social ladder" (9).

3. The history of capitalism as a history of metrology

The history of capitalism is a history of struggle over the terms by which to evaluate human labor and the products of nature. It is, therefore, a history of metrology. To scientists, "metrology" is the field concerned with investigating, creating, and disseminating standard values. These values, disseminated either as calculations or embodied in special artifacts, are meant to unify scientific activity and regulate activities that depend on it.[46] To historians and sociologists of science, however, "metrology" denotes the social work that turns certain values into apparently natural or self-evident ways of measuring the world.[47] The precision and accuracy of measurements and values—their success at measuring and representing some property the world—themselves need cultural and social histories as the consequences rather than the reasons for consensus.[48]

In the sociologist Harry Collins's famous analogy, standards are like ships in bottles: obvious human creations whose power comes from seeming to have, nonetheless, always existed.[49] The physical, intellectual, and social work that underlies a standard

46. See Bureau International de Poids et Mesures, "What is metrology?", http://www.bipm.org/en/convention/wmd/2004/, and http://www.bipm.org/en/convention/wmd/2004/introduction.html.

47. Schaffer, Simon. "Late Victorian Metrology and Its Instrumentation: A Manufactory of Ohms." In The Science Studies Reader, edited by Mario Biagioli. New York: Routledge, 1999; Schaffer, Simon. "Accurate Measurement Is an English Science." In The Values of Precision, edited by M. Norton Wise, 135–72. Princeton, N.J: Princeton University Press, 1995..

48. Donald Mackenzie, *Inventing Accuracy: A Sociology of Nuclear Missile Guidance*; Schaffer, "Accurate Measurement,"136.

49. Harry Collins, *Changing Order: Replication and Induction in Scientific Practice*. See also Bruno Latour, "Give Me a Laboratory and I Will Raise the World"; and, for a wonderful analysis of the hidden "gestural knowledge" underlying one of the most famous metrological creations, the mechanical equivalent of heat, see Heinz Otto Sibum, "Reworking the mechanical value of heat: instruments of precision and

needs to be hidden for that standard to seem the result of self-evident properties of nature, rather than of scientific practitioners' activities. Though produced in singular laboratories, through highly specific techniques, and by specially credentialed and certified individuals, standard values cannot be taken to represent the particular circumstances of their creation, lest they be seen to be useless at evaluating nature in any other context. Meanwhile, the network of human beings that "lets" a standard value do its job of coordinating humans' behavior cannot be taken for granted. Instead, the construction of that network itself requires explanation.[50] The travel of commodities depends on the same kind of networks. The history of metrology, therefore, is necessary for understanding the ways that control over the means of measurement of valuable commodities was central to the rise of capitalist political economy during the seventeenth and eighteenth centuries.

The classification and measurement of natural specimens troubled natural philosophers of the Enlightenment. Such troubles were directly linked to the fruits of new military and commercial empires. It was not obvious how to determine whether similar-seeming substances were in fact "the same" as those drawn from faraway places, especially from the new and unexplored American landmass. In the late seventeenth century, John Locke and Isaac Newton struggled to find means by which to reliably

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gestures of accuracy in early Victorian England," *Studies in History and Philosophy of Science* 26, no. 1 (1995): 73-106.

50. For example, Joseph O'Connell notes that the global representative of the universal volt, an electric cell, only "works" as a standard when it is carried from place to place by hand, not tipped more than 45°, and let rest in an oil bath at its "favourite temperature" for a month. O'Connell writes: "It does no good to replace a universalistic account of scientific entities like the volt with an equally universalistic account of why people believe they need the volt." See O'Connell, Joseph. "Metrology: The Creation of Universality by the Circulation of Particulars" *Social Studies of Science* 23, no. 1 (February 1, 1993): 129–73.

distinguish pure from alloyed gold.[51] Locke noted that humans could never directly observe substances' essences, but could only test their "powers, either active or passive, in reference to other bodies."[52] Yet it was difficult to agree on what powers "gold" ought to possess, let alone to compel people in distant environments to come to consensus. In Spain's New Granada, for instance, miners judged platinum to be merely gold that was yet "unripe."[53] In the end, Locke concluded, it was merely "convenience that made men express several parcels of yellow matter coming from Guinea and Peru under the same name."[54] The chemist Robert Boyle, Locke's friend and ally, developed instruments to enable English traders to distinguish true from false gold when in Guinea, and for Newton, head of the Royal Mint, to use in prosecuting forgers and clippers.[55] The notion of a pure universal form of a substance, especially one traded as a commodity, was the result and not the cause of judgments about who were such instruments' reliable users and how they should in fact use them.

The free play and ambiguities within systems of measurement, and more fundamentally the choices between different systems of measurement and how they would be enforced and supervised, were weapons wielded by the seventeenth- and

51. Simon Schaffer, "Golden Means: Assay Instruments and the Geography of Precision in the Guinea Trade," in *Instruments, Travel and Science: Itineraries of Precision from the Seventeenth to the Twentieth Century*, ed. Marie-Noëlle Bourguet, Christian Licoppe, and Heinz Otto Sibum (London: Routledge, 2002).

52. Locke, *An Essay Concerning Humane Understanding*, Book III, Chapter IX: On the imperfection of words.

53. Kris Lane, "Gone Platinum: Contraband and Chemistry in Eighteenth-Century Colombia," *Colonial Latin American Review* 20, no. 1 (2011): 61-79, on 68.

54. Locke, Essay concerning human understanding, Book III, Chapter VI, of the names of substances.

55. Schaffer writes of dramatic public assays at Newton's mints. "Assays worked because of their theatre of proof...[The] assay ceremony was a ritual of state power over value." Only with the "right choreography" could it the hydrometer seem, in Newton's words, "the standing universall rule of Valuing Gold in all Nations." Schaffer, "Golden Means," 43.

eighteenth-century London merchant class against the people who worked on the Thames. With the aid of Parliament, they redefined the "customary wages" of sailors, slaves, and lightermen, who swept up loose bits of tobacco, as fraudulent or corrupt practices. At the same time, of course, they engaged in brutally illicit behavior themselves: one common tactic for tobacco merchants was to pick the government's pocket "by colluding with the Thames landwaiters to short-weight his imports, a practice known as 'hickory puckery', thereby reducing his duty, and then by bribing the searcher to long-weight the same consignment on re-export, thereby increasing his drawback; a practice known as 'puckery hickory'."[56] Thus, Linebaugh argues that the "class struggle in the oceanic tobacco trade took a metrological form."[57] At the end of the eighteenth century, the new River Thames police helped secure the newly enclosed West India docks against workers' takings of "sweepings" of sugar. By controlling access and even the workers' manner of dress, the police created a new wage labor force whose discipline was measurable in the difference between the manifest and landed weight of hogsheads.[58]

Domestically, metrological choices shaped the very structure of the industrializing British economy. As William Ashworth and James Sumner have demonstrated, institutions from breweries to textile works were physically and conceptually reorganized to suit the measurement practices of Excise officials.[59] In France, Ken Alder has shown,

56. Peter Linebaugh, *The London Hanged*, Chapter 5, "Socking, the Hogshead, and Excise," esp. 155.
57. Linebaugh, *London Hanged*, 163.
58. At the end of the next century, London's sugar merchants built huge, enclosed "wet docks," whose security would so impress generations of American travelers. The object of their enclosure was to effectively police the workers' allowances of sugar. See Linebaugh, Chapter 12, "Sugar and Police: The London Working Class in the 1790s."
59. William J. Ashworth, *Customs and Excise: Trade, Production, and Consumption in England,*

revolutionaries planned their new metric system to supersede idiosyncratic provincial measures. The new decimal units would help centralize power in Paris and provide a stable basis for a newly national market economy. But such units were resisted, both by producers who cherished their measures tied to land and labor, and by bureaucrats who complained about uncomfortable new calculations in unfamiliar ratios.[60]

Nineteenth-century science was occupied with creating and spreading standard measurements and the practices for making them. As European states worked to consolidate empires, their interest in metrology only strengthened. Late-nineteenth-century empires confronted the problem of synchronizing armies, navies, railroads, and communications on a global scale.[61] Alongside numerous international scientific meetings to agree upon formal definitions of units, the end of the nineteenth century witnessed the establishment of new bureaucracies for theoretical, practical, and legal metrology, in Germany, Britain, France, and the United States, and elsewhere. Yet, as with any

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1640-1845 (New York: Oxford University Press, 2003), 6; James Sumner, "John Richardson, Saccharometry and the Pounds-Per-Barrel Extract: The Construction of a Quantity," *The British Journal for the History of Science* 34, no. 3 (September 1, 2001). The case Sumner examines has informative parallels with the construction of "sucrose" in the sugar trade. Sumner showed how the brewing technologist John Richardson simultaneously promoted both a unit of measurement of his own concoction, called the "pounds-per-barrel extract," and also the instrument, which he called a "saccharometer," that he designed in order to measure that unit. Unlike the subjects of most historical-sociology exercises in the decomposition of naturalized units of measure, Richardson's concept seems to the lay observer to be self-evidently constructed. Yet Richardson sought to make it the center of a theory of brewing, tying his extract to existing artisans' understandings of their liquids while nonetheless claiming advantages of precision and economy. Whereas brewers had attempted to compare the alcoholic content of their beers based on the volume of malt, Richardson declared that the beer's "strength" was not just better measured by his saccharometer, but that "strength" was what the saccharometer and only the saccharometer measured. Ultimately Richardson hoped his unit would rationalize taxation and eliminate the supposed arbitrariness of the Exciseman's judgment. By the time this took place, a century later, the pounds-per-barrel-extract "was now so firmly entrenched in the brewery context as to require no justification."

60. Ken Alder, "A Revolution to Measure: The Political Economy of the Metric System in France," in M. Norton Wise, ed., *The Values of Precision* (Princeton: Princeton University Press, 1995).

61. See Peter Galison, *Einstein's Clocks, Poincare's Maps: Empires of Time* (New York: W. W. Norton, 2003).

diplomatic gathering, their mandates were ambiguous, and it was therefore collaboration within and among groups of local scientists and standards laboratories that, first, practically defined the standards that these conventions supposedly established, and second, endowed them with their strength and resilience.[62]

Historians of science have by now comprehensively shown that the successful operation of instruments is a local and contingent process like any other. The ability to propagate standards anywhere always depends on the ability to recreate scientific technique and material culture. Not long ago, historians accepted that instruments maintained their reliability when they traveled. This imperviousness to context, in fact, seemed to be the source of their power. Bruno Latour famously argued that what made scientific laboratories powerful was their ability to monopolize the production of "immutable mobiles," inscriptions that worked equally well everywhere in the world.[63] Indeed, the definitions of "success" and "operate" are precisely what is being contested in each case. No instrument works in a new social and material context without a great deal of work to prepare the way. Likewise, rather than existing in discrete functioning or dysfunctional states of being, instruments are, like other technological objects, constantly

62. Michael Kershaw, "The international electrical units: a failure in standardisation?" Studies in the History and Philosophy of Science 2007. For a recent analysis of the relationship between matters of fact and what one might term "matters of convention," see Ken Alder, "Scientific Conventions: International Assemblies and Technical Standards from the Republic of Letters to Global Science," in Mario Biagioli and Jessica Riskin, eds., *Nature Engaged: Science in Practice from the Renaissance to the Present* (New York: Palgrave MacMillan, 2012), 19-40. For bureaus of standards see Raymond C. Cochrane, *Measures for Progress: A History of the National Bureau of Standards* (Washington: U. S. Department of Commerce, 1966).

63. See Bruno Latour, *Science in Action: How to Follow Scientists and Engineers through Society* (Cambridge, MA: Harvard University Press, 1987).

broken and constantly being repaired and maintained.[64] Such maintenance requires not formal rules or designs but the ability to tinker, as well as unformalized, and indeed unformalizable, tacit understandings. Far from stability inhering in instruments themselves, therefore the fact that an instrument "looked and behaved as it had on the other side of the world" is itself a remarkable achievement—the explanandum rather than the explanation.[65] The supposed "universality" of knowledge made with instruments was actually fundamentally grounded in local knowledge and in the construction of "proper" situations for the use of those instruments.

Like empires, such new ways of understanding the world are never extended by fiat. Historians of science have sought to show the enormous difficulties of coordinating at vast distances how devices and people behave. In doing so they have have complicated existing narratives about the relationship between science and empire. Many historians have emphasized the power of metropolitan institutions to project European forms of knowledge, as in Richard Drayton's analysis placing the Kew gardens at the center of its own empire of economic botany.[66] Even an individual like Darwin gained much of his power and influence from being at the center of a worldwide correspondence network that depended on his wealth and position in British society.[67] Importantly, "hard" or

64. For histories of maintenance, see David Edgerton, *The Shock of the Old: Technology and Global History since 1900* (New York: Oxford University Press, 2007), and Simon Schaffer, "Easily Cracked: Scientific Instruments in States of Disrepair," *Isis* 102, no. 4 (December 1, 2011): 706–17.

65. Nicky Reeves, "Constructing an Instrument: Nevil Maskelyne and the Zenith Sector, 1760-1774" (PhD dissertation, University of Cambridge, 2008), 4; Nicholas Dew, "Vers La Ligne: Circulating Measurements around the French Atlantic," in *Science and Empire in the Atlantic World*, ed. James Delbourgo and Nicholas Dew (New York: Routledge, 2008), 53–72.

66. Richard Harry Drayton, *Nature's Government: Science, Imperial Britain, and the "Improvement" of the World* (New Haven: Yale University Press, 2000).

67. Janet Browne. *Charles Darwin: The Power of Place* and *Voyaging*. 2 vols. Princeton, NJ: Princeton University Press, 1996, 2002.

"exact" sciences like physics, astronomy, and chemistry relied just as completely on the infrastructure of empire to spread their values, moral and calculated, as did natural history or medicine. Yet at the same time, if the modern dominance of scientific ways of understanding the world is not due to neither its inherent universal appeal, neither can it be attributed to the all-controlling social power of metropolitan institutions or Latourian "centers of calculation."[68] The "tyranny of distance," as Jim Endersby notes in his study of the negotiated exchanges between botanic gardens in Sydney and London, extended both ways. If it was hard for a colonially-emplaced scientist to draw attention to his work, it was very nearly as difficult for those in the center to make their authority felt far away.[69] The relation between kinds of imperial power and the projection of knowledge, once imagined as direct, is more accurately depicted as a field of negotiation among many actors with different social resources at their command. In an Atlantic sugar economy that lacked pretenders to inherent authority, such a perspective is important at every level: between American factory owners and central-factory chemists, between Glasgow machine makers and Caribbean machine users, and between the Custom House in Manhattan and the docks on the Brooklyn waterfront.

In an important article, Ken Alder examines the ways that eighteenth-century French military engineers worked to manufacture interchangeable parts that could be relied upon to function identically. "Things are 'thick'," Alder argues: "the material world

68. James Delbourgo and Nicholas Dew, eds., *Science and Empire in the Atlantic World* (New York: Routledge, 2008), 20-21.

69.Jim Endersby, "A Garden Enclosed: Botanical Barter in Sydney, 1818-39," *The British Journal for the History of Science* 33, no. 3 (September 2000), and *Imperial Nature: Joseph Hooker and the Practices of Victorian Science* (Chicago: University of Chicago Press, 2008. See also Mario Biagioli, *Galileo's Instruments of Credit: Telescopes, Images, Secrecy* (Chicago: University of Chicago Press, 2006).

is lumpy, recalcitrant, and inconsistent."[70] Coordinating the people who produced military goods across France meant controlling how they were depicted—literally, the way that they were "thinned" onto sheets of paper. Engineers standardized the creation, form, and distribution not just of artifacts, but of drawings. They made the "objectivity" of drawings into a term with political weight that could be of use against their rivals for control of production among artisans and merchants. Alder thus calls for scholars of the "social life of things" to address not just their production and exchange, but also those who represent those things and have power over forms of representation.

Similarly, I am calling attention to those who crafted uniformity out of the "thickness" of the natural diversity of the sugar cane, and to the act of crafting that uniformity itself. In fact, as Ortiz might have pointed out, extracting sugar from the cane is so elaborate a process that it should be considered as much a technological artifact as an organic object. Once again, however, it is important to emphasize that the power of the concept of sucrose lay in the fact that it was portrayed not as an analogous "thinning" of the "thickness" of sugar. Instead sucrose was allegedly sugar's very essence. It was the fundamental property at which previous descriptions of sugar's substance had been only awkwardly gesturing, in contrast to the self-evidently human creations of arbitrary categories like grades of wheat. To put it another way, the point is not that sugar was a substance especially "thick" and understandable in multiple ways. The point is that, like other commodities, it was a "thick" product, but one which contemporaries claimed could

70. Alder, "Making Things the Same: Representation, Tolerance, and the End of the Ancien Regime in France," *Social Studies of Science* 28, no. 4 (August, 1998), 499-545.

be thinned through the power of chemical instruments and analysis. No one would have claimed to reduce cotton, wheat, tobacco, or beer to a number, and to have, in doing so, captured all that was of value about it.[71]

In challenging the stability of the concept of sucrose itself, this dissertation also builds on important recent work showing how dichotomies central to histories of industry and of science are not useful categories of analysis but rather precisely the subjects that historians ought to analyze. The editors of the recent essays collected in the volume *The Mindful Hand* argue cogently and persuasively that the "historical map shaped by oppositional and hierarchically ordered pairs: scholar/artisan, science/technology, pure/ applied and theory/practice" is itself the product of political and social work during the scientific and industrial revolutions. Historians that take them at face value become "the heirs of those enterprises."[72] The creation of material objects and of natural knowledge is always a single hybrid activity rather than two that are linked by the diffusion of knowledge to practice, a diffusion which inevitably takes place downward in a hierarchy of status. Thus "'pure' science," Simon Schaffer and Lissa Roberts write in their preface,

71. For the ways that quantitative objectivity is used to produce trust in impersonal organizations and societies, see Theodore M. Porter, *Trust in Numbers: The Pursuit of Objectivity in Science and Public Life* (Princeton, N.J.: Princeton University Press, 1996). Alder is explicitly following Porter in showing how objectivity is a political label given to "the kind of description of nature...which experts provide when they wish to present their conclusions as having been derived with a minimum of human intervention." But Porter argues that numerical expertise is required by modern societies that are not bound by trust.

72. Simon Schaffer and Lissa Roberts, in *The Mindful Hand: Inquiry and Invention from the Late Renaissance to Early Industrialisation* (Amsterdam : Koninkliijke Nederlandse Akademie van Wetenschappen, 2007), xiv.

"is better seen as a rhetorical category put to work for various purposes of persuasion than objective description of the content and goal of scientific work."[73]

By questioning those distinctions and terms, such an approach also challenges linear, diffusive narratives of industrialization, in which revolutionary changes supposedly overtook first Britain, then Europe, thence the world. Instead, it suggests that historians should not just seek the local contingencies of the production of knowledge, nor assert the coordination of global networks, but instead attempt to explain how those two seemingly contradictory properties of scientific knowledge are connected as part of the same phenomena.[74] Part of the answer lies in acknowledging that systems of categorizing nature are linked to methods of standardizing and regulating labor. Such links, Schaffer and Roberts argue, were foremost in the minds of the proponents and designers of those systems. Labor history has paid attention to the way that standardized production methods were opposed by workers, and how workers exerted influence over those new standards and new methods, but even more fundamentally the redefinition of categories of privileged knowers took place alongside the redefinition of categories of what was there to be known and how. Sugar's status as a globally exchanged object, one that had always been and continued to be produced and traded through the integrated operation of mind and hand, makes it a ripe target for just this sort of analysis. The fact that the relationship between mind and hand in the sugar economy was in flux in the late nineteenth and early twentieth centuries serves to brilliantly illuminate the reshaping of

73. Ibid., xix.
74. Ibid., xxi.

that relationship before it solidified and came again to seem as natural in its new form as it previously had in its old.

4. The perfect commodity

This dissertation initially proposed to question one crucial element of the process of standardization and distancing that we call "commodification": namely, the erasure of information about the place and people who originated that product. Such an erasure seemed an important but underemphasized argument in what remains the canonical account of how nature is transformed into market goods. Though nearly a quarter-century old, William Cronon's *Nature's Metropolis* tells a compelling story of how the "first nature" of wheat, trees, and livestock were converted to a "second nature" of grades, lumber, and choice cuts. Eventually, these facilitated the exchange of pure promises for the future delivery of such standardized items. The scale of these paper fortunes and the volume of their trade vastly outstripped the amount of real material wealth on which they were founded. Following Cronon, other environmental historians and historians of capitalism have shown that new technologies and bodies of knowledge turned diverse nature into standard market goods.[75] Producing these new commodities from nature

75. The roster of works, frequently straddling the boundary between history and anthropology, that use a commodity's traffic as their centerpiece is far too long to enumerate here. The commodities examined range from the seemingly lowest in technical sophistication (bananas bred for their consistency) to the highest (uranium-235 extracted for atomic bombs). Gabrielle Hecht, *Being Nuclear: Africans and the Global Uranium Trade* (Cambridge, Mass: MIT Press, 2012); Steve Striffler and Mark Moberg, eds., *Banana Wars: Power, Production, and History in the Americas* (Durham: Duke University Press, 2003). One of the classic topics for commodity studies has been cotton, the subject of a recent work by Walter Johnson focused on the Mississippi Valley and a forthcoming global history by Sven Beckert. See Walter

required not just the deployment of heavy machinery, but also for distant individuals to achieve a working consensus on what the valuable properties of those pieces of nature should be, and how they should be measured.[76] Their boosters called upon new scientific disciplines like organic chemistry, or new technologies like refrigerated ships, to proclaim that their products were reliable, consistent, and safe.[77] As these new means of measurement and production seemed to render nature into market goods, they made states and market participants more dependent than ever on the experts responsible for making those products seem standard and universal.[78]

Johnson, *River of Dark Dreams: Slavery and Empire in the Cotton Kingdom* (Belknap Press, 2013), and Sven Beckert, *Empire of Cotton: A Global History* (New York: Knopf, 2014). The role of late-nineteenth-century technologies in transforming natural products into commodities has been examined in, for example, Prakash Kumar, *Indigo Plantations and Science in Colonial India* (New York: Cambridge University Press, 2012), or Rebecca J. H. Woods, "The Herds Shot Round the World: Native Breeds and the British Empire, 1800-1900" (Massachusetts Institute of Technology, 2013).

Studying a commodity allows the examination either of global networks or of the local construction of value: see, for example Theodore C. Bestor, *Tsukiji: The Fish Market at the Center of the World*, California Studies in Food and Culture 11 (Berkeley: University of California Press, 2004), and Koray Çalışkan, *Market Threads: How Cotton Farmers and Traders Create a Global Commodity* (Princeton, N.J: Princeton University Press, 2010). Commodity biography has also proven to be a genre that appeals to readers of "popular" histories. Sometimes it seems as if authors compete to vivify the most mundane substance possible, a competition led easily by Mark Kurlansky's *Cod: A Biography of the Fish that Changed the World* (New York: Walker and Co., 1997) and *Salt: A World History* (New York: Walker and Co., 2002).

76. For a call to focus on the means by which science is communicated, see James A. Secord, "Knowledge in Transit," *Isis* 95, no. 4 (December 1, 2004). Walter Johnson, in *River of Dark Dreams*, shows in detail how the demands of cotton traders in Liverpool for certain kinds of whiteness in their cotton affected plantations in the Mississippi Valley. Everything from the landscaping of plantations, to the patterns and rhythms of slaves' labor, to the kinds of supervision and scale of punishments to which the slaves were subjected, and to planters' calculations of "bales per hand per acre" were traceable to these transoceanic relationships. See Johnson, *River of Dark Dreams*, especially Chapter 9, "The Mississippi Valley in the Time of Cotton."

77. Benjamin R. Cohen, "Analysis as Border Patrol: Chemists Along the Boundary Between Pure Food and Real Adulteration," *Endeavour* 35, no. 2–3 (June 2011): 66–73; Peter W. Atkins, *Liquid Materialities: A History of Milk, Science and the Law* (Farnham, England : Ashgate, 2010).

78. One recent example of work similarly that similarly shows the construction of the natural idea of a commodity is Barbara Hahn's *Making Tobacco Bright: Creating an American Commodity, 1617-1937* (Baltimore: Johns Hopkins University Press, 2011). Hahn asks how the desirable variety of "Bright Tobacco" became an identifiable kind, and considers it as a form of technology whose history is one of social construction. Her story incorporates colonial Virginian laws that forbade the sale of any but first-grown leaves, so the harvest took place as late as possible to make them as heavy as they could be; post-Civil War annual contracts that reorganized labor around growing techniques that allowed for divisions of money and crops in December; and the IRS's need to determine where agriculture ended and manufacturing began, which led to USDA's creation of a standard taxonomy after 1880. The New Deal

In his third chapter, “Pricing the Future: Grain,” Cronon shows how new technologies and formalizations of exchange evolved in tandem. Prior to the 1840s, the St. Louis riverfront was the great grain center of the American west. There, merchants bought and sold sacks of wheat that remained legally the possession of the farmer who had grown it. The sale price depended not just on the quality of the wheat but on the reputations of seller and farmer alike. As railroads brought increasingly large quantities of wheat to Chicago, however, they also changed patterns of ownership. Hopper cars and grain elevators radically reduced the cost of moving and storing a bushel of wheat in bulk. But once it was intermixed farmers had no way of retrieving “their” grain, rendering pointless the notion that they might still legally own it it. By inventing standard categories of wheat, the new Chicago Board of Trade provided a mechanism by which farmers could receive receipts from elevators to retrieve a quantity of “equivalent” grain. Now “grain” could safely be traded by exchanging those receipts, turning that paper into money and grain into flowing gold. This grading system is key to Cronon’s story. What enabled a market in contracts for the future delivery of grain to arise was that the Board’s traders imposed their “second nature” of grades on the “first nature” of wheat itself. The Board faced problems “where its market fictions intersected with the real world”: futures

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state further “stabilized” (her purposeful double entendre) bright tobacco, as agricultural stabilization meant limiting who could grow which varieties where and when, but the USDA simultaneously recognized that varieties were identical. In telling this story Hahn shows how, as she writes, “The development of tobacco into categories can help demonstrate how the world around us comes to seem natural, outside our power” (p. 12). In the case of Bright Tobacco, one kind among many, scientific knowledge (in the form of genetics) claims it is indistinguishable from other forms; in the case of sucrose, scientific knowledge (in the form of analytical chemistry) claims it is unique.

markets could be cornered precisely because legally the contracts required owners to deliver grain—real grain—at the end of a specified period.

Yet the more I learned of sugar, the more Cronon's grain tale seemed peculiar rather than paradigmatic, even for commodities that traveled the world in similarly pulverized form. Well into the twentieth century, I observed, even the purest sugar still moved in a sack, one that could be traced back to the factory from which it came. What I planned to show, in contrast to his story of increasing mechanical uniformity, was that sugar became a commodity by its subjection to the standardizing power of laboratory science, and the reduction of its economic value to the measurement of a chemical property. This difference mattered, I proposed, because where there is no erasure of information about origins—and merely a declaration that some information about a sack of sugar is valuable and pertinent while other information is neither—then different parts of the world still depend on each other to make judgments in the marketplace. Oil, ore, natural gas, rare earths, and other twentieth- and twenty-first-century commodities, whose value in exchange and in use depend on their properties being ascertained by scientific practices, appear more like sugar in 1900 than like wheat in 1850. Grain, in fact, judged by the eye into admittedly arbitrary grades, seemed the last of an old form of commodity, rather than the first of this new, modern kind.

But instead of simply offering a complementary account of commodification, one that encompasses commodities measured by allegedly "scientific" means, my research into the sugar trade of the late nineteenth and early twentieth centuries has led me to attempt a more fundamental critique. Social, cultural, and environmental histories of capitalism that attempt to answer how nature was turned into commodities, this dissertation argues, may presuppose the existence of the order they attempt to explain. I encountered, over and over again, the enormous diversity of products lumped under the name "sugar," I found myself asking in what sense we could ever say that sugar had been standardized or that nature had been commodified. Increasingly, "how was nature commodified?" seemed the wrong question entirely, because it begged the question of what really needed explanation. The idea that billions of natural objects could be said to be "the same" seemed not, and certainly not just, an analytic fact retrospectively arrived at by scholarship. It was, instead, at least as much a product of the economic, political, and social powers of modern capitalism as was the (alleged) actual, material fact of commodification itself.[79] The claim of commodification, in other words, is an interested one, laden with motive. As historians, therefore, we should look to assess critically its origins, who advocated for it, and who benefited from it, and we should be careful not

79. In *The Social Life of Things*, Arjun Appadurai observed that people can move things in and out of commodity-dom, though "it is commoditization as a worldwide historical process that determines in very important ways the shifting relationship between singular and homogenous things." But rather than presuppose the existence of a process of commodification, I argue instead that it is the way people think of singularity and homogeneity that shapes what they consider a commodity. So while Igor Kopytoff more perceptively suggested that a commodity "is best looked upon as a process of becoming rather than as an all-or-none state of being", he also posited that an object's status as a commodity is most secure and concrete at the moment of its exchange. On the contrary, this dissertation shows instead that in the process of exchange, an object is at its least commodified state of all, because it is at that moment that its idiosyncratic properties are, in fact, called upon to determine its price and its value. Arjun Appadurai, "Introduction: Commodities and the Politics of Value," 3–63, and Igor Kopytoff, "The Cultural Biography of Things: Commoditization as Process," 64-91, in *The Social Life of Things: Commodities in Cultural Perspective*, ed. Arjun Appadurai (New York: Cambridge University Press, 1986).

accept it as both the start and end point of our analyses, from which we work backwards to explain how it came to be.[80]

It is, in fact, precisely the ways in which an object or class of objects deviates from an idealized "perfect commodity," abstracted from the place and means and people of its production, that shape the market that exists in and for them, at the same time that they make them valuable.[81] As Michel Callon has recently argued, such properties are not passively detected or observed, as if they "already exist [and] information simply has to be produced so that everyone can be aware of them." Instead, an object's characteristics must be actively determined: through tests, measurements, experiments, and trials, through scientific activity mediated by instruments.[82] It is by paying attention to the

80. Take, for example, the recent volume edited by Jonathan Curry-Machado, *Global Histories, Imperial Commodities, Local Interactions* (London: Palgrave Macmillan, 2013), in which there is an unacknowledged conflict between the emphasis on the power of global networks to transform the world and the importance of "local actors" in the creation of those networks. More problematically, the existence of "global trade" is taken almost as a given, e.g.: "At times, it was local initiative that began the process of global engagement, and some commodities could only extend globally because of their local acceptance....Of course, there were many cases in which the imperial metropolitan powers did impose their needs upon the farming and trading practices of local societies" (6-7). But once we discard the notion that global capitalism could be "imposed from above," then we also have to reject the idea that "some commodities could only extend globally because of their local acceptance": this is true of all commodities. What makes something a commodity, in fact, is precisely its "local acceptance."

More fundamentally, if power in an empire is something that is projected from the center and can only be "contested" by "locals," then such stories will just be about resistance to the inevitable. But this definition relies on the narratives of power that the empires themselves propagated to make their existence seem inevitable, especially in retrospect. But looked at symmetrically, the relational nature of power becomes apparent, and we see how the metropole had to bargain with and cajole the periphery just as much as the other way around.

81. In the market for Mexican antiquities and natural history specimens, for instance, Miruna Achim has perceptively argued that the market value of such an object depends on its not being a commodity at all. An antiquity must carry its provenance into the transaction, because "an antiquity without a biography of some sort is not an antiquity at all." The nearer these objects get to being fully exchangeable, therefore, the more their value is endangered. Miruna Achim, "The art of the deal: Mexican antiquities for mounted birds," paper delivered at the conference on "Nonhuman Empires," Department of the History and Philosophy of Science, March 2012. I am grateful to Professor Achim for her personal permission to cite her unpublished paper.

82. Callon proposed an "economy of qualities." He reminds us to distinguish between "products," objects that have careers of production and circulation, and "goods," whose "bundle of characteristics" is taken to satisfy consumers' wants. As a product moves among economic actors its perceived characteristics change, but these characteristics are never passively observed: echoing Locke, he writes that they must

material, practical, and conceptual bases of such tests and instruments that this dissertation joins the history of capitalism and the history and sociology of science and technology. Such trials are necessary not just for relics, antiquities, art, fossils, or other goods in similarly idiosyncratic markets, but of all objects for which the label of "commodity" is claimed. Foodstuffs spoil; metals are heavy and expensive to move; people resist. The ways in which a unit of cotton, tobacco, wool, iron, coal, tea, grain, meat, or sugar—or the labor of people—is not purely interchangeable with any other in the world makes the world of that commodity what it is. It is therefore essential to attempt to recover the nature of the expertise and the expert labor that continually reaffirms the commodity status of a mass of natural specimens. Each of the following chapters does so by examining a key site of the nineteenth- and early-twentieth-century sugar trade.

5. Structure of the dissertation

In Chapter 2, I focus on the nature of labor inside the new industrial sugar factories of the Caribbean, specifically in Puerto Rico and Cuba. An essential component of the operation of these factories was control and surveillance by chemists, who promised to guarantee efficient production of chemically pure sugar. But the introduction

instead be "'revealed' through tests or trials." Yet to speak of markets and competition implies "agreement, at least tacit or even imaginable, on the list of products and their characteristics." Michel Callon, Cécile Méadel & Volona Rabeharisoa, "The Economy of Qualities," *Economy and Society* 31, no. 2 (2011): 194-217 of chemical testing heightened tensions between owners' insistent demands for quantifiable work and their continuing reliance on workers' skill and senses for the process of quantification itself. Chemists and managers tried to design procedures and machines to eliminate the need for skilled labor in sugar-making, yet still depended on artisanal knowledge at crucial points. Ironically, the more persuasively chemists described the factory as a laboratory or as a machine, and the more they established the equation of pure sugar and sucrose, the more they rendered their own hard work invisible alongside that of the artisans.

Turning the factory into a laboratory meant trying to isolate it from the agricultural hinterland that was considered a source of uncleanliness, ambiguity, and even dishonesty on the part of farmers. But the feeling was mutual: growers and mill-workers alike came to distrust chemists and their instruments, the supposedly objective arbiters of purity and value. The meanings of purity became the terrain on which struggles over economic and social power were fought. When factories began, in the early twentieth century, to rewrite their contracts with cane farmers in terms of sucrose content rather than weight, growers turned to the state to legislate proper scientific practice both inside the factory and in the cane field.

I then turn in Chapter 3 to the specialized engineering firms of Glasgow, Scotland, who built the vast majority of the machines that filled sugar factories. This chapter shows how and why special expertise was required to create and maintain the expensive and customized mills, evaporators, and other devices that had to survive many decades in taxing environments hostile to mechanical apparatus. Glasgow firms faced novel challenges for both the design of their products and the transoceanic management of information over great distances of time and space. As a result, these companies built decades-long relationships with sugar plantations and central factories abroad, sending specially trained draftsmen and engineers for consultations, inspections, and follow-up visits. The knowledge acquired from these journeys, and through communication by the transmission of plans and designs, helped them track their creations for decades, through changes of owners, plantations, and islands. In narrating the relationships between human users and machines that could last several lifetimes, forms of record-keeping themselves play a crucial role, by exposing the ambitions and outlook of the engineers who inscribed them and used them to navigate the world of their metal creations. As the market for sugar itself became standardized, the building of sugar machines remained a personal business.

In the Caribbean, new machines and new techniques of sugar production let sugar factories attempt to apply an ideal of consistency, interchangeability, and chemical purity, an ideal that was allied to efforts to de-skill the craft labor of sugar-factory workers. Those efforts depended on Glasgow firms' continuing reliance on customary and craft methods of design and construction, and on their maintenance of cooperative models of engineering work. More than simply bringing Glasgow into the sugar world that it constructed, therefore, this chapter shows how the persistent authority and status of craftsmanship in these machinery workshops enabled the scientific discipline and standardization that de-skilled labor elsewhere in the sugar economy.

Finally, in Chapter 4, I analyze the sugar trade in New York City during a period when the tariff on imported sugar was the single biggest source of the Federal government's revenue. With so much lucre at stake, refiners, scientists, and Treasury officials contested the ways sugar would be valued in the nation's customs houses.[83] The introduction of chemical testing of sugar imports, introduced to allay fears of widespread fraud, instead allowed the largest refiners to use the ambiguities of scientific knowledge and practice to their own ends, and to siphon tens of millions of dollars from the Federal coffers. In searching for new means to enforce tariff laws, Congress and the Treasury found themselves beholden to the power of samplers, appraisers, and chemists, those who actually manipulated the sugar itself. Their expertise and their places of work in sites like refinery docks made them resistant to close government supervision, even as it made them attractive targets for influence by moneyed interests. By examining how tariffs were actually enforced in New York harbor, we can see how the agents and employees of the Federal government could slip between spaces of state and commercial authority, and

83. Conflicts within the sugar trade created volumes of records to exploit, and late-nineteenth century American courts were overwhelmed with cases about sugar tariffs. Historians have repeatedly demonstrated that such disputes and legal cases are remarkable sources, because testimony and court filings expose the assumptions and behaviors that remain hidden when transactional or scientific results are not in question. Likewise conflicts about experiments have been used to show how contested results become matters of fact. See Harry Collins and Trevor Pinch, *The Golem*, 1998, and Steven Shapin and Simon Schaffer, *Leviathan and the Air Pump: Hobbes, Boyle, and the Experimental Life*, 1985. D. Graham Burnett has used an 1818 trial over the taxation of whale oil to expose that period's variety of claims to expertise about nature, while Walter Johnson brilliantly excavated cases about slave sales as the basis for a detailed description of the New Orleans slave market. D. Graham Burnett, *Trying Leviathan: The Nineteenth-Century New York Court Case That Put the Whale on Trial and Challenged the Order of Nature* (Princeton: Princeton University Press, 2007); Walter Johnson, *Soul by Soul: Life Inside the Antebellum Slave Market* (Cambridge, Mass: Harvard University Press, 1999).

how they exploited that mobility for their own advantage. The rise of the Gilded Age's infamous Sugar Trust monopoly, which wielded power over American economic policy and expansion overseas, was directly linked to its ability to manipulate these new chemical ways of assessing value. By weaving together the history of science, the history of capitalism, and the history of American politics, the story this chapter tells has particular implications for historians' understanding of regulatory power and corruption in the postbellum American state.

Chapter 2:

Chemical control in the Caribbean central factory

1. Introduction

In 1926, Edwin Atkins sat down to write the memoirs of a successful Boston sugar magnate. He had gone into business after his father, and over the course of his career had enlarged an empire of plantations in Cuba and refineries in the United States. His six decades in the business, he observed, "have seen such a revolution in the production and manufacture of sugar, and in all business methods, as probably, in a like term, will never be repeated."[84] Three quarters of a century earlier, cane sugar had supported the world's richest and most powerful industry. Almost 90% of the world's sugar that year came from the cane harvested and processed in the overseas colonies of Europe. But by the time Atkins had taken over business from his father, the protected and subsidized sugar-beet refiners of Europe had seized control of the booming market: by 1900, 65% percent of the world's sugar came from the beet. As a result, in the last quarter of the nineteenth century and the first quarter of the twentieth, Atkins's "revolution" had replaced the traditional mill and plantation estate, built on enslaved labor, with great steam-driven central factories that matched their beet-sugar brethren in technical sophistication. Atkins recalled that "almost every year, some new machinery was installed at Soledad," his own central, "which enabled us to do better work, increasing

84. Edwin Farnsworth Atkins, Sixty Years in Cuba, Reminiscences of Edwin F. Atkins (Cambridge: Privately printed at the Riverside Press, 1926), 1

our production and decreasing the cost of labor." He had bought new mills to crush cane for its juice, a new vacuum pan to more finely control the reduction of the juice to a mass of molasses and crystals, and a centrifuge to separate the two.

Even this mechanical marvel, of course, still needed a workforce, and in the mid-1880s, the final years of Cuban slavery, Atkins had hired indentured Chinese contract laborers, whom he praised as "faithful men and never missing from their places." Faithful or not, they still needed supervision. Thus he was glad that Soledad's increased revenue meant that he was able to hire "higher-salaried men in the responsible positions." Most of all, he had found a trustworthy deputy in "our" chemist, a Canadian named Wilfrid Skaife, who "took charge of the sugar house and was the greatest help to me." For improving the factory, Atkins recalled fondly in 1926, "he was full of new ideas."[85]

The language of revolution in the industrial production of Caribbean sugar in the second half of the nineteenth century has been consistent for a century and a half, both among the industry's participants and its analysts. Contemporaries of that process in the nineteenth and early twentieth centuries, as well as later historians, emphasized the dazzling chemical consistency of sugar that emerged from the "central factories" of Cuba,

85. Atkins, *Sixty Years*, 109-110. See Skaife, "Sugar Producing Plants," *Canadian Record of Science* 3, no. 8 (October 1889); "Future Industrial Opportunities in Cuba," *The Engineering Magazine* 15, no. 3 (June, 1898); "The Field for Chemical Improvement in the Manufacture of Sugar," *Journal of the Franklin Institute* (March, 1899): 215-226. While extolling the investment possibilities in Cuba after its independence from Spain, Skaife was far less sanguine about its creole peoples. "The whites control the island, and outnumber the colored races," he wrote to the readership of The *Engineering Magazine* in 1898. "There may be trouble yet between the races, but the whites will win in any struggle, and preserve the island from the fate which has overtaken Jamaica, San Domingo, and others. The domination of the blacks means industrial and political death....Any investor or settler in Cuba must, from the beginning, fight heart and soul against anything that will give power into the negroes' hands, for they will use it mercilessly against the whites" ("Future Industrial Opportunities," 370).

Puerto Rico, and other sugar territories. The means by which such sugar was actually produced, however, have remained oddly mechanical, both literally and in metaphor. As these machines begin to appear en masse after 1850, so too do narratives about how sugar was made begin to change. Up to that point, they are stories about human skill. Afterwards, they become stories about machines. Thus, as the machines that filled sugar factories become more impressive, and as the factories themselves come to dominate the Caribbean landscapes, they overwhelm the human beings who still worked skillfully within them.[86]

The next two chapters of this dissertation each counteract an aspect of this mechanism. The third chapter shows how the actual, physical machines on which sugar came to be made were the products of specific milieux and particular institutions. It attempts to recover the specialized skills and knowledge that made those machines capable of operating in tropical sugar factories thousands of miles from the sites of their production. The present chapter, however, focuses on those sites of production themselves: the modern, sophisticated, industrial sugar factory, for whose operation the science of chemistry was essential. It begins to recover the nature of skilled labor within the industrial sugar factory at the end of the nineteenth and beginning of the twentieth

86. This chapter does not address the engineers, maquinistas, whose international movements facilitated the spread and were necessary to the management and operation of steam technology. See the work of Jonathan Curry-Machado on their role as "sub-imperial agents." Jonathan Curry-Machado, "'Rich Flames and Hired Tears': Sugar, Sub-Imperial Agents and the Cuban Phoenix of Empire," *Journal of Global History* 4, no. 01 (2009): 33–56, and *Cuban Sugar Industry: Transnational Networks and Engineering Migrants in Mid-Nineteenth Century Cuba* (Palgrave Macmillan, 2011).

centuries. That labor took two forms, both of which have been invisible, but in different ways and for different reasons.

The first form is that of the sugar makers who worked in factories like Soledad. The sweltering, noisy, open-kettle sugar boiling houses of the seventeenth, eighteenth, and early nineteenth centuries depended on the nous of enslaved artisans in well-documented ways. This dependence was so fundamental that even their own enslavers themselves largely could not ignore it.[87] Theirs are the skills which are supposed to have been obviated and rendered unnecessary by the sophisticated, chemically-controlled industrial processes of the sugar mill. This chapter shows, however, how discrete points in the otherwise continuous production process within the industrial sugar factory allowed and indeed required the perseverance of multisensory knowledge and tactile intelligence.[88] It was such tacit skill which the designers of these factories were unable, to their frustration, to acquire or eliminate. Yet the holders of these skills found themselves the lone artisans within a sugar machine, rather than just one artisan among many with varying skills, and their position therefore remained precarious.

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87. Eric Otremba has recently shown how the sugar plantation was coopted by the Royal Society's experimental philosophers as a justification for their program. Here, enslaved sugar boilers were the invisible technicians, rather than Robert Boyle's helpers. See Otremba, "Enlightened Institutions" (PhD, University of Minnesota, 2012).

88. The deskilling of labor or making control automatic is far easier to achieve where, as David Noble pointed out, "the product itself is in a liquid or gaseous form and can thus flow through pipes or membranes," so automated control systems emerged within industries that were ending batch to continuous processing. The same thing occurred in the transition from iron to steel in the late nineteenth century United States, as David Montgomery showed; see Montgomery, *The Fall of the House of Labor: The Workplace, the State, and American Labor Activism, 1865-1925* (New York: Cambridge University Press, 1987), and David F. Noble, *Forces of Production: a Social History of Industrial Automation*, 1st ed (New York: Knopf, 1984), 58.

The second form is the labor of chemists like Wilfrid Skaife. It was chemists' rhetorical, intellectual, and social labor, as well as their actual work within the factory itself, that helped render invisible the role of the sugar artisan. Yet, ironically, accepting the notion of sugar as a globally uniform chemical commodity has meant ignoring the activity of the people responsible for determining that uniformity. The more important that chemical purity becomes as the standard measure of value, the more peripheral and obscure does the work of factory chemists themselves appear to be—even, at times, among chemists themselves.[89] Their presence is never in doubt: men and women called chemists (a term of some dispute) appear in nearly every description of the industrialization and centralization of sugar production in the Caribbean.[90] Most historians, however, have been content to invoke chemistry's authority and take chemists' expertise as givens. From that vantage, the tools and techniques of chemistry appear

89. In its April 1915 issue, the Journal of Industrial and Engineering Chemistry published a short piece by the consulting chemist W. D. Horne entitled "Contributions of the Chemist to the Sugar Industry." Yet despite this title, "the chemist" barely figures. Instead, "Chemistry as a science" does most of the work, punctuated by brief appearances by individual pioneers of various processes (including Horne himself). The ordinary chemist in the sugar factory is a passive participant, e.g.: "Well-equipped laboratories are maintained by all factories and refineries where routine testing and analytical work are carried on constantly and where investigations are made." W. D. Horne, "Contributions of the Chemist to the Sugar Industry," *Journal of Industrial & Engineering Chemistry* 7, no. 4 (April 1915): 278–279. For the role of "puzzle-solvers" in the history of science, see Thomas S. Kuhn, *The Structure of Scientific Revolutions* (Chicago: University of Chicago Press, 1962), though Kuhn's use of the term was not derisive in the way that it is often remembered.

90. In 1890, a New York *Times* reporter investigating that city's Custom House wrote that there were four self-described "chemists, or polariscope readers, *as they are called by the Appraiser*." See "No sand in this sugar: how Uncle Sam tests the imported article. The functions of the polariscope and the nicety to which it determines the grade of sugar," 27 July, 1890. Speaking to the United States special commissioner Henry K. Carroll in January 1899, the mayor of Guayama bemoaned the fact that, although Puerto Rico had produced over 65,000 metric tons of sugar in 1897, "for the manufacture of such an important [sic] quantity of sugar there is not in the whole island an individual who can claim the title of a chemical expert. Owing to the want of a technical school in Porto Rico, those who devote themselves to the preparation of this product have no further knowledge than that acquired by routine…they have not the slightest scientific knowledge…" Henry K. Carroll, *Report on the Island of Porto Rico* (New York: Arno Press, 1975), 109. Dominguez called for a school like the Audubon Sugar School at Louisiana State University.

simply to have been applied to the problem of the sugar-production process, a problem that was fundamentally one of chemical engineering. A few scholars have fruitfully investigated chemists' training, education, and methods, but they too have taken chemistry's claims for its superior knowledge, and for the notion that sugar has always been sucrose, at face value.[91] As with much metrological work elsewhere across the history of the sciences, the work chemists performed in enforcing the uniformity of commodities has been left unwritten.

In January 1890 the internationally read journal *The Sugar Cane* reprinted an item from the previous year's *Louisiana Planter and Sugar Manufacturer*, under the title "The Nigger's Wail":

> Befo' de wah, when de sugar we made
> was biled in de ole fashioned kettle,
> De grindin' time was a merry-go-round,
> for us niggers, bofe big and little;
> But now dese mens, wid de spy glass and chubes,
> biles de juice in a cast iron drum;
> Dey makes all de stuff into crystals and cubes,
> and leaves no merlasses for rum.
> De boss tink he know
> Mo' dan ebber befo',
> Since dem kemmis done show him some nonsense;

91. See Heitmann, *Modernization of the Louisiana Sugar Industry*, and García Muñiz, *Sugar and Power in the Caribbean.* For one of the few examples tracing the career of a sugar chemist, see Oscar Zanetti Lecuona, Hernán Venegas Delgado, y Humberto García Muñiz, "Noël Deerr en la Guayana Británica, Cuba y Puerto Rico (1897-1921): Memorándum para la historia del azúcar en el Caribe," *Revista Mexicana del Caribe* 6, no. 11 (2001): 57-154.

But de niggers say, "Hi!
We goan all of us die,
For we got to drink whisky in consikence."[92]

This bit of doggerel blackface reveals relatively little about how sugar-factory workers thought their ways of work were being altered, but much more about what those factories' owners, managers, and chemists thought they could achieve. "The implication was clear enough," as David Noble wrote of petroleum industries in the 1940s: "up to now the workers had somehow successfully run refineries without the aid of reason, but management was no longer willing to rely upon such routine miracles."[93] This chapter therefore attempts to reconstruct the nature of the work of chemical control in the sugar factory. The evidence for that work comes in large part from examining their own handbooks, articles, and other documentation of how chemical control was to be implemented.[94] In another irony, it is these same works that reveal the places that artisanal skills survived in the sugar-factory itself, and attest to the kinds of knowledge that "chemical control" could not control.[95]

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92. *The Sugar Cane*, January 1890, 42. J. Carlyle Sitterson, "Expansion, Reversion, and Revolution in the Southern Sugar Industry: 1850-1910," *Bulletin of the Business Historical Society* 27, no. 3 (1953): 129-140, 139. Sitterson comments only that "One unknown wag put the advances in sugar manufacture into verse form."

93. Noble, *Forces of Production*, 59-63.

94. Close readings of factory records can reveal much about the daily nature of work and the activity of the otherwise voiceless. An understanding of how a sugar factory was physically and humanly organized makes the hidden work in even a blank form visible. Chemists' test sheets, factory managers' reports to their employer, and weekly production totals can reveal much more than they explicitly state, because making each of the hundreds of daily measurements required taking a sample from somewhere along the production line. Proper sampling, cleanliness, and other such laboratory-like techniques became hardly less than moral virtues within the factory, and chemists devised various means to prevent and detect careless mistakes or malfeasance. A chemist's time was valuable: every box in the table represents work. Chemists' handbooks and trade journals can expose assumptions of chemists and managers that framed how they approached work in factories—both as collections of machines that needed to be made more efficient and as assemblies of untrustworthy people who needed careful monitoring.

95. Simon Schaffer, in "Babbage's Intelligence: Calculating Machines and the Factory System" (*Critical Inquiry* 21, no. 1, Autumn 1994), shows how Babbage wanted the factory system, described as a machine, to replace the intelligence, judgment, and knowledge of craftsmen, and to be thereby seen as a model for society as a whole and for the universe as it already existed. "The systematic

2. Skilled labor in the ingenio

The basic mechanics of producing some form of crystalline sugar from the sugar cane plant are a standard element of nearly every history of Caribbean sugar or slavery.[96] The fundamental principle was that the juice of the cane began to ferment as soon as it was cut. Before a few short hours had passed, therefore, the juice had to be extracted from the canes, and within a few hours of being extracted it had to be boiled.[97] It was this biological clock which dictated both the size and configuration of the plantation as an agricultural-industrial unit, and the organization and discipline of the sugar mill itself. Within the constraints of the six-month grinding season, sugar plantings were generally divided so that each one would reach its peak sweetness in sequence, not simultaneously. In this way, each field could be harvested, carted to the mill, and ground when it was as close to its maximum sweetness as possible, without creating costly traffic jams at the mill gates The "ideal organization of land use" within a sugar plantation placed the mill at the center of concentric rings: first of cane field, then forested land for timber, then food crops and finally pasture. But it is questionable how frequently this ideal was ever

gaze," Schaffer writes, "was designed to produce the rational order it purported to discover." But he too encountered nearly intractable resistance from the necessity of his workers' skills, when he tried to effectively automate the production of the calculating engines that were to serve as the model for all of these systems.

96. See, e.g., Richard S Dunn, *Sugar and Slaves: the Rise of the Planter Class in the English West Indies*, 1624-1713 (Chapel Hill: Published for the Institute of Early American History and Culture at Williamsburg, Va., by the University of North Carolina Press, 1972), Ch. 6, "Sugar,"; J. H Galloway, *The Sugar Cane Industry: An Historical Geography from Its Origins to 1914* (Cambridge: Cambridge University Press, 1989), chapter 5, "The American Sugar Industry in the Eighteenth Century."

97. Dunn, *Sugar and Slaves*, 195.

achieved.[98] And this fine timing meant that the system included multiple bottlenecks, the plugging of any one of which could hold up the grinding and cause the cane and unprocessed juice to begin to sour.

Once slaves had carted the cut cane to the mill house, others fed the shoots through the rollers of the mill itself. From the seventeenth to the nineteenth centuries the standard arrangement was to have three wooden rollers, aligned and oriented vertically.[99] Depending on topography, the location of steady wind or water, and the availability of fodder, the rollers might be turned by a water-wheel, a windmill, or by animals. As depicted in numerous seventeenth- and eighteenth-century drawings and accounts, a slave fed the cane between the first and second rollers, and another returned it from the opposite between the second and third. Such mill work was notoriously dangerous to those who were forced to conduct it. The question was not whether, but when, the spinning rollers and whipping cane would snag a digit, a limb, or the edge of a garment.[100] For just that circumstance, a machete or hatchet was always kept close to hand. This implement, it has been pointed out, should be seen not as an accessory to sugar

98. Galloway, *Sugar Cane Industry*, 90.

99. Following Deerr (1949, 536ff), most historians have accepted that the three-roller mill was developed in Sicily and brought from there to the New World via the Spanish Atlantic islands. But for evidence that the three-roller mill may have been developed in India or China and brought to Peru and Mexico by Jesuits, and not from the Mediterranean, see John Daniels and Christian Daniels, "The Origin of the Sugarcane Roller Mill," Technology and Culture 29, no. 3 (July 1, 1988): 493–535.

100. In Voltaire's *Candide*, while traveling in Suriname, the eponymous protagonist is shocked to encounter a slave who has lost his left leg and his right hand. "Quand nous travaillons aux sucreries," he explains, "et que la meule nous attrape le doigt, on nous coupe la main: quand nous voulons nous enfuir, on nous coupe la jambe: je me suis trouvé dans les deux cas. C'est à ce prix que vous mangez du sucre en Europe." Voltaire, *Candide ou l'optimisme*, ed. David Ross (Newark, Del.: European Masterpieces, 2007), 100.

production, conceptualized and often pictured off to the side, but as integral a part of the machinery of sugar production as was the mill itself.[101]

As the cane was crushed, the juice flowed through pipes to the mill's boiling-house. The smashed canes, known as bagasse, still contained a large portion of juice, so in order for them to later be used as fuel they were carried into the sun and left to dry. The centerpiece of the boiling house was a series of increasingly small kettles, called coppers or taches. In each of these, the juice was successively heated and cooled by adding more fuel to the fire below. As various particulates and other substances floated to the top, they were skimmed off, lest they impede crystallization or give undesirable flavors. By the beginning of the nineteenth century, sugarmasters were adding a quantity of lime to precipitate more of these substances out of solution.[102] The art and skill of sugar boiling lay in reducing the liquid in the open kettles without beginning to burn the sugar itself. In plantations that used the so-called "Jamaica train," in which all coppers were built into the same unit of brickwork and heated by the same furnace, the temperature was

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101. Elizabeth Maddock Dillon, "The Cost of Sugar: Narratives of Loss of Life and Limb," talk delivered at "Beyond Sweetness: New Histories of Sugar in the Early Atlantic World," conference hosted by the John Carter Brown Library, Brown University, October 24-26, 2013.

102. Moreno Fraginals, in The Sugarmill (p. 39) dates both the introduction of lime and of specially-designed kettles for clarification to 1798. The clarifying kettles featured a spigot near the bottom, so that rather than clearing scum from the top the clarified liquid could be removed from beneath it. But, in keeping with his general thesis that slavery and mechanization were incompatible, Moreno writes that even "this elementary mechanical operation was so complicated under a slave-labor setup that use of the clarifier was soon abandoned," and that rather than adopt such sophisticated and complex devices planters elected to intensify the work of the sugar-house by augmenting the number of ordinary kettles used for clarification.

In keeping with the clear distinction Moreno draws between the knowledge regimes of the industrial and pre-industrial sugarmills, he highlights (ibid.) the "rural alchemistic techniques" used to produce the lye "from the ashes of certain trees...mixed with quicklime and a herb called 'vixen's tail.'" Moreover, he emphasizes the imprecision of the artisan methods and measurements: the lime's "quantities were calculated in 'coconuts'—the shell of that fruit being used as a measure—and the degree of alkalinization was judged by the smell of the juice."

"controlled by yells" from the slave at the kettle to the furnace-minder.[103] From copper to copper, slaves carried the thickening syrup. Finally, in the smallest kettle, the sugarmaster manipulated the heat and additives to bring the solution to point where crystals began to form. Then he made his "strike"—removed the syrup from the heat and transferred it to troughs, where it was beaten with wooden paddles as it cooled to encourage it to crystallize further.

Knowing when this point had been reached was perhaps the sugarmaster's most prized ability. In 1765, the Antiguan planter Samuel Martin complained that the "art of boiling sugar [is] generally least understood either by overseers or their masters; but...trusted wholly to the skill of negro-boilers, who indeed arrive by long habit to some degree of judgment by the eye only."[104] But, in fact, far more than optics was necessary to understand when to strike, a skill which required five senses at least. The sugarmaster dipped into the scalding syrup and stretched it between his fingers to test its elasticity, he tasted it, inhaled its odors, and waited for it to make a certain sound as it bubbled—what was known, in Spanish colonies, as the *huevo* (egg) or *chicharrón* (pork-crackling) point.

Once the semicrystalline mass had cooled it was carried to the curing-house and poured into great inverted conical molds. Over several weeks, the molasses, the thick sweet liquid from which crystals could no longer be coaxed, drained out through the bottom and into troughs that collected it for future use, while the loaf itself dried in the

103. Ibid., 116.

104. Samuel Martin, *An Essay on Plantership: Inscribed to Sir George Thomas, Bart. as a Monument to Ancient Friendship. The Seventh Edition, with All the Additions from the Author's Experiments to the Time of His Death. By Colonel Martin of Antigua* (Antigua: printed by Robert Mearns, 1785), 23.

sun. Molasses was fermented into rum, it was sold of its own accord, or it was returned to the syrup as it boiled, to extract a few more granules from it. In countries where wet clay was abundant the molds were often topped off with a layer whose moisture would help cleanse the cone of its molasses even further, producing a sugarloaf that was whiter than most. The loaf could be sold whole, or, in "the most personal operation in the mill," it might be divided by the sugarmaster's own eye, wherever he judged a layer of one marketable quality to yield to another.[105]

On the sugar plantation, the successful grinding of cane and crystallization of sugar required an extensive degree of chronological coordination not just within the organization of the cane fields, but between those working in the fields and in the sugar-mill itself. This need for synchrony of the rhythms of agriculture and of processing, and their close physical proximity, led Mintz to argue that the pre-industrial sugar plantation was a "synthesis of factory and field." It was hard to point to the spot where the "field" ended and the "factory" began, either spatially or conceptually.[106] The conjoined nature of agriculture and production would later be identified as a key point at which the new kind of factory should diverge from the ordinary plantation, and particularly by chemists who strove to control the factory's interior space.[107]

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105. Moreno Fraginals, The Sugarmill, 116.

106. Mintz, 47.

107. For the classic statements of the construction of proper spaces for scientific activity, see Steven Shapin, "The House of Experiment in Seventeenth-Century England," *Isis* 79, no. 3 (September 1, 1988): 373–404; Owen Hannaway, "Laboratory Design and the Aim of Science: Andreas Libavius Versus Tycho Brahe," *Isis* 77, no. 4 (December 1, 1986): 585–610; and Jole Shackelford, "Tycho Brahe, Laboratory Design, and the Aim of Science: Reading Plans in Context," *Isis* 84, no. 2 (June 1, 1993): 211–230. See also David N. Livingstone, ed., *Geographies of Nineteenth-century Science* (Chicago: The University of Chicago Press, 2011), and Livingstone, *Putting Science in Its Place: Geographies of Scientific Knowledge* (Chicago: University of Chicago Press, 2003).

3. New technology and the central factory

If the sugar plantation was arguably "proto-industrial" because of its coordinations and divisions of work, then the central factories that began to supplant it in the Caribbean in the middle of the nineteenth century were industrial in many more obvious ways. The usual deterministic story of the changes in Caribbean sugar production in the course of the nineteenth century revolves heavily around three large pieces of expensive technology. What had been an industry that was arguably "extremely conservative in its adoption of innovations in the milling and manufacture of sugar" prior to 1800 was transformed by the mill, the vacuum pan and the centrifuge.[108]

"New technology created larger mills and factories," argued the historical geographer J. H. Galloway: the investment required to purchase these expensive machines meant they could be financed only by the profits from the agricultural product of much larger catchments of cane fields. This need in turn "led to an increase in the optimum size of plantations and so impelled a consolidation of landholdings that in turn had repercussions on settlement patterns." Financing these installations was a burden that, especially after the destructiveness of two wars in twenty years in Cuba, and after American seizure of power there and in Puerto Rico in 1898, led control of the means of sugar production to gradually but significantly shift from creole elites to syndicates of

108. See Deerr, *History*, Vol 2., for what is still the exhaustive standard history of the varieties of technologies of sugar production, although many of his specific claims have been questioned.

British, French, and especially American investors.[109] To feed the appetite of these new machines and the factories that contained them, railroads brought cane faster and from farther away.[110] Thus central factories, *ingenios centrales*, or just centrals, were ones in which the sugar was produced on massive, steam-powered machinery, and to which sugar cane was brought by railroad from far greater distances and in quantities greater by orders of magnitude than had ever been possible in a small plantation. No longer integrated with the landscape, they were now meant to be isolated from it **(Figure 2.1)**. By and large, rather than growing their own cane, they purchased it from *colonos*, farms run by former landowning planters or renting farmers, known in the Spanish-speaking Caribbean as *colonatos*.

109. See Galloway, *Sugar Cane Industry*, 134ff. For an overview of "centralization" see Christian Schnakenbourg, "From the Sugar Estate to Central Factory: The Industrial Revolution in the Caribbean (18401905)," in *Crisis and Change in the International Sugar Economy 1860-1914*, ed. Bill Albert and Adrian Graves, 1984. For the argument that new technologies facilitated foreign control of Caribbean sugar making see Jonathan Curry-Machado, *Cuban Sugar Industry*; for financial networks of of North American control over sugar factories in the Caribbean post-1898 see César J. Ayala, American Sugar Kingdom: The Plantation Economy of the Spanish Caribbean, 1898-1934 (Chapel Hill: University of North Carolina Press, 1999).; Andres Ramos Mattei, "Las Inversiones Norteamericanas en Puerto Rico y la Ley Foraker, 1898-1900," *Caribbean Studies* 14, No. 3 (Oct., 1974), 53-69. For contemporary surveys of the ownership of Puerto Rican sugar factories at the turn of the century see J. Ferreras Pagan, *Biografia de las Riquezas de Puerto Rico, Vol. 1* (San Juan: Luis Ferreras, 1902).

110. For the ways in which the construction of the Cuban railroad network was controlled by its sugarocracy, see Oscar Zanetti Lecuona and Alejandro Garcia, *Sugar and Railroads: A Cuban History*.

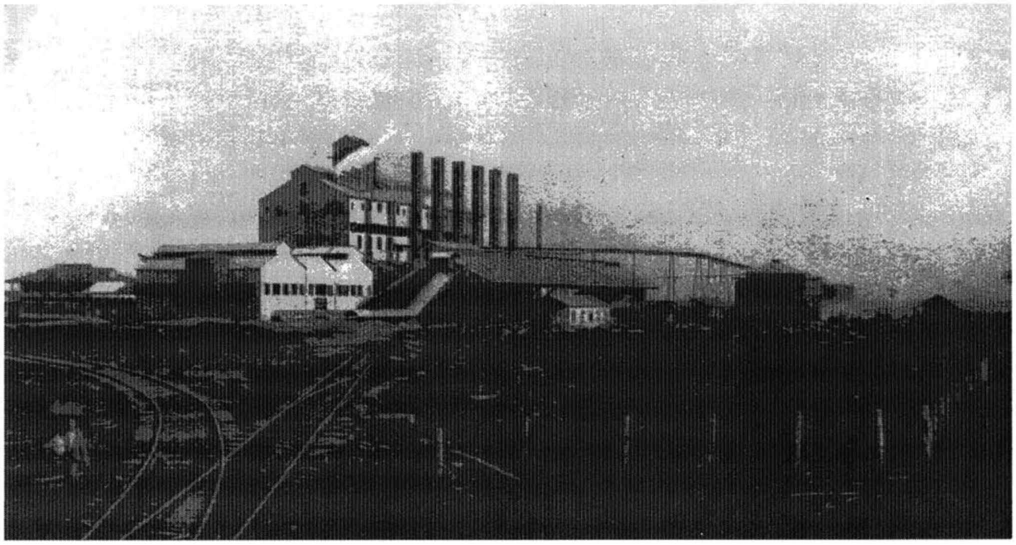

Figure 2.1: Cuban central, early 1900s, showing the railroads leading directly into the factory (from Jones and Scard, *Manufacture of Cane Sugar*, 1909, p. 446)

The application of steam power to milling, in place of wind, water, or animals, came first. By rotating the orientation of the three rollers horizontally and arranging them at the vertices of a triangle, a steam engine could more efficiently be geared to drive the mill. The excess of power meant that they needed to be worked from metal rather than wood.[111] To further their extractive power, such horizontal mills lent themselves to attachment in trains or "tandems," so that the cane could be passed through several mills before being discarded as bagasse and used as fuel. As the steam mill replaced the animal one, the depressurized "vacuum pan" rendered obsolete the train of open cauldrons. By sealing the juice from the atmosphere and lowering its pressure, the boiling point could be lowered and with it the consumption of fuel.[112] In the eighteen-forties, these too were

111. For the ways in which steam power for sugar mills was a transnational project, see Lizette Cabrera Salcedo, *De los Bueyes al Vapor: Caminos de la Tecnologia en Puerto Rico y el Caribe* (San Juan, Puerto Rico: La Editorial, Universidad de Puerto Rico, 2010), and Daniel Rood's thoughtful and incisive review in *Caribbean Studies* 39, nos. 1-2 (January-December 2011).

112. For the European origins of the vacuum pan see Moreno Fraginals, *The Sugarmill*, 112-114, but

chained together, in the so-called "multiple effect evaporator" credited to the Louisianan Norbert Rilieux. A sequence of increasingly lower-pressure chambers let the vapor from one pan boil the liquid in the next. In spite of "sound predictions of its usefulness"[113] the vacuum pan was acquired by planters much more slowly than the steam mill, partly because of its enormous cost.[114] The third and final transformative device was the centrifugal for separating sugar crystals from molasses. Rather than leaving the wet mass to drain in conical molds, the boiling house worker place it within the perforated basket of a centrifuge, which spun at several thousand revolutions per minute. Centrifugals dried sugar on the order of tons per hour, several orders of magnitude faster than was possible under manual methods **(Figure 2.2)**.

see Rood, "Plantation Technocrats," for a more sophisticated analysis of the ways that Derosne's vacuum pan was actually the result of a collaborative enterprise among Caribbean planters, managers, and engineers, whose expertise Derosne relied upon as well as his own time spent in Spanish and French colonies. Without that experience, Rood writes in his review of Cabrera Salcedo, Derosne "would have had much more trouble adapting the machine to the strict timelines and sensitive chemistry of sugar-making in the tropics."

113. Galloway, *Sugar Cane Industry* 137.

114. R. W. Beachey, *The British West Indies Sugar Industry in the Late 19th Century* (Oxford: Blackwell, 1957), 68; Curry-Machado, *Cuban Sugar Industry*, 27.

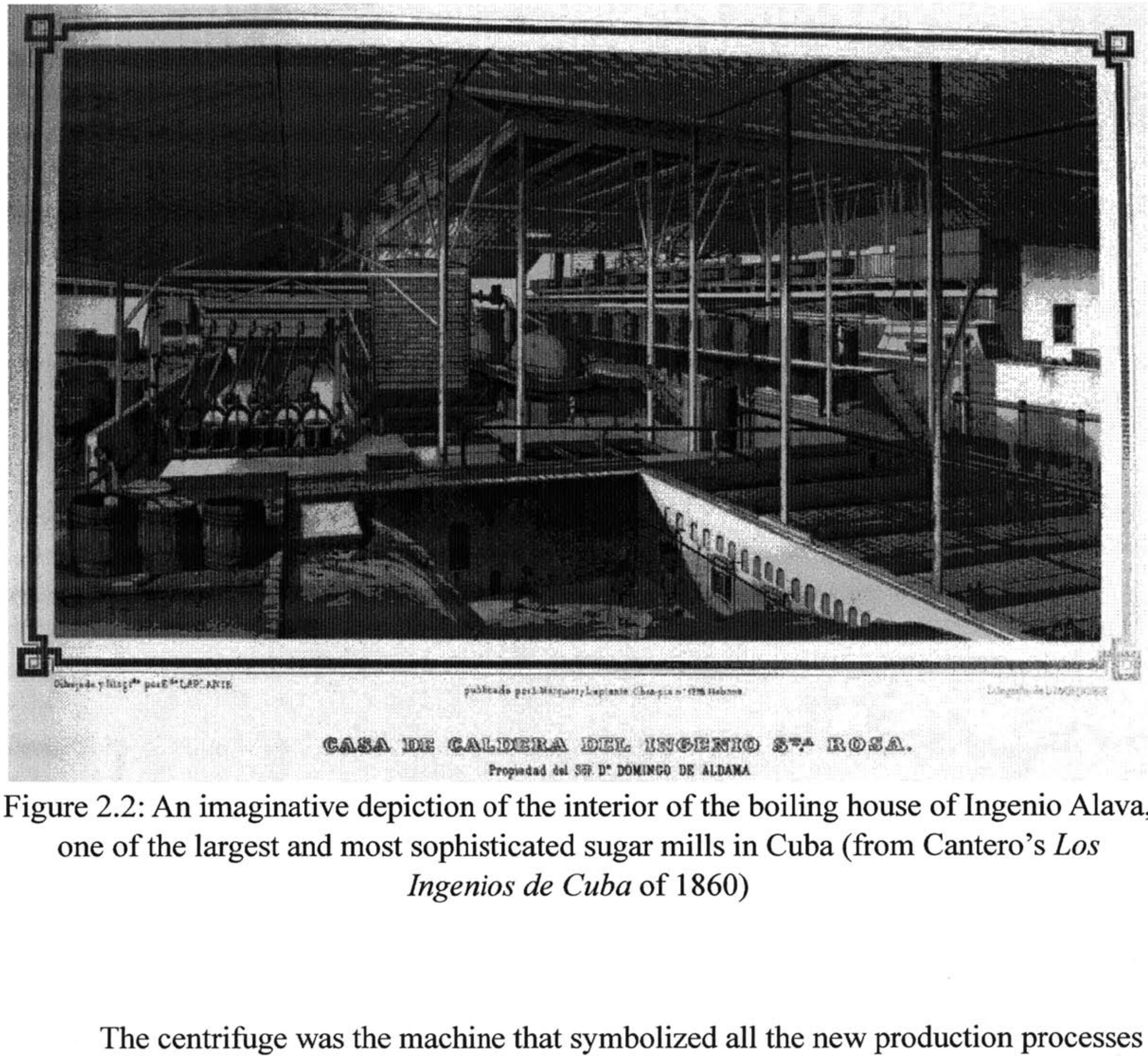

Figure 2.2: An imaginative depiction of the interior of the boiling house of Ingenio Alava, one of the largest and most sophisticated sugar mills in Cuba (from Cantero's *Los Ingenios de Cuba* of 1860)

The centrifuge was the machine that symbolized all the new production processes and the sugar that emerged from them. The workings of the centrifuge itself entranced William Henry Hurlbert, a Bostonian traveler to Cuba in the eighteen-fifties, when centrifuges were relatively novel. "For three minutes you see only a white indistinct whirling," he marveled, "then the motion is arrested; slowly and more slowly the cylinders revolve, then stop, and behold! the whole inner surface of the inner cylinder is covered with beautiful crystallizations of a light yellow sugar!"[115] By the time the

115. *Gan-Eden: Or, Pictures of Cuba* (Boston: John P. Jewett, 1854), 154, Louis A. Perez, *Slaves, Sugar, & Colonial Society: Travel Accounts of Cuba, 1801-1899* (Wilmington, Del.: Scholarly Resources, 1992).

Spaniard Carlos Peñaranda visited San Vicente, the first central in Puerto Rico, in 1878, the presence of the centrifuge was well established. Yet he too was dazzled by the centrifuge's product.[116] The sugar, he wrote in his *Cartas Puertorriqueñas*,

> purified of all its molasses, which filters to another external vessel, washed by steam, and dried and compacted by the speed of the air that forcefully dismisses it to the sidewalls of the drum, forms tight masses, and is conducted on litters of white wood to the general warehouse, inspiring envy, with its purity and transparency, in crystal and snow.[117]

Not just the quality of the sugar that emerged from the centrifuge but the machine itself could inspire heavenly flights of rhetoric. Hurlburt, "watching this ingenious process...used to fancy that somewhat in this wise, might the nebulae of space be slowly fashioning into worlds." He was not the only visitor reaching for politically contentious cosmological analogies.[118] Peñaranda, imagining what this "marvelous assembly of order

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116. For Central San Vicente, see Teresita Martínez Vergne, *Capitalism in Colonial Puerto Rico: Central San Vicente in the Late Nineteenth Century* (Gainesville, Fla: University Press of Florida, 1992), and Andrés Ramos Mattei, *La Sociedad Del Azúcar En Puerto Rico, 1870-1910* (Río Piedras: Universidad de Puerto Rico, Recinto de Río Piedras, 1988).

117. Carlos Peñaranda, *Cartas Puertorriqueñas: Dirigidas Al Célebre Poeta Don Ventura Ruiz Aguilera, 1878-1880* (Madrid: Tip. Sucesores de Rivadeneyra, 1885), 87. "El azúcar, depurada de toda miel, que filtra á otro depósito exterior, lavada por el vapor, y seca y compacta por la rapidez del aire que la despide con fuerza á las paredes laterales del tambor, forma apretadas masas, y es conducida en andas de blanca madera al almacén general, *dando envidia con su pureza y transparencia al cristal y á la nieve.*" Translation my own.

118. The fact that both Hurlburt and Peñaranda reached for the metaphor of the nebula is striking. The "nebular hypothesis," the idea that the amoebic shapes then visible through the newest telescopes, were clouds of indistinguishable dust on their way to forming stars and planets, rather than stars and planets themselves, and indeed that our own system was the product of such a cloud, was certainly still religiously and politically questionable in the eighteen-forties. For the politics of the nebular hypothesis see Simon Schaffer, "The nebular hypothesis and the science of progress," in James Moore, ed., History, Humanity, and Evolution: Essays for John C. Greene. Schaffer, elsewhere, has posited a tropical and imperial connection for nebulae too, in an "aesthetic empire" which analogized Europeans' need to find ways of representing natural history with earthlings' need to find ways of representing distant cosmic phenomena. "Whereas in the tropics 'the Earth reveals a spectacle just as varied as the starry vault of heaven, which hides none of its constellations,' isolated European physiognomists must use representational techniques 'to

and precision" would say to him if it could, wrote that its machinery "combines the atoms and compresses and concentrates them with its fiery hands, and condenses the nebulae, sets them alight and converts them into suns of eternal light, which redden the vacuum to participate in the harmonious life of the universe." These travelers, lay observers of the central and centrifuge, thus linked the power of sugar chemistry to the smooth operation of the sugar factory itself.[119]

Both the centrifuge and the vacuum pan in the cane sugar factory were adaptations of machines first developed for use by beet sugar manufacturers in Europe. Supported by competing nation-states and subsidized by a fiscally ruinous system of export bounties, beet sugar grew from nothing in 1800 to become a rival to the cane itself by midcentury. In 1880, for the first time, the industry devoted to the extraction of beet sugar produced more tonnage of sugar than that dependent on the sugar cane.[120] Planters across the cane sugar world, looking enviously at their temperate competitors, imported these machines and the mechanical experts needed to operate them. At the same time, they also began to advocate a reorganization of the plantation system itself based on a

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enjoy in thought the appearance of distant regions,' celestial and natural historical...Like Herschel, whom he judged 'astronomer, physicist and poetical cosmologist all at once,' Humboldt reckoned that condensing nebulae were the sources of stars, [and] there was a close analogy between nebular and organic history, so the physiognomy of natural forms could be applied to astronomical objects." See the Afterword to David Philip Miller and Peter Hanns Reill, *Visions of Empire: Voyages, Botany, and Representations of Nature* (Cambridge: Cambridge University Press, 1996). For the ways in which the controversial depiction of nebulae was made into a dispute about draftsmen's skills, see Schaffer, "The Leviathan of Parsonstown," in *Inscribing Science: Scientific Texts and the Materiality of Communication*, ed. Timothy Lenoir (Stanford, California: Stanford University Press, 1998), 182–222, and "On Astronomical Drawing," in *Picturing Science, Producing Art*, ed. Caroline A. Jones and Peter Galison (New York: Routledge, 1998), 441–474..

119. Peñaranda, *Cartas*, 89: "Soy la suma de tus fuerzas, el brazo ejecutor de tu idea; soy un destello de esa mente creadora que agrupa los átomos y los oprime y concentra con sus manos de fuego, y condensa las nebulosas, las inflama y convierte en soles de eterna luz, que arroja al vacío á participar de la vida armónia del universo."

120. Deerr, *History*, vol. 2, 490.

crucial element of the organization of beet sugar production: the separation, rather than the integration, of what were taken to be the distinct agricultural and industrial segments of sugar manufacturing.[121]

By the late eighteen-seventies, proponents of the centralization of sugar production in the Caribbean and elsewhere wrote of the need for a strict "division of labor."[122] This common phrase did not, however, refer to its ordinary meaning of the specialization of tasks within the factory itself, nor to the routinization of previously skilled work. Rather, it meant separating the agricultural zone where sugar cane was grown from the mill where it was ground and processed for sale. This separation was, as most *centralistas* articulated it, chiefly legal, financial, and economic. It was, they claimed, the only lesson to be drawn from the success of beet sugar producers in Europe, whose factories owned no agricultural land, only purchasing their beet supplies through contracts with independent farmers. But it would also come to be important for chemists seeking control over the factory space.

One vocal proponent of centralization was James McCormick, a Scotsman long resident in Puerto Rico. In 1880, he was commissioned by the Provincial Deputation on the island to report on the prospects for central factories.[123] McCormick argued that the ruination of Puerto Rico's agriculture and industry was due to the competition from beet

121. John Perkins, "The Political Economy of the Sugar Beet in Imperial Germany," in *Crisis and Change in the International Sugar Economy 1860-1914*, ed. Bill Albert and Adrian Graves, 1984.

122. For non-Caribbean advocacy of the central system, see for example the Louisiana planter John Dymond, in the *Sugar Cane* in 1887, 345 (and cf. Heitmann, *Modernization*, 66), and for Mauritius see A. De Boucherville, *L'Avenir D'une Colonie Sucrière* (Extrait de la Revue Coloniale Internationale, 1886), 7.

123. For McCormick see *Rudolph Adams Van Middledyk, The History of Puerto Rico, from the Spanish Discovery to the American Occupation* (New York: D. Appleton & Co., 1903), 178, 228.

sugar. McCormick attributed the thirty years of growth of beet sugar that culminated in its current "amazing proportions of production" to its factories' rigorous commitment to "the complete separation of the agricultural work from the manufacturing process." Only such separation could facilitate the industry's development by means of "the resources of skill and science, [by which] they have arrived at almost complete perfection" in the extraction of sugar from the plant. Dividing the ownership and management of the central factory from that of agriculture had multiple functions. The first was the one most often articulated by its economic promoters. "The planter of the canes," McCormick wrote, "must not be the maker of the sugar." As long as one entity, let alone a single individual, was responsible for supervising both aspects of sugar production, then each "is necessarily cramped and contracted, and neither operation can reach the full satisfactory development."[124]

In 1886, McCormick traveled to Barbados to participate in an "experiment" on the comparative efficiency of muscovado and vacuum-pan sugars, organized by John Harrison, the head of that island's Government Laboratory, who in turn cited McCormick as a "recognised authority" on modern techniques of sugar production.[125] The goal of Harrison's experiment was to see whether the costs of a large plant came out "in favour, or otherwise, of the system of Central Factories." So his assembled committee had examined one estate, containing "a vertical wind mill and train of open tayches," another with a steam mill, clarifiers, and filter press, and finally one "not only with a steam mill,

124. McCormick in *The Sugar Cane*, 1886, 176-8.
125. Harrison in *The Sugar Cane*, 1886, 96.

but also with a vacuum pan." In terms of their market value, Harrison concluded that the vacuum-pan-equipped estate's products would bring forty-six percent more revenue, but even this experiment was limited to integrated though mechanized plantations, not centrals divided from their fields. "All therefore that our experiments can do is to illustrate in a general way the advantages of improved machinery," Harrison wrote in *The Sugar Cane*, "leaving it as an a fortiori deduction to the common sense of all to apply the principle of complete factories in general."[126] McCormick took the argument a step further: any of the technical developments in sugar production "are more or less objectionable, unsatisfactory, and...unprofitable, so long as the division of labour, or the separation of the work of the agriculturist from that of the manufacturer be not the primary condition upon which the business be founded."[127] This division of labor, McCormick and others argued, was the only logical outgrowth of the new technologies of the sugar factory.

4. Chemical control and the separation of factory and field

By the middle of the nineteenth century, as first the grinding, then the boiling, then the drying became largely mechanized in Cuban and some Puerto Rican sugarmills, their conditions of life and work reached a "super-barbaric stage." The parts of the process that remained manual became bottlenecks to the flux capacity of the whole mill,

126. "Report on Result of Experiments Conducted at Bulkeley's, Jordan's, and Bentley's Estates, Barbados, by a committee of the Agricultural Society," *The Sugar Cane*, November 1886, 577.

127. McCormick, in *The Sugar Cane* 1886, 178.

and pressure was applied across that gradient to force people to work ever harder. The beginnings of industrialization "increased the traditional barbarism of the mill by demanding synchronization of manual work with mechanical processes." Thus machines intensified the violence of slavery rather than ending it, and sugar houses became "huge grinders which chewed up blacks like cane."[128] At the same time, the hacendados who owned "semi-mechanized mills" also sought to quantify and measure those elements of production which remained directly in workers' hands.[129]

Mid-twentieth-century historians who extolled the progressive industrialization of sugar production in the West Indies had suggested that "wastefulness and slovenliness" were the predominant characteristics sugar production that antedated the central factory and its machines.[130] In fact, planters tried extensively to monitor that which was not "understood either by overseers or their masters," as Samuel Martin had worried.[131] As Caitlin Rosenthal has recently shown, it was precisely because labor on a slave plantation was in theory subject to round the clock oversight that planters found it useful to implement systems of financial and productive accounting. Their power meant they could

128. Moreno Fraginals, *The Sugarmill*, 142-44.

129. In sugar, Moreno Fraginals writes, "from the end of the eighteenth century, tasks were measured with watch in hand, and systems for gaining seconds in manual labor were studied." See E. P. Thompson, "Time, Work-Discipline, and Industrial Capitalism," *Past and Present* 38 (December 1967): 56-97. For thanatocracy and labor control, see William J. Ashworth, "'System of Terror': Samuel Bentham, Accountability and Dockyard Reform during the Napoleonic Wars," *Social History* 23, no. 1 (Jan., 1998): 63-79.

130. Beachey, *British West Indies*, 61.

131. It was not the case, Moreno argues, that "sugarmill tasks in the [nineteenth] century were carried out without specific controls," nor was it true that those "cost and production reports and careful standards which enable daily labor distribution and efficiency to be analyzed" were solely "modern" creations. *The Sugarmill*, 145-48.

both enforce the collection of information and felt they could calculate its utility.[132] A blank form from Cuba's Ingenio La Ninfa, printed during the first decade of the nineteenth century, shows the information its owner demanded from thirteen divisions: the mill, boiling house, purging house, drying room, and sugar and molasses stores to the distillery, sawmill, carpenter, forge, grain mill, and butcher. And slaves—bought, sold, born, died, or escaped—were enumerated in identically formatted boxes.[133]

La Ninfa's categories themselves indicate the integrated agricultural-industrial workings of the plantation. The central factory system, as we have seen, was built on a different principle—on the separation of the field from the factory. Central factories posed problems for control because of their sheer size and complexity. A strict distinction between their interior and exterior, both in reality and in rhetoric, proved to be important as chemists sought to conceive of the space within the factory as one that was like a laboratory. This was true even as controlling a factory meant a vast web of disciplinary and measurement practices that extended beyond the bench, out of the the laboratory, past the gates of the central, even to distant outposts in the canefields.

As the work of the sugar industry's most widely respected sugar chemist, Noël Deerr's chapters on "the control of the factory" can teach us much about the nature of chemical control as it was envisioned by its most widely read proponent. His books were written over the course of decades as a factory chemist, largely in Cuba, Puerto Rico, and

132. Caitlin Rosenthal, "From Memory to Mastery: Accounting for Control in America, 1750-1880," (PhD dissertation, Harvard University, 2012).

133. Moreno Fraginals, *The Sugarmill*, 145-48.

the British Caribbean colonies.[134] Thus, even as he depicted, in many ways, an idealized version of laboratory and factory, he also explicitly acknowledged and implicitly revealed the way chemical practitioners had to negotiate with the other human beings who populated the cane-sugar world, and with the material limitations and environmental realities of sugar production. "A modern factory must be conducted from the mill to the distillery as a huge chemical experiment," he began, "and efforts be made to account for every pound of sugar."[135] But in many ways the rest of his textbook was devoted to showing where sugar chemists should compromise and where they should not. "No hard and fast rules can be laid down for the determination of yield and losses," Deerr admitted: "a great deal depends on the skill and ingenuity of the chemist." The very vagary of chemical administration of a factory was why the chemist "should alone be responsible for this department."[136]

The most important number for accounting for sugar within the factory was the amount of sugar that entered it in trapped in cane. Where factories received cane from a network of weighing or assembly stations, however, "the question of loss of weight of canes between cutting and milling is very serious." How—which is to say where—the weight was defined, either at the "outlying balance" or at the gates of the factory itself, could yield radically different intermediate and final measures of purity, yield, and efficiency. Juice in the cane would evaporate, sugar would ferment, and the calculations

134. Noël Deerr, *Sugar and the Sugar Cane: An Elementary Treatise on the Agriculture of the Sugar Cane and on the Manufacture of Cane Sugar* (Altrincham: N. Rodger, 1905); Óscar Zanetti et al., "Noël Deerr en la Guayana Britanica."

135. Deerr, *Sugar and the Sugar Cane*, 281.

136. Ibid., 296.

on which the factory's experimental efficiency depended would become increasingly imprecise.

In large factories, canes were weighed when they arrived on balances that designed to make large but accurate measurements. Only two "precautions" were in order: confirmation of the "exactitude" of the scales themselves and calibration of "the (in general) native [sic] operator." The goal was to turn the sugar worker, whether in the field, in the factory, or in the places they intersected, into a piece of machinery, but one whose potential for malfunction or malfeasance was limited by the system of which he was a part. "Automatic" balances that were "self-registering" put any potential manipulation "beyond the control of the attendant, whose functions are [now] merely mechanical."[137] The arrival of the cane by rail facilitated control, since railroad scales could weigh entire cars against their tare set at the beginning of the season.[138] At the large Puerto Rican central of Guanica, the general manager was an ex-railroad employee, and made checking the cane, juice, and sugar scales with standard weights at least twice a week.[139]

Deerr emphasized and reemphasized that the fundamental source of most losses was human error on the part of the sugar factory's own workers. Losses that could not be accounted for he attributed to three sources. One was errors in the chemical analysis of the "molasses and low products" that contained less sugar and greater amounts of other

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137. Ibid., 282-3.

138. Thomas Hawkins Percy Heriot, *Science in Sugar Production: An Introduction to Methods of Chemical Control* (Altrincham: N. Rodger, 1907), 14.

139. Hubert Edson, *Sugar, from Scarcity to Surplus* (New York: Chemical Pub. Co, 1958). 95.

substances, which made such analyses more complex. Another was loss to inversion to uncrystallizable glucose and fructose, especially where acids were used to brighten or whiten the sugar to make it attractive for direct consumption. The third, "entrainment losses," mostly meant sugar that had been lost through workers' activity that was perceived to be avoidable, even if "very hard to determine directly." These included sugar that fell out during direct handling; "sugar lost in boiling over in the pans and triple [effect]," which theoretically, under proper manipulation, should never happen; and "sugar eaten and stolen by the workmen."[140] Likewise, various automatic juice-weighing devices were again intended as checks against the feared inaccuracy or worse of the "operators" of the discrete and continuous processes.

At the same time as chemists expressed mistrust of the workforce, however, his treatises on chemical control also revealed the degree to which the actual practical work of a chemist in a large factory was dependent on the workers themselves. Consider the way Deerr suggested determining the sugar content of canes. In one of the factories in which he had worked, which, he recalled, took in and ground sixteen carloads of cane per hour, he retrieved one cane shoot from each car. His method of sampling the canes themselves was elaborately fastidious. Of sixteen canes each hour, he cut the top sixteenth of the first cane, the second sixteenth of the second, and so on, down to the sixteenth part of the sixteenth cane. These he then had cut with a large knife into halves, then into quarters, and eventually into eighths, producing a final sample of between two

140. Deerr, *Sugar and the Sugar Cane*, 295-6.

and three hundred grams. "Proceeding systematically on these lines," he wrote, "as many as 100 canes can easily be analysed in a day of eight hours." But cutting sugarcane was not easy, and the chemist in Deerr's example had done no actual analysis yet. For the chemist, the analysis of 100 canes a day was very hard work—and this was only the beginning of his supposed "control."[141]

Likewise Hubert Edson, who began a long career as an important factory chemist and engineering consultant as a Department of Agriculture liaison in Louisiana in the late 1880s, remarked in his memoirs on the enormous task he had faced. "Starting with a calculation of the sucrose in the cane," he wrote, "I planned to follow through with analyses of sucrose in each succeeding step through the factory." He wanted to test the mill juice, clarified juice, evaporator syrup, massecuites after boiling, and the sugar and molasses themselves. "Each of these several products had to be accurately measured or weighed and, with sixty or seventy analyses a day, I had to spend an average of eighteen hours a day in the laboratory....I came out of it tired but happy." Yet he considered the list of tasks he was asked to accomplish as a young chemist almost comically excessive. Even Edson, "with my limited experience," he recalled, "fully realized that it would be impossible for one chemist to do even a minor part of the program presented."[142]

So it was no surprise that Deerr admitted that in many cases "the necessary control work of a sugar factory is performed by unskilled assistance."[143] He acknowledged that "by simple analyses, such as can be performed by any member of the

141. Ibid., 329.
142. Edson, *From Scarcity to Surplus*, 52.
143. Deerr, Sugar and the Sugar Cane, 327.

estates' [sic] staff, combined with attention to correct measurements and sampling, valuable and reliable data can be obtained."[144] Other chemists, in their own handbooks, textbooks, treatises, and manuals, spoke of how "samples of materials at essential process points were collected continuously," without mentioning by whom.[145] Guilford Spencer, another of Harvey Wiley's chemical protégés at the USDA, asked in his *Handbook for Sugar Manufacturers* whether one chemist could perform all that was necessary for factory control. "If the chemist is located in a house provided with crude measuring apparatus, where he must superintend his own sampling and keep a watchful eye on his employés, he will require several assistants," Spencer wrote. "If careless work is the rule instead of the exception, his labor will be largely increased." He recommended finding "a reliable man" who could be entrusted with supervision of the sampling, leaving the chemist himself and his assistant "to study the work of the sugar-house, and the resulting improvements will be of great advantage."[146] The sugar chemist's control over the factory workforce depended on collaborative activity with and trust in that workforce itself **(Figure 2.3)**.

144. Ibid., 281.
145. Edson, 95.
146. Guilford Spencer, A hand-book for sugar manufacturers and their chemists (New York : J. Wiley, 1893), 16.

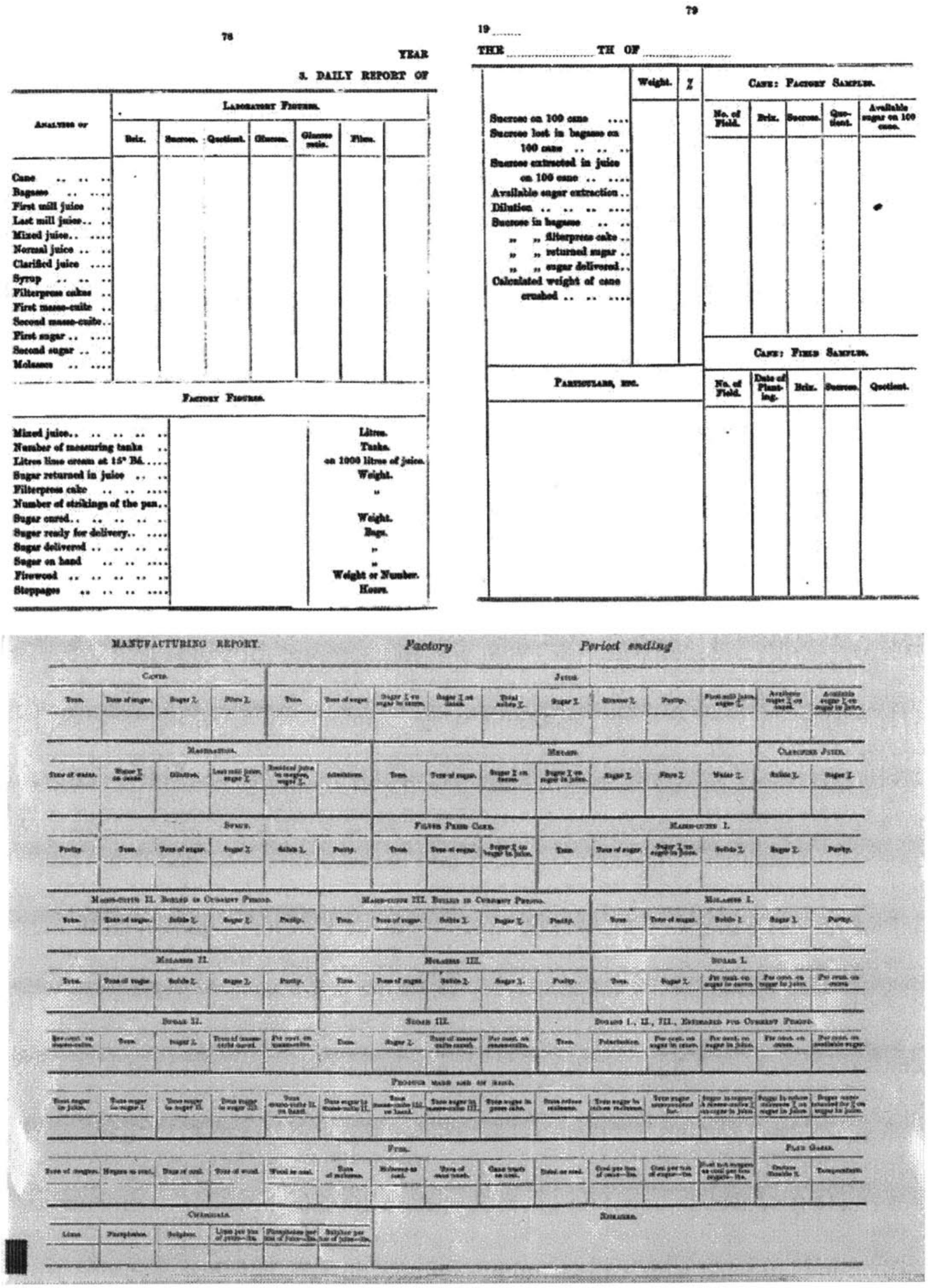

Figure 2.3: Sample chemists' factory reports, from H. C. Prinsen Geerligs's *Methods of Control in Cane Factories* (1905) and Noël Deerr's *Sugar House Notes and Tables* (1900)

Unfortunately for purposes of historical research, the number of surviving chemical reports of the above form does not reflect the number which must have been created. Those completed reports which are available, however, contain a wealth of information of use to historians beyond the production statistics they enumerate. The extant chemist's reports for the huge Central Aguirre in Puerto Rico, owned by the New York-based South Porto Rico Sugar Company and founded immediately after the island's acquisition by the United States, demonstrate the way that the supervision of labor and the supervision of sucrose production were intertwined, and provides a sense of the intensive enumeration at the center of chemical control of a large and recently-built factory **(Figure 2.4).**

George Rolfe, who on May 19, 1908, signed the report for that year's *zafra*, or harvest (from December 12th, 1907, to May 6th), had come to Aguirre as chief chemist from his position as instructor in sugar analysis at the Massachusetts Institute of Technology.[147] At the top of his sheet of yields and losses, Rolfe recorded that Aguirre had taken in 25,875,994 pounds of sucrose that year "entered by Cane," and an additional 136,700 pounds of remelted third sugars from 1907 and prior crops, for a total of 26,012, 694 pounds of sucrose. Of this, 21,405,165 pounds had been recovered, and 4,607,529 pounds "lost" in manufacture. Of that loss, a tiny fraction had vanished with the mud or filter-press cake (211,212 pounds), in the molasses (3,360,369 pounds), and, worryingly, 1,035,948 pounds to what were called "undetermined" losses. This last category, Rolfe conceded elsewhere, was always to be expected within the range of 0.2% to 0.4% of the

147. Prior to taking up that position he had served for almost twenty years as "technical chemist in the sugarhouses of the West Indies [and] in the glucose industry of the West." See Rolfe, *Polariscope in the Chemical Laboratory*, vi.

weight of cane, and marked the conceptual limit of the chemists' power over what went on within the central's walls.[148] And, ultimately, there was the sucrose that had never made it through the mills into the factory, 3,347,060 pounds of which had been burnt in the furnaces with the bagasse. But all of these numbers were simply presented as sucrose—and what was bagged and shipped from Aguirre was not sucrose but sugar. So the final line of the report, above Rolfe's signature, read "Commercial Sugar: 22,483,990 lbs., Polarization 95.20%," or 9.733% by weight of the cane. And then a "Note: Nothing left in tanks."[149]

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148. "The destruction of sugar in process is by no means well understood," Rolfe wrote in his treatise, but included its inversion to uncrystallizable forms or its "mechanical loss" in transfer. Further, "refinery experiments in Europe" seemed to show that four tenths of one percent vanished in every pan-strike. And finally, there was the unavoidable error of the process of observation and measurement, the "'apparent' loss due to errors inherent in polariscope measurement, which according to some authorities, amount to some tenths of a per cent." The one realm of undetermined loss that was not to be accepted was loss through the fermenting action of microorganisms, which "under ordinary conditions of work are inexcusable," and owed their occurrence to the fault of the factory's staff, designers, and labor force to maintain an environment of "absolute cleanliness." Rolfe, 140.

149. "Yields & Losses for the Crop of 1908," in Central Aguirre chemical reports, Colección Mercedita, Archivo General de Puerto Rico (henceforth AGPR).

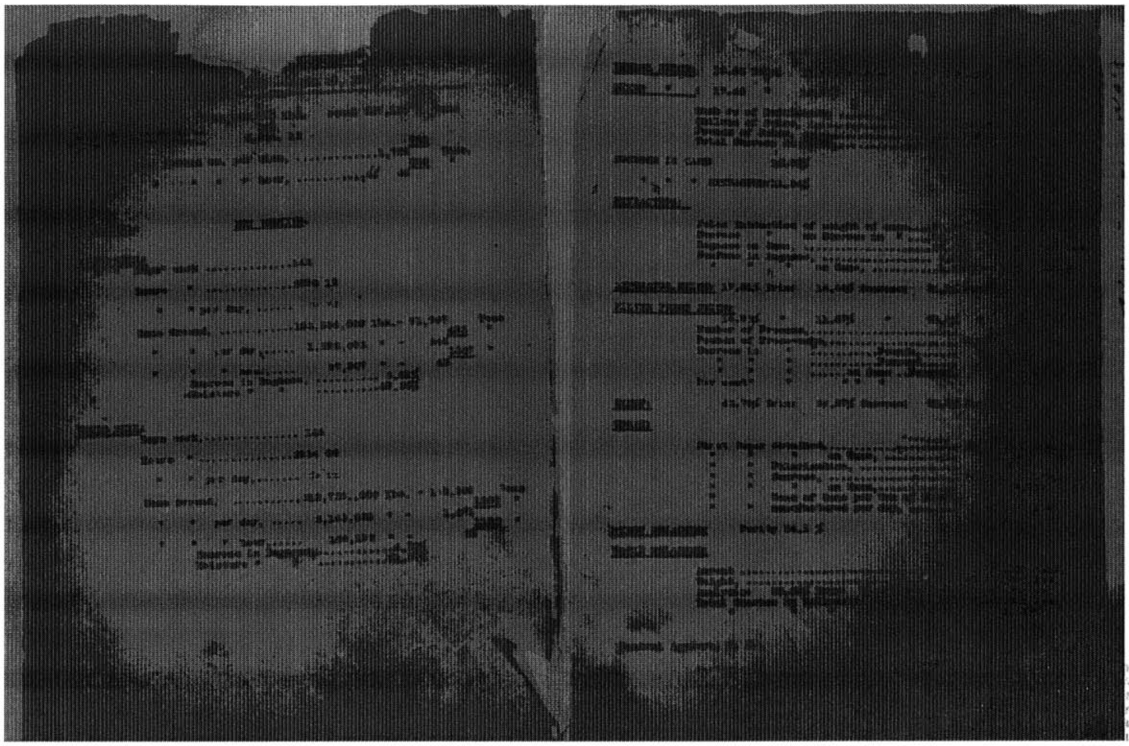

Figure 2.4: Central Aguirre chemical report for 1909 (Colección Central Mercedita, AGPR)

On subsequent pages Rolfe detailed the links between sucrose and work. The central had ground 115,497 tons and 410 pounds of cane in the course of 109 "Days Work in House," or, more precisely, 2776 hours and fifteen minutes: an average of 1,059.6 tons a day, or 41.6 tons an hour. But these had by no means been evenly split among Aguirre's three mills.[150] Instead Mill No. 1 had barely operated all season, for seven days of just over twelve hours each, while No. 2 had worked for 72 days, though only averaging 9 hours and 17 minutes per day. Only Mill No. 3 had run for 108 of the 109 days, for eighteen and three-quarters hours on average. Rather than periodically but completely breaking down, however, Nos. 1 and 2 seem to have been less than fully functional even

150. Although it is not explicit in the report itself, it is clear these three "mills" are three distinct tandems independently grinding cane rather than a triplet of three-roller mills linked into a single tandem. This is because the amount of cane each is listed as having ground—4,129,000 lbs, 45,429,920 lbs, and 181,435,490 lbs, respectively—adds up to the 230,994,410 lbs ground by the whole central.

when they were running. The former, for instance, during its brief week, had only managed to grind 24.05 tons of cane per hour, or barely half of what No. 3 was able to crush. And its bagasse was 5.72% sucrose rather than No. 3's 4.82%—in other words, Aguirre was losing 17% more of the substance it had paid for. Indeed, although daily and weekly reports and other documents from this period in the central no longer exist to confirm it, it seems likely that the alarmingly high sucrose content of the bagasse was at least part of the reason that the mill unit was shut down in the first place.[151]

The situation of the mill deteriorated. The next year, in the crop of 1909, which ran from November 21st 1908 to May 27th, 1909, the first mill worked no days at all. Apparently, it never worked any again: the Aguirre chemist wrote "FIRST MILL: NOT WORKING" through the 1919 crop, after which the report only bothered to list the second and third mill at all.[152] The 1910 crop reported a slight increase in the polarization of the first sugar—95.36% over 95.2%. The following year, however, the Aguirre chemist rather remarkably reported that the polarization of the 20,799.91 tons of "commercial sugar" that the central had bagged, the average polarization was exactly 96.00%. In 1912, the sugar was 96.09% sucrose, and in 1913, 96.24%. The way that such numbers orbit and approximate the idealized purity of 96° polarization—which, it is useful to recall, was acknowledged to be not exactly the same as 96% sucrose—exposes

151. "Chemist's Report for the Crop of 1908," in Central Aguirre chemical reports, Colección Mercedita, AGPR.

152. But because Mill No. 2 had remained online for 119 of 132 days (though of less than ten hours apiece, as opposed to No. 3's eighteen and a half), the central as a whole had ground nearly 179,000 tons of cane. The yield report for the next year, the crop that ran from December 23, 1909 to June 30, 1910, did not even bother to provide spaces for the days, hours, cane, bagasse, and sucrose calculations for No. 1, but saved space by printing "NOT WORKING." Central Aguirre chemists' reports, 1910 and subsequent years, Colección Mercedita, AGPR.

once again the fact that the much-remarked-upon uniformity of sugar was always, on close inspection, illusory.[153]

The 1914 report was different, however, listing not only the bagged sugar, but its polarization "at Aguirre" of 96.43%, and its equivalent at 96°—in other words the tons of sugar that would have been bagged had the factory managed to manipulate its processes to produce sugar of the idealized market standard of polarization. And indeed over the following years the factory made no attempt to keep the sucrose content of its sugar rising. Instead they seem to have strived to maintain the polarization of their output within one or at most two tenths of a degree of the 96° target. The year-end reports do not yield much information about the practices of the factory's laboratory. The chemist and superintendent who followed Rolfe towards 1910 had begun to note, in their annual submission, that the sucrose in the molasses was being measured by the more time-consuming but precise technique of the Clerget method, rather than a single "direct" polarization. The fact that Aguirre's chemists began to note "Sucrose (Clerget)" in their analysis of the central's waste molasses may suggest that the South Porto Rico Sugar Company had assigned enough labor to the laboratory to permit the procedure to become routine. Close readings of these reports can reveal much about the way that the numbers they represent were produced.

5. The vacuum pan and the limits of control

153. For the seemingly paradoxical necessity of inaccuracy and "error" in measurement, see Thomas Kuhn, *The Essential Tension: Selected Studies in Scientific Tradition and Change* (Chicago: University of Chicago Press, 1977), chapter 8, "The Function of Measurement in Modern Physical Science."

Chemical control, as this chapter shows, was always about command of labor and not of the new machines that have been taken to define the central factory. Despite the efforts of central-factory owners and managers to eliminate artisan skill from sugar production, however, there was one crucial point of the process at which they were, to their frustration, unable to do so. This was the "strike" from the vacuum pan.

The notion that the slave artisan sugarmaster was rendered obsolete by new technology encapsulates the same paradoxical juxtaposition that renders the chemical sugar factory both revolutionary and evolutionary at once. "There is some justification for saying," Moreno Fraginals suggests, "that modern sugarmill controls have added little to the system established long ago."[154] But he himself goes on to dispute this. What steam technologies and chemical knowledge added to the control of labor was the introduction of supposedly objective standards for valuing the sugar itself. Thus, the "most slandered of all workers was the sugarmaster," whose expertise at discriminating among the qualities of a loaf was rendered irrelevant by the uniformity of centrifugal sugar. The sugarmaster's knowledge, Moreno writes, "threw the producers into despair." He concludes his first volume with an elegy on the destruction of the sugarmaster's authority:

> All his secrets were the result of long practice, obtained in daily contact with canefields and boiling rooms. He was basically an artisan, guided by judgment which years of living with sugar had acutely sensitized. Calculating everything by sight, smell, and taste, he knew if enough lime had been added, when clarification or

154. Moreno Fraginals, *The Sugarmill*, 145–48.

> defecation was completed, and when the conglomerate had reached the sugaring point....The tragedy of the sugarmaster, his loss of supremacy, came when vacuum pans were introduced *and his judgment was replaced by physical measuring apparatuses.*[155]

Yet this judgment was not, in fact, replaced by the polariscope. The old ingenio was more systematically controlled than propagandists of mechanization, automation, and the central-factory system would later claim. But Moreno Fraginals, the preeminent analyst of central-factory labor, is, at the same time, too credulous of claims that new mechanical apparatus and systems of chemical control could quantify completely the "secrets" of the sugarmaster. Sugar chemists themselves, in their own words, were more circumspect, and consistently reluctant to make promises of control over a process that was mostly opaque and from which visual access did not yield much insight. This was especially problematic after the end of slavery in Cuba and, after 1873, in Puerto Rico, when owners and managers of sugar factories no longer felt sure they could trust the labor force they had once been comfortable controlling.

The legal status of workers in the Spanish Antilles was in flux just as their technical milieu was changing. In 1861-1862, when the government of Cuba conducted its first census in a decade and a half, it found an island that was becoming increasingly populated by Creoles—people of light skin born in the New World. Of the 1,359,000 inhabitants, nearly 730,000 were white, and most of those were Creole, though *peninsulares* held a disproportionate number of powerful positions. About 225,000 were

155. Ibid., 153, emphasis added.

free people of color, manumitted or descended from freed ancestors. There were only slightly more slaves than there had been in 1846: 369,000 as against 323,000. Half of them worked on sugar plantations. There were, however, over thirty-four thousand indentured workers from China, who had begun to arrive the year after the previous census. These were the first of 141,000 who would be induced to travel to Cuba, and of 125,000 who would survive the voyage, between 1847 and 1874, when the Chinese government banned the deceptive tactics of the procurement agents in its port cities and interior towns.[156] The labor force of Chinese people subjected to indentured servitude, like South Asians brought to the British Caribbean colonies, was intended to replace the manpower of slaves after the effective end of the slave trade in the mid-1840s.[157] Edwin Atkins credited his Chinese laborers as being much of the reason that his sugar factory at

156. For the demographics in 1861 see Scott, *Slave Emancipation in Cuba*, 6–41.

157. Both the juridical and actual status of these "coolies" has been hotly disputed, and has implications for the discussion of whether slavery and the mechanization of sugar were somehow fundamentally incompatible. Moreno Fraginals and others contend that the different legal status of these laborers is an indication that planters themselves recognized the contradiction. Legally free coolies, they argue, were brought specifically to work in the mills where legally enslaved Afro-Cubans were unable to. In contrast, Scott points out, the standard eight-year contract and near-total power over the Chinese laborer by the planter meant that economic relations between them were functionally identical to those between master and slave, and if so, she writes it is hard to see how the mere fact of their technical legal freedom matters to their capacity to handle industrial machinery and complex mechanical processes.

But as with other oppressive regimes, the peculiar desire on the part of oppressors to maintain the legal fiction of a free society can be a powerful weapon in the hands of the oppressed themselves. Thus, as Evelyn Hu-Dehart has pointed out, the ways in which the Cuban and Spanish governments tried strenuously to maintain the legal distinction between slaves and "sponsored settlers" (*colonos asiaticos*) was precisely what gave these Chinese contract laborers leverage to make appeals in court for the enforcement of the contracts they had originally signed. "What [the Cuban elite] might not have foreseen was how clearly the coolies understood and how deeply they internalized what they were entitled to as *not slaves*." Scott, *Slave Emancipation in Cuba*, esp. Chapter 4; Evelyn Hu-Dehart, "Sugar and Coolies: The Use of Chinese Contract Laborers on the Sugar Plantations of Nineteenth Century Cuba," talk delivered at "Beyond Sweetness: New Histories of Sugar in the Early Atlantic World," conference hosted by the John Carter Brown Library, Brown University, October 24-26, 2013. Emphasis original.

Soledad, full of new vacuum pans, crushers, mills, and centrifuges, "was thoroughly organized and everything went like clockwork."[158]

The rebellion, based in the eastern provinces, that waged the Ten Years' War against Madrid's government in Cuba between 1868 and 1878 offered legal freedom to slaves who joined it as well as abolition if the rebels were victorious. The crown's response was the Moret Law, which in 1870 freed children and the elderly, at least nominally, but planters and their allies in the island's government continued to use their hold on power to limit slaves' practical freedom where it would interfere with their own economic interests, at least in the short and medium term. Between the 1861 census and the end of the war, Scott writes, "where sugar prospered, slavery persisted." Planters found various ways to incorporate Chinese and free workers while maintaining a labor force composed mostly of slaves. Slavery was extensive even in the largest and most technically sophisticated centrals. But the planters and factory-owners did so at the cost of opening the eyes of the enslaved to alternatives that were within their grasp. Within a decade of the Moret Law, the *patronato* law established ten-year indentures for those currently enslaved, at the end of which would come the full abolition that the law in fact was intended to delay. But within barely half that span, the state abandoned its planned gradualism and abolished slavery entirely.[159] In addition to the chemist's reports and yield summaries that he signed, George Rolfe also produced a treatise on *The Polariscope in the Chemical Laboratory*, published by Macmillan in 1905.[160] "In most first-class cane

158. Atkins, *Sixty Years*, 109.
159. Scott, *Slave Emancipation in Cuba*, 82, 87, and generally chs. 6-12.
160. Ferdinand Wiechmann, the American Sugar Refining Company's chief chemist, gave the book a

sugarhouses," he wrote, "the chemist is the superintendent of sugar manufacturing, *as he should be*."Chemical control had as one of its purposes "the guidance of the daily routine of the house."[161] It was the part that was not routine that posed the most problems for chemical control. Chief among these was the vacuum pan, whose operator, Rolfe emphasized, required "special skills."

The amount of syrup that the "pan man" allowed into the pan, called the charge, had to be of just the right volume so that when sugar crystallized out of the syrup it would "just fill the pan full," no more and no less. Here, the economy of the sugar factory, and the maximization of the capital invested in the expensively fragile vacuum pan, depended unavoidably on the brain under the worker's hat. Predicting the quantity of syrup that could be nurtured into the desired volume of crystals of the appropriate size was, Rolfe wrote, "obviously...a matter requiring considerable experience," being "conditioned on the quality of the juice, as well as the size of the crystals required, and the polarization." Once the pan operator felt he had charged the appropriate initial quantity of meladura, he began the process of crystallization, a task Rolfe conceded was "also a matter requiring much skill and experience." This was because further "drinks" of meladura had to be allowed into the pan in order to regulate the growth of the crystals. "On this will depend

mixed review in the April 20, 1906 issue of *Science* (New Series, Vol. 23, No. 590: 627-628). Wiechmann, unsurprisingly, criticized Rolfe's treatment of the "alleged influence of temperature on the specific rotation of sucrose," and berated him for not highlighting the methods of the International Commission for Uniform Methods of Sugar Analysis, "which no doubt will soon find general application in this country." A few months later, Rolfe responded to *Science* from Puerto Rico that Wiechmann ignored how the sugar business had to work outside of Manhattan. "What are facts of experiments in temperature influence on pure sugar polarizations must be carefully differentiated from what is the most consistent and fairest way to estimate the sugar value of a commercial product," he concluded, "by the indications of a method which at its best is subject to errors as yet incapable of exact control; errors which are small but yet significant in light of the magnitude of sugar transactions" (*Science*, New Series, Vol. 24, No. 610: 307-308).

161. Rolfe, *Polariscope in the Chemical Laboratory*, 144, 136.

to a large extent the quantity of finished sugar of the required polarization, as well as the size of the crystals themselves." Yet while the latter might be observed by drawing samples of the syrup out through the stop-cock, the polarization of the sugar crystals themselves could not be determined during the crystallization process. Once the pan was struck into the centrifuges, the polarization of the resulting massecuite could be tested. That of the crystals themselves, separate from their viscous medium, could be measured once the crystals had been spun dry and freed from their molasses—but not before. So the pan-operator had to manipulate the input of meladura and its temperature in ways that related to the nature of the initial juice. But it was not just juice of "poor quality" that needed the unquantifiable expertise of the pan-operator; the task was no less mechanical nor reducible in the ideal case of juice from healthy canes, produced on the central's own land, under the supervision of its management. The "subsequent additions of meladura must be made skillfully" in every case, "so that the crystal growth will proceed regularly and continuously."[162] Chemical expertise could produce no formula that incorporated, on the one hand, all the factors that comprised the juice's "quality"—such as its purity, acidity, and albumin—and pointed to the desired temperature and flux of syrup on the other.

What the "skillful pan men" knew also how to avoid was the "'false' or 'second grain'" by which sugar crystallized and then separated into smaller particulates. Between tiny grains and tinier it was not clear which was worse. If the false crystals were not small

162. Ibid., 131.

enough to escape the centrifuge, they made purging the sugar of its molasses more difficult. Moreover, because a mixture of differently-sized particles packs together more closely, their presence in the final sugar paradoxically increased its capillary capacity to carry moisture and thereby decreased its reading in the polariscope. But if the second grain was fine enough to escape the basket and drain away with the molasses, then it raised the sucrose content of the molasses while decreasing the yield of the factory's first and most valuable sugars. Rolfe reiterated the priority of expertise in this particular labor, which lay at the center of the sugar factory's process. "Skill engendered of long experience and familiarity with the workings of his pan are essential qualifications of a first-class sugar boiler. Such men, in raw-sugar work, command high pay and have much responsibility." By contrast, "an unskillful man may cause a loss of hundreds of dollars a week."[163] Maintaining the syrup at the proper temperature, pressure, and water content to grow crystals to a large enough size took serious knowledge. "By skilful pan-boiling, the crystallised sugar is obtained in a form permitting of easy separation from the molasses," Deerr wrote, while "the presence of fine crystals may cause considerable losses." Hence "the determination of the crystallised sugar" in the massecuite "affords a valuable check on the pan-boiler," his skill, and his ability or willingness to deploy it.[164] Measurement of the sugar content of massecuites thereby afforded another opportunity in the chemist's eyes for a check on theft.

163. Ibid., 132.
164. Deerr, *Sugar and the Sugar Cane*, 347.

As a result, the position of the pan operator was fundamentally an anxious and precarious one. The best observers of this were the authors of popular (or at least popularly-aimed) tours of the sugar industry. Edith Browne, who published hers as part of a British series in 1911, was, on the subject of the vacuum pan, an improbably subversive observer who emphasized a different aspect of the skill, labor, and status of the man operating it. "Whilst the crystals are incubating," she wrote of the central factory she visited in Demerara, "constant tests are made of the condition of the boiling," tests which, she cautioned, should not be mistaken for "pleasant reminiscences of toffee-making" tastings. "To note the gradual growth of the crystals, he exposes a small quantity of the boiling [sic] on an ordinary piece of glass," she wrote of the operator, "and there is a look of great anxiety in his eyes as he examines the specimen substance [sic] of his pan." Instead, she pointed her readers to the scrutiny and surveillance under which the boiler found himself. He, though a "native [!] operator, holds a most responsible position; a trifle too little or a trifle too much boiling, and the contents of his pan are spoiled—moreover, his reputation, very likely an excellent one of long standing, has gone for ever."[165] The precariousness of the operator of the vacuum pan was not dependent on his position as a "native" within a sugar colony. The men who operated the vacuum pans in metropolitan sugar refineries, whether in Liverpool or in Brooklyn, were under the same surveillance.[166]

165. Edith Browne, *Peeps at Industries: Sugar*, 44.

166. Ibid., 85. Browne emphasized the similarities between overseas factories and domestic refineries. "You recognize the vacuum pans," she wrote. "You can sympathize with the anxiety of the pan-boiler as he scrutinizes samples of the boiling on a piece of glass, for you realize that with him rests the responsibility of deciding when the masse-cuite [sic] is ready to leave the pans."

6. Sucrose contracts

The separation of the factory and the field, however, which both defined the central and was important to chemical control, did not mean that chemists would not attempt to exert control over the places where sugar cane was grown. In the early twentieth century the work and expertise of chemists became the focus of conflict between the colonato farmers and the owners of central factories.

The analysis of the relationship between central and colono has been an important question for historians' understanding of the patterns of economic development in the large sugar islands of the Spanish Caribbean after emancipation and particularly after 1898. Ramiro Guerra y Sánchez argued that the railroad, by extending the mill's range, allowed these outposts of American imperialism to exert control over a larger zone and eventually to absorb smaller landholdings into huge latifundia.[167] The extensive and lengthy data available for Cuba allowed the economist Alan Dye to argue that that differences in relationships between colonos and centrals contributed to the pattern of investments by American capitalists made in the late nineteenth and early twentieth centuries. In the west, the oldest and most densely-settled part of Cuba, colonos tended to be former planters themselves, while in eastern Cuba the landowners were less wealthy, less well established, and therefore less powerful. The central factories built in the west, therefore, tended to have more difficulty negotiating with *independiente* cane suppliers,

167. Ramiro Guerra y Sánchez, *Sugar and Society in the Caribbean: An Economic History of Cuban Agriculture*, trans. Marjory M. Urquidi (New Haven: Yale University Press, 1964).

and less frequently owned the land while subcontracting out the operation. But problematically for a crop that depended so significantly on coordination between agriculture and processing, the scattered ownership of the cane fields made it more difficult to coordinate planting and harvest schedules. Thus, Dye argues, centrals were forced to attempt to exert control through contracts that more strictly defined how and when the cane was to be grown, harvested, and delivered.

By contrast the eastern provinces of the island, especially the far east, had remained relatively undeveloped in the preceding decades and centuries, and it became far easier to establish a new central and to accumulate large tracts of land under its own auspices or legally possessed by of closely interrelated companies.[168] These could then be rented or leased to colonos who would plant and manage and harvest the cane itself. The central's ownership of its cane land also helped, from its management's perspective, to solve the problem of its strategic vulnerability to a colono who refused to deliver his cane.[169] The need for the cane of a particular field at a particular time meant that a colono who chose his moment could throw the grinding schedule into disarray and potentially extract significantly higher payments from a central's management, who feared letting their expensive investment begin to rust.[170]

168. See Ayala, *American Sugar Kingdom*, for the massively "interlocking directorates" of American sugar companies in the Caribbean.

169. Economists' term for this phenomenon is that the "asset specificity" of the canefield renders the central liable to holdup. See Alan Dye, "Avoiding Holdup: Asset Specificity and Technical Change in the Cuban Sugar Industry, 1899-1929," *Journal of Economic History* 54 (1994): 628-53, and Chapter 6 of his *Cuban Sugar in the Age of Mass Production.*

170. Dye, *Cuban Sugar in the Age of Mass Production*, chapter 6.

An alternative was for the central not merely to own land but to manage it as well, and closely supervise the growing of the cane with its own personnel. Such land was known as "administration land" and the cane produced under the central's direct ownership as "administration cane." Yet at least through the early 1930s, the share of cane supplied to central factories by lands under their administration and the share supplied by colonos independientes both declined, replaced by colonos *del central*, managing land owned by the mills themselves.[171] In Dye's persuasive analysis, it was the logistical and biological problem of coordinating the reliable delivery of the sugar cane that spurred the growth of the large latifundia, not merely a local form of miniaturized imperialism.[172]

Yet though the central could, in its contracts, mandate the agricultural techniques used by colonos del central or independientes, the quality of the cane delivered and its suitability for grinding was harder to specify and hard to measure. The purchase of cane, even from those working on a central's land, meant more work for the factory's chemists and assistants to do in a shorter period of time.[173] And in the early years of the twentieth

171. Ibid., 253-4.

172. For the problems of "American imperialism" as an explanation in general, see James A. Field, Jr. "American Imperialism: The Worst Chapter in Almost Any Book," *American Historical Review* 83, No. 3 (June 1978): 644-668.

173. Guilford Spencer, *General Instructions*, 16.

century there took place a crucial shift in the terms under which those contracts were assessed.[174]

In 1928, the new Brookings Institution devoted one of its first reports was devoted to a general exploration of the economic and social difficulties of Puerto Rico. Its appendix on "The Sugar Industry" was republished, at the request of the island's Association of Sugar Producers, under the new title "The Sugar Problem of Puerto Rico."[175] Contracts between growers and grinders were a subject on which the Brookings investigators focused. They noticed that these documents, "essentially crop loan agreements," did not in fact stipulate that the central was required to grind the cane it purchased. As they put it, "the mill's interest in performing this service is so obvious that the obligation is not usually recorded." But given the disruption to a mill's operation when a roller or other piece of machinery broke—from the consequent degradation of the juice in the cut stalks waiting to be crushed, and the subsequent rush to make up for lost time—this was, in all likelihood, not a neglectful omission. Rather it was, on the part of the factory itself, a wise way to avoid a legal obligation to grind unprofitable. If forced to

174. The "model contract" that Guerra y Sánchez reproduces at the end of *Sugar and Society in the Caribbean* provides that the colono's cane "will be paid for on the basis of its weight as indicated by the scale of the mill yard of the plantation where it is ground." The colono's representative could check this weight (though not explicitly the scale itself) "at his own expense." The terms of the payment are somewhat unclear, stating that "the Company [i.e., the central] will pay the colono the value in official currency of five and a quarter (5¼) arrobas of centrifugal sugar, with juice [?] of a polarization of 96 degrees," based on the previous fortnight's average price as quoted by the Association of Havana Sugar Brokers. Guerra y Sanchez, 198-199.

175. The Association hoped to defend itself against the charge that the size of the latifundia on the island was keeping the island's economy underdeveloped. To the Association, the mills were occupying prime coastal land for its transport benefits, demonstrating the planters' "intelligen[ce] and fores[ight]." "Preface: Why this Pamphlet," in Brookings Institution, *The Sugar Problem of Puerto Rico* (San Juan, Puerto Rico: Association of Sugar Producers of Puerto Rico, 1936). See Stuart McCook, *States of Nature: Science, Agriculture, and Environment in the Spanish Caribbean, 1760-1940*, chs. 3 and 4, for this and other associations of planters in the Caribbean.

mill cane that had fermented into unprofitable territory, a central would then find that the newer cane was piling at its gates, its juice inverting by the minute.[176] The centrals also might use their contracts to stipulate the cane variety, irrigation, and fertilizer, and to cover those expenses frequently advanced cash to colonos until the grinding season, expenses of a sum that was often not enumerated but rather expressed as "sufficient to raise the crop." This meant that banks loaned to colonos at a greater interest rate than to coffee or tobacco farms. A central did have a strong interest in grinding the cane of its own debtors first. This was not only when the central was pressed, in case of a logjam, but so as to maximize the return to those farmers who would then be obligated to it.[177]

Contracts between the colono and the central had, since their establishment after emancipation, been denominated in pounds of sugar per hundredweight of cane. Between five and seven pounds of sugar per hundred pounds delivered would ordinarily be returned to the grower to sell himself, or the central could be paid a fee to sell the sugar on his behalf.[178] These contracts, centrals and their chemists argued, yielded cane that was liable to be poorer quality and filled with "cane trash." If the colono were paid based on the measured purity of the cane he transferred to the central, then, as the investigators

176. Brookings, *Sugar Problem*, 16.

177. Ibid., 18.

178. See Rebecca J. Scott, *Degrees of Freedom: Louisiana and Cuba After Slavery* (Cambridge, Mass.: Belknap Press of Harvard University Press, 2005), 117. Ayala contradicts himself on the question of method of payments within a single paragraph. He writes that colonos were "paid a certain percentage of the sugar contents of the cane," yet immediately states that a hundred tons of cane "typically" yielded thirteen tons of sugar, of which the colono received five. Then he suggests that payments were based on twice-monthly prices for sugar in Havana, and finally that "payment for the cane was based on its sucrose content as measured by a chemist employed by the mill." (Ayala, *American Sugar Kingdom*, 133). This inconsistency is reflective of the way in which the transition to the use of sucrose and purity as a measure has not been taken to have represented a shift in knowledge regimes within the sugar economy. See note 182 below.

from the Brookings Institution argued, he would have an "incentive to raise a high quality of cane and to deliver it in the best possible conditions."[179] But as sugar prices remained relatively low after 1921, and as chemists' knowledge became the only valid one throughout the sugar factory, such contracts came to be denominated in sucrose content and purity. In 1928, in Puerto Rico, 605 contracts denominated in hundredweights and 178 in sucrose were registered with the insular government. But this system placed enormous advantages in the hands of the central. The juice of the cane could only be analyzed after it was crushed, and therefore all the power to decide the value of cane rested in the hands of the mill and its chemist. This power was amplified by the frequent requirement "that the cane shall come up to a minimum standard of purity and sucrose content, subject to penalties" if violated.

The authority thereby vested in the chemists of the centrals led to calls for legislation that would establish a force of chemists under the auspices of the government itself, in order to oversee the analyses of juice and even chemical control in the mills themselves. The proposed laws would also mandate that a colono was entitled to at least sixty-five percent of the sucrose content of the cane he delivered. After several attempts to mollify these concerns in the 1920s and early 1930s,[180] the still-dissatisfied colonos finally succeeded, in 1934, in achieving legislation by Puerto Rico's Asamblea Legislativa that specified and regulated the details of the practice and place of sugar chemistry. "An Act to create the Division of Inspection of Chemical Laboratories of

179. Brookings, 17-19.

180. See *Laws of Puerto Rico* 1925, Act no. 10; 1927, Act no. 31; 1930, Act no. 32; 1932, Act no. 31.

Puerto Rico in the Department of Agriculture and Commerce" defined a "chemical laboratory" to be any "place or premises where chemical analyses or syntheses are carried out."[181] The new island-wide division of inspection was to be staffed by five chemists, who would be authorized to obtain and analyze "any sample of the cane juice of any *colono*, pertaining to cane ground in any sugar factory in the island, in order to contrast[182] the analyses made at the laboratory in such factory." More generally they were to serve as a referee (*árbitro*) of each "controversy" between colono and factory, to register all chemists and chemical engineers, and to dictate "the rules and system for taking samples and analyzing the cane juices" in factories' laboratories.[183]

By this point, in the nineteen-thirties, each American company dictated its own particular terms of payment to its colonos. These varied considerably, and were never straightforward mathematical or chemical calculations. Central Aguirre, for instance, paid 65% of the expected recovery of sugar, calculated at New York prices minus the cost of freight. Fajardo paid 62.5% minus freight. Eastern Sugar Associates paid 65%, but at Puerto Rican prices, and they took a minimum of 3.5% by cane weight for the mill—a system designed to further reduce the incentives to deliver what the central considered lower-value cane.[184] On top of that, the colono selling to Eastern received not sugar but

181. *Laws of Puerto Rico* 1934, no. 71, section 1.

182. "*Para contrastar*," in the parallel Spanish text of the bill.

183. *Laws of Puerto Rico* 1934 no. 71, sec. 4

184. This was because unless the central were able to extract 10.5% or more sugar, the colono would not receive the 7 percent by weight that was still the expected norm. Gayer and his fellow researchers collected the records of payment covering 50% of the island's production for the preceding decades, and found that, measured by weight of cane, the average percentage paid to the colonos was 7.3%, and very few were above 7.5% or below 6.5%. "It would appear," they wrote, that seven pounds of sugar per 100 pounds of cane was still considered the norm, "and that the various systems are designed to average out at about that rate for cane of average good quality. *In other words, the more refined methods of liquidation appear to make the older rough-and-ready system their point of departure.*" Arthur D. Gayer, Paul T. Homan, and

warehouse receipts, and then had to either market his sugar himself or pay Eastern to do it for him.

Central Cambalache, in the north near Arecibo, took a different tactic.[185] It had tried analyzing each colono's cane, but by the mid-thirties, returned to the simpler basis of paying 7% by weight. Cambalache drew upon a particularly large number of particularly small growers, and its managers decided against the expense of chemical labor required to draw samples from each shipment. Yet they felt this would not reduce the quality of sugarcane Cambalache received, since the incentive effects of chemical control paled in comparison to the "aid in cultivation rendered by the mill's field inspectors."

The power of the centrals to control the specifics of those formulas had long been a source of contention among sugar-cane growers, and indeed among mills themselves. Some mills were upset that "some competitor 'sweetened' the rates or the chemical analyses, to lure growers to its mill," reported a Columbia University study in the nineteen-thirties, while colonos complained that mills seemed to find an excessive number of deductions and demerits to reduce their payment. Cane weighing and analysis were judged by these researchers the least important points of contention in mill-colono relations. Although they argued that it was impossible to know whether the power of the companies to measure weights and conduct tests was being abused, the potential for abuse was real, "and its very existence can be the source of suspicion of unfair dealing

Earle K. James, *The Sugar Economy of Puerto Rico* (New York: Columbia University Press, 1938), 143.
185. For Cambalache, see García Muñiz, *Sugar and Power*, 81.

and discrimination." Individually, each central defended its own idiosyncratic formula by pointing to an increasing body of chemists' evidence. But together, the effect of multiple, contradictory, supposedly rational formulae paradoxically reinforced a widespread sentiment among colonos that those same formulae were never purely "non-economic and technical in character." Their multiplicity "furnished a basis for popular suspicion "that they did not always operate to do strict justice to growers," and regardless of whether this was the case it remained a severe irritant to the kind of relations between mills and colonos that both wanted, albeit on their own terms. If a decision among such formulae might and ought to be made on the basis of "careful technical study," it therefore seemed that any differences among them, on the part of centrals who claimed access to reserves of chemical expertise, were in fact the result of malfeasance.[186]

Thus, the 1934 legislation was followed three years later by another bill, one even more explicitly intended to regulate contracts for cane purchases and, specifically, to establish "the procedure to be followed by the centrals of Puerto Rico in determining the crystallizable sugar per cent in the cane delivered by the colonos for grinding."[187] It defined a colono as any individual or corporation "delivering sugar cane for grinding to a central," and any central as any entity operating a sugar mill. And this new act attempted to further regulate the relationship between the mill and the field. The colono and central were to agree on the variety of local cane to be cultivated from those "which, because of their adaptation and noble qualities, may have become generalized in the region." The

186. Gayer et al., *Sugar Economy*, Chapter XIX, "The Distribution of Income from Sugar," 275-277.
187. *Laws of Puerto Rico*, Act 112 of 1937.

colono was responsible for his cane until delivery to the central or its agents. In return the central was now obligated to grind the cane within twenty-four hours. And in a concession to the centrals, all of the cane that it processed, whether from its own lands or purchased, was to be "free from trash and earth." When the grinding season came to an end, each central was to file "a true copy of the final report on manufacture," including the mean analysis of the cane juice and the yield of 96°, commercial-grade sugar.[188]

But it was not just the inspecting engineer, as an agent of the state, who was granted authority as arbitrator to enter and inspect the analytical premises of the central. Colonos had, as we have seen, long complained that the mills had total control over the analyses, "both in adopting formulas and in administering them," and that a colono delivering cane to the mill "could not *know* whether he was fairly treated or not, so the suspicion of evil had a breeding-ground."[189] Now cane-growers themselves were granted the right to inspect their purchasers as well. This power was not, within the bill's text, temporally tied to the status of a contract: it could be exercised before, during, or after the grinding of a colono's cane, and both inside and outside the factory, at its scales in the field or incorporated into the railways, and in the "laboratories of the central" itself. Finally, and most remarkably, the law authorized them not just to "observe" but also to "intervene" in all the operations of chemical control: "the taring of cars, weighing of sugar, examination of scales, weighing of cane and juice, taking of samples and analyses

188. *Laws of Puerto Rico* 1937, no 112. This was in order that the inspecting chemical engineer, whose office had been created in 1934, could calculate the factor in each factory for the coming season, thereby making sure that the estimated yield did not exceed the real yield.

189. Gayer et al. Chapter X, "Relations between mill owners and growers (colonos)," 137.

of cane." For its part, the central was "obliged to permit access of such personnel to said dependencies of the factory, and to offer them reasonable facilities for the performance of their duties"—which might presumably include the facilities of the central's laboratory itself.[190]

Legislation to standardize the formula for the remuneration of cane-growers all over the island was intended to clarify that the clash of interests between mills and colonos was an economic one, fought over the fraction of the price of sugar that each should receive. But this conflict had, of course, been present in the formula all along. It was one final way in which the supposedly mechanical power of the central to transform sugar cane into pure sucrose actually depended on various kinds of skilled work, and the battle to control it. Some of these forms of work remained from the plantation, others of which were new to the central itself. The next chapter shows how the machines that enabled the central factories themselves depended on the maintenance of more collaborative and craftsmanlike ways of working.

190. *Laws of Puerto Rico* 1937 no. 112, section 14

Chapter 3:

"Sugar machinery is all of a special nature": engineering for purity in Glasgow in the nineteenth and early twentieth centuries

1. Introduction: the demanding nature of sugar machinery

The devices that the Glasgow engineering firm of Mirrlees, Tait, & Watson sent to the 1876 Centennial Exhibition in Philadelphia, where they were put on display in the British section of the Machinery Hall, represented a firm at the peak of its powers. Mirrlees had dispatched a huge sugar mill, with its companion steam engine, as well as a second, smaller mill unit. Both of them, claimed the chemical engineer John Mayer in his survey of Glasgow's industries that year, had "been exciting a considerable amount of attention in America," attention he partly credited to the machines' "improved details of construction."[191] More particularly, he applauded the way those details accommodated such enormous pieces of heavy machinery to the exigencies of the exhausting work that would be demanded of them, once installed in a sugar factory situated in the tropics. An American observer of the event wrote in his own illustrated guide that the "huge sugar mill...was one of the most solid-looking institutions in the Machinery Hall." He too commented approvingly on the size and scale of the flywheel, the gears, the rollers, and the shafts.[192]

191. John Mayer, *Notices of Some of the Principal Manufactures of the West of Scotland* (Glasgow: Blackie and Sons, 1876), 118.

192. J. S. Ingram, *The Centennial Exposition, Described and Illustrated, being a Concise and Graphic*

The mid-1870s were a significant moment for Mirrlees, Tait, & Watson, the largest and best-reputed of all Glasgow's sugar engineering firms, and for the small number of other Glasgow concerns that were its competitors and collaborators. In the three prior decades, Mirrlees had sent over two thousand sugar mills overseas. Glasgow was the largest supplier of machinery in much of the Caribbean. The British consul in San Juan reported in 1878 that "such well-known names as Tait and Mirelees [sic] and Buchanan [another partner in the firm] are to be seen on scores of sugar plantations."[193] In fact, during the nineteenth century, eighty percent of the machinery for the world's sugar factories was built in the city of Glasgow.[194]

This dissertation shows the ways that, in the Atlantic cane sugar economy, the reinvention of sugar itself as a chemical commodity transformed relationships between labor and management, artisan skill and scientific knowledge, old technique and new technology, and market participants and the substance in which they traded. It is important, therefore, to note just where within the taxonomy of the 1876 exhibition its organizers had placed sugar production and the related machinery. The judges of Mirrlees's equipment were the same as those who judged samples of sugar itself, along with everything else under the group "Chemistry and Pharmacy, including Apparatus."

Description of this Grand Enterprise, Commemorative of the First Centennary of American Independence (Philadelphia: Hubbard Bros., 1876), 180. For the relation of the 1876 centennial exposition and America's role in the world, see Robert Rydell, *All the World's a Fair: Visions of Empire at the American International Expositions, 1876-1916* (Chicago: University of Chicago Press, 1987), chapter 1.

193. "Report by Consul Bidwell on the Trade and Commerce of the island of Porto Rico for the Year 1878," in Gervasio L. García Rodríguez and Emma Aurora Dávila Cox, eds., *Puerto Rico En La Mirada Extranjera: La Correspondencia de Los Cónsules Norteamericanos, Franceses E Ingleses, 1869-1900* (Río Piedras, Puerto Rico: Centro de Investigaciones Históricas, Decanato de Estudios Graduados e Investigación, Universidad de Puerto Rico, Recinto de Río Piedras, 2005), 165.

194. Michael S. Moss and John R Hume, *Workshop of the British Empire: Engineering and Shipbuilding in the West of Scotland* (London: Heinemann, 1977), 3.

This encompassed substances from perfumes, varnishes, and inks to bleach, salt, hydrochloric acid, and natural gas.[195] If the question this dissertation answers is, in a sense, how and why sugar got to be part of "Chemistry and Pharmacy" alongside such materials, this chapter connects that reinvention of tropical cane sugar as chemical commodity to the chief place where the machines used to produce that sugar were themselves designed and built. The industrialization of sugar production from the second half of the nineteenth century into the beginning decades of the twentieth affords a unique opportunity to tie together the workshop of the British empire and the empire of sugar, and thus to bring to the fore the builders of the infrastructure that underlay the Atlantic commodity networks with which historians and other scholars are by now familiar. It thus represents an attempt to bring the city that facilitated and quite literally constructed the nineteenth-century sugar world into the history of that world.

By 1860, seventy percent of mills in Cuba, the best-capitalized and most technically advanced sugar-producing region, were running on steam.[196] Enormous social, economic, and political ramifications have been attributed to the introduction of steam-powered machines into the cane sugar-producing world.[197] Stronger mills that turned under regular power allowed a greater proportion of the juice in the cane to be extracted from it. Clarifiers, multiple-effect evaporators, vacuum pans, and centrifuges, in addition to mills, vastly increased the efficiency of sugar-cane processing, and provided returns to

195. Francis Amasa Walker, ed., *International Exhibition, 1876, Reports and Awards, Vol. IV (Groups III-VII)* (Washington: Government Printing Office, 1880), v.
196. Curry-Machado, *Cuban Sugar Industry*, 28.
197. See in particular Galloway, *Sugar Cane Industry*, chapter 6, "The Innovations of the Long Nineteenth Century: 1790-1914," esp. 135.

scale in a way that animal-, wind-, or water-powered sugar production had not. They were enormously expensive in both capital and operating terms, however, and by 1870, just twenty percent of the mills in neighboring Puerto Rico, an island whose industry was chronically short of capital, were powered by a steam engine.[198] These costly apparatus of sugar production were expected by both their makers and their buyers to last many decades.[199] One of Mirrlees Watson's first mills, for instance—number 76—was produced and shipped in 1850, and not broken up until 1927.[200]

Yet almost nothing at all has been written about these companies themselves, who built the steam-powered sugar factories that transformed the tropics. Such a complete absence of scholarship on these firms, so crucial to the sugar world, is perhaps attributable to the fact that while these firms were sizable and reputable members of the Glasgow business environment, their products, unlike ships or armaments, rarely made headlines themselves. The firms, in other words, were too well-behaved to have attracted the attention of the large community of British historians of technology, of industry, and of labor.[201] At the same time, these firms seem to have fallen outside the remit of historians of Atlantic sugar, and sugar elsewhere. The index for J. H. Galloway's *The*

198. Andrés Ramos Mattei, "Technical Innovations and Social Change in the Sugar Industry of Puerto Rico," in *Between Slavery and Free Labor: The Spanish-Speaking Caribbean in the Nineteenth Century*, ed. Manuel Moreno Fraginals, Frank Moya Pons, and Stanley L. Engerman (Baltimore: Johns Hopkins University Press, 1985), 158–178.

199. Of course, the useful life of a technological object is not a fixed or inherent property but is the result of its users' calculations and beliefs about the costs and potential benefits. Costliness is relative; even marginal gains in efficiency from upgrading machines can merit the expenditure if profits are high or if capital reserves are sufficient to absorb the cost. Like any other investment in production, the question of whether machines are "worth it" depends on the price their product can demand. Sugar manufacturers rarely bought new mills at least in part because sugar prices were fickle and frequently low, and plantations and factories were often indebted.

200. Mirrlees Watson Mill and Krajewskis Order Book, UGD118/2/4/37, University of Glasgow Archives (hereafter UGA).

201. I am grateful to Professor Ray Stokes of the University of Glasgow for this insight.

Sugar Cane Industry does not even include an entry for "Glasgow,"[202] and while that for Noël Deerr's standard and encyclopedic *History of Sugar* does mention the names of specific machinery producers, it includes only an entry for Glasgow "as refining centre."[203]

Like most nineteenth century Glasgow engineering companies, sugar machinery makers were private partnerships. The partners of these firms, like the firms themselves, were, within the firmament of the Glasgow business elite, notable and respected figures: not tycoons on the scale of a steel, ship, and weapons magnate such as William Beardmore, but wealthy and powerful enough to marry into such families. Beardmore's daughter, for instance, married Duncan Stewart, who, in 1886, was petitioned to stand for Parliament as a Unionist in the Bridgeton district, in the eastern part of the city where his London Road Ironworks were sited, by two thousand electors—half the number needed for outright victory. Other "well-known names" in the sugar world, such as William McOnie, James Buchanan Mirrlees, and William Rennie Watson, were equally reputed in Glasgow. All three served on the Glasgow Town Council. McOnie, Stewart, and Watson also served as governors of the prestigious Glasgow School of Art and Haldane Academy, Watson as the appointee of the Institution of Engineers and Shipbuilders in 1893, while Stewart also served as an Examiner.[204] McOnie, for his part, even served three years as

202. Galloway, *Sugar Cane Industry*, 261

203. Deerr, *History*, vol. 2, 610.

204. "Governors 1845-1982," Glasgow School of Art Archives, Glasgow, Scotland. For Duncan Stewart as examiner I am grateful to Susannah Waters, GSA Archivist, in a personal communication.

Lord Provost of the entire city in the middle of the 1880s, albeit by all accounts undistinguished ones.[205]

For all the attention scholars have devoted to the ways sugar was made on machines and the deployment of particular kinds of machines transformed the plantation, and for all the ink that has been spilled over priority disputes in the invention and innovation of new technologies for the extraction of sugar from the cane and the beet, the machines themselves have emerged, more or less, *deus ex machina*—machines themselves produced by some other, distant, impersonal machine. Historians and other scholars of Caribbean sugar plantations invoke the authoritativeness of companies with distinguished-sounding names: A. & W. Smith; Mirrlees, Tait, & Watson; Duncan Stewart; Fletcher; Manlove & Alliot. But what of these companies themselves, and the—mostly—men whom they employed? This chapter begins to reconstruct the history and nature of the skills and knowledge that created the machines for standardized sugar-making in the industrial central factories of the Atlantic world and beyond, and made possible the attempt to subject the sugar trade to chemical control. It first explains the origins of Glasgow's sugar-machinery makers in the city's mercantile power of the eighteenth century. It argues that, driven by the tremendous lifespans of their products, these firms maintained strong human and paper links with the places their machines were used, and maintained traditions of craft production in Glasgow well into the middle of the

205. S. G. Checkland and Anthony Slaven, eds., *Dictionary of Scottish Business Biography, 1860-1960* (Aberdeen: Aberdeen University Press, 1986), 174-75, 182-183, 188-189, 194.

twentieth century.[206] In this way, the story of industrial sugar production becomes one told not *deus ex machina*, but rather *machina ex Caledonia*.

When it exhibited machinery in Philadelphia, Mirrlees was expanding. In addition to their now nearly twenty-year-old main works, "one of the most splendid and completely equipped engineering establishments in the kingdom," Mayer wrote, Mirrlees were in the process of constructing a foundry "which, when it is finished, will be unequalled by any other establishment of the sort in Scotland." This was in order to manufacture castings for its sugar equipment, the "special machinery made by that firm in such extraordinary quantities." At full capacity, the partnership employed 800 workmen.[207] Along with the other large firm of W. & A. McOnie, it would routinely charter entire vessels, of many hundreds of tons, for the delivery of their equipment to clients across the planet. Up to a dozen such charters each year might carry as much as £12,000 or £15,000 worth of equipment apiece.[208] In 1876, it was estimated, the Clyde Valley built and shipped nearly £400,000 worth of sugar machinery.[209] These went to plantations and refineries largely scattered across the agricultural, cane-growing regions of the globe, both those within and those without the British empire, from the West Indies to the South African province of Natal, from Queensland to Brazil. Between 1878 and

206. As David Montgomery shows, metalworking industries that produced large and intricate machines were unable to introduce continuous-flow processes, which were the key to crushing labor's autonomy. Where plants were large but economies to scale were limited and possibly negative, firms "were hopelessly dependent on the skills of labor, in a multitude of different crafts: machinists, pattern makers, molders, blacksmiths, metal polishers, fitters, electricians, sheet-metal craftsmen, and others. This was the domain of the most bitter and protracted struggles of the epoch to change work practices, the cradle in which scientific management was born." Montgomery, *Fall of the House of Labor*, 55-6.

207. Mayer, *Notices*, 66, 118.

208. Partners might invest directly in shipping concerns themselves. Checkland and Slaven, eds., *Dictionary*, 182.

209. Moss and Hume, 31.

1884 the firm would ship 45,000 tons of equipment, worth over one and a half million pounds. In one of those years, they dispatched more than a thousand tons a month for eleven months.[210] A single one of the segmented gears on which Mallet commented was nineteen feet wide and two feet thick, made of eight arms bolted to eight rim segments, and weighing thirty-four tons in total. To the editors and readership of the magazine *Engineering* in 1896, such a wheel "indicat[es] the massive character of the machinery" that Mirrlees and its fellow firms produced.[211] Likewise, vacuum pans for sugar were the largest copper items made in Scotland.[212] Mirrlees and its fellow sugar-machinery specialists were significant and substantial firms by Glasgow's engineering standards, and provided the infrastructure on which any industrial sugar economy depended.

The middle of the eighteen-seventies also marked a turning point in the North Atlantic industrial economy. The previous decades had been ones of rapid and sustained growth in both Britain and America. The coming ones would witness a prolonged depression in the former, and slower growth and more frequent downturns in the latter.[213] Those years also represented significant dates in the Atlantic sugar economy, as a decade of war in Cuba was drawing to a close. The creole planter class of Cuba saw its sugar investments destroyed by the fighting since 1868 or else victoriously expropriated by

210. "The Mirrlees, Watson, and Yaryan Company's Works and Sugar Machinery," *Engineering: An Illustrated Weekly Journal*, 1896, 534.

211. "Mirrlees, Watson," *Engineering*, 606.

212. David Bremner, *The Industries of Scotland* (1869), 136.

213. E. J. Hobsbawm, *Industry and Empire: An Economic History of Britain since 1750* (Harmondsworth, Middlesex: Penguin, 1968), chapter 9, "The Beginnings of Decline"; Montgomery, *Fall of the House of Labor*, 51.

Madrid at its close.[214] In 1876, too, Hawaii began its reciprocal tariff arrangements with the United States, making financially attractive the construction of large sugar plantations in the archipelago, and eventually providing the source of fuel for Claus Spreckels' West Coast refining empire in its war with the eastern Sugar Trust.[215]

The designers of the machines used to make sugar had to confront the nearly constant danger to their creations. The judges tied this sensitivity to the needs of the sugar factory to more than just the talents and training of the machine's designers. Their plans would be meaningless without the techniques of the foundry that was tasked with implementing them and the skilled workforce to turn them into metal. Mayer, the chemical engineer and Glasgow booster, attributed the Mirrlees apparatus' minor Philadelphian celebrity to "the manner in which the heavy spurwheels and flywheels are made in segments, all by machine tools, and without any hand fitting."[216] The use of these new mechanical technologies of ironfounding was an attraction for potential customers of Glasgow's capital-engineering products. And in their official report, the Philadelphia judges admired the thought that went into the designs as well as the skill of the constructors.

Mirrlees had chosen to have the mill "exhibited in motion," so the judges could note the ways the design took "precautions in favor of equalization of pressure and avoidance of choking" if too much cane were forced through at once. Yet its designers

214. Louis Perez, *Cuba: Between Reform and Revolution*, 3rd ed (New York: Oxford University Press, 2005), 102-3.
215. Jacob Adler, *Claus Spreckels: the Sugar King in Hawaii* (Honolulu: University of Hawaii Press, 1966).
216. Mayer, *Notices*, 118.

were also attuned to the need for repair and maintenance on the spot. Horizontal rollers made of iron were vastly more powerful than wooden ones, yet the latter could be repaired locally, while the necessary foundry expertise was not always available to repair the metal. Thus, a cracked roller was one of the great fears of the sugar-factory manager, since it had the potential to bring the whole mill to a halt, causing costly disruption to the time-sensitive production line of a sugar factory. For this reason, the judges, including the expert sugar chemists Charles Chandler of Columbia and J. W. Mallet of the University of Virginia, approved of “a well-contrived horizontal opening in the main frame,” which would allow one of the lower rollers to be removed from the side and replaced with another, yet requiring “scarcely any lifting of its great weight.”

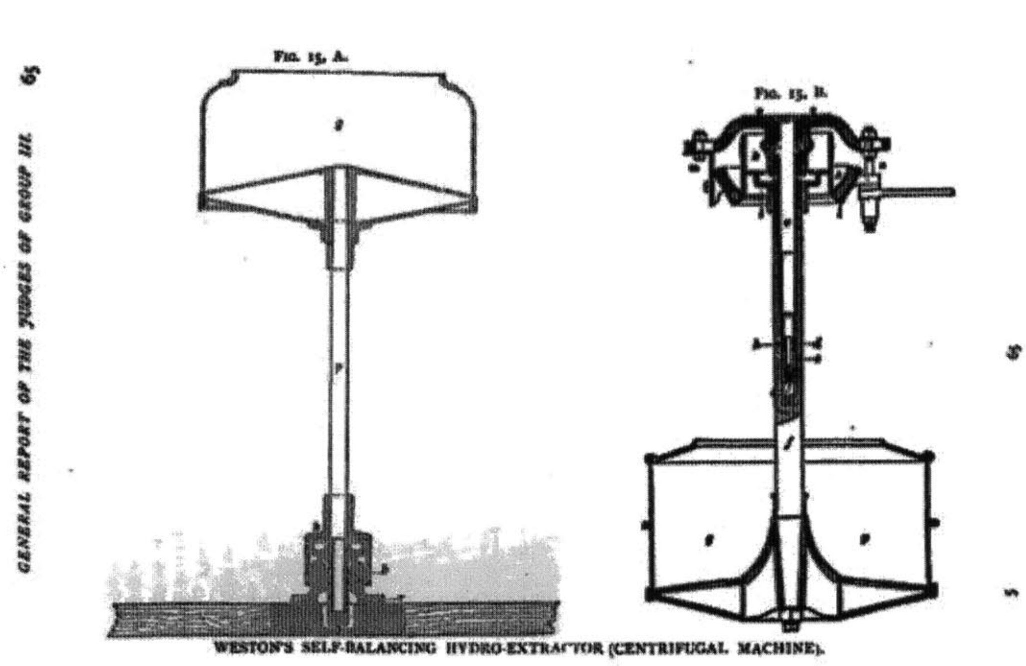

Figure 3.1: Mirrlees Watson centrifugals, displayed in Philadelphia in 1876, from J. W. Mallet’s report

Mirrlees also displayed a working pump to depressurize a vacuum pan, though they showed no pan itself, since this could not have easily been demonstrated "in motion" in the way a mill or pump might. There was no syrup from which to make massecuite, had they wanted to; but more fundamentally, the operation of a vacuum pan was, as the previous chapter showed, a process by its nature frustratingly difficult to observe.[217] Finally, Mirrlees also had installed three centrifuges, each of which could drain four to five tons of sugar per day **(Figure 3.1)**. Nine or ten would be needed to process the 300 tons of cane that the mill on display could handle. They were based on the lucrative Weston patent, of which they were the sole British licensee, for a "self-balancing" device, in which the basket was suspended on a central gimbal-like mechanism, to avoid the danger which asymmetric loading of the mass of molasses and crystals could pose to the rapidly spinning basket.

Yet, at the same time, those customers needed to be convinced that machine tools operated by "semi-skilled" workers could produce finished goods of a quality equivalent to what had long been made by the workmanship of the hand fitters.[218] Mayer had been proud to say that construction had gone without the formerly trusted skill of those

217. Mallet lamented that though the vacuum pan had become essential to sugar production few vacuum pans were exhibited. He mentioned specifically only one eight-foot pan, which "was of good, sound workmanship, but presented no special novelty in design" (Walker, 57). Curiously, however, Ingram wrote that a thirty-five foot vacuum pan was shown at the hall's western end, "and was a very imposing exhibit on account of its enormous dimensions and the beauty of workmanship. Rising to a height of some thirty-five feet the huge ten feet [wide] vacuum pan looked like a monster carboy with ash and walnut lagging" (Ingram, 184).

218. Glenn Adamson, *The Invention of Craft* (London: Bloomsbury, 2013), chapters 1 and 3, and see the discussion of repetition as craft later in this chapter.

craftsmen, and the contrast of the judges' report to Mayer's own description is notable. Virginia's Mallet, the lead author of the report, paid tribute to the craft of the ironfounders. "Due care had been bestowed upon making the teeth [of the spur wheel] true....While there was no attempt at a showy finish, the workmanship throughout appeared to be thoroughly sound and substantial."[219] Sugar machinery makers wanted to assure their buyers of the precision of their construction, while reassuring them that the customization they prized was not about to be lost.

219. Walker, 41.

Figure 3.2: Cracked sugar-mill roller, cross section, mid-twentieth century. The roller was returned to its maker, A. & W. Smith, which concluded that the roller had not been defective but had been subjected to "undue stress...either through faulty handling of the equipment or through lack of alignment in the assembly." (UGD137/1/53, University of Glasgow Archives)

This machinery was not only meant to work continuously for fifty to a hundred years, however: it had to do so at an immense distance from the engineering workshops whose minds and hands had designed and built the equipment itself.[220] This chapter's analysis of the design and production of sugar machines emphasizes how they were designed for long lives at a distance, and demonstrates the relevance of David Edgerton's call for historians to put maintenance at the forefront of stories about technology.[221] The transatlantic history of the equipment that filled the industrial sugar factory is a story of maintenance as well **(Figure 3.2)**. The hot, noisy, and moist sugar factory placed immense demands on humans and on technical objects. During the six-month Caribbean grinding season, a mill was run almost round-the-clock. Every day brought more things to lubricate and to tighten; every week or two everything had to be given a full inspection. Both people and machines disintegrated under the strain. These machines had to be, paradoxically, both robust and impermanent: at the end of each season they were dismantled and packed away to preserve them from the humidity.[222] Hence Mallet and Mayer emphasized the reparability and modularity of the equipment, and the thought that went into their design. Sugar machines broke, and broke often, and when they broke, they were far from the tools and expertise that had made them.

220. For a discussion of the perils involved with managing seventeenth-century sugar plantations at a distance, see Dunn, *Sugar and Slaves*, 200-201.

221. Edgerton, *Shock of the Old*, 77.

222. Curry-Machado, *Cuban Sugar Industry*, 80-82, 94-95.

2. Sugar engineers in the mercantile city

From a small seventeenth-century fishing town, Glasgow grew into an eighteenth-century mercantile power, and then, in the nineteenth century, became the world's premier producer of heavy engineering equipment. In the twentieth century, the city's fortunes faded, as it faced strengthened rivals across the Channel, the Atlantic and the world. The rise of ironworking and engineering in the city was facilitated by easy access, in the west of Scotland, to coal and to iron ore, and what the city produced depended on its merchants' standing commercial interests.

As Jamaica, Virginia, and St. Vincent Streets in its center indicate, Glasgow rose to prominence as a commercial power in the century after the 1707 Acts of Union by trading with Britain's colonies on the Atlantic's western edge. The city's first fortunes were made through the financing of voyages for New World cash crops, and chief among these was tobacco, especially after 1740. Glasgow's merchants were heavily linked with the slave states of the American South, and its "tobacco lords" were a social and economic oligarchy in the relatively small world of the eighteenth-century city. On the eve of the American Revolution, the city imported 47 million pounds of tobacco, a growth of five hundred percent since 1740. The overwhelming bulk of its imports were shipped back out to be resold abroad. In exchange for tobacco, the city's merchants supplied the colonies with everything that American slave society demanded: foodstuffs, iron goods, cloth, luxury items, and, increasingly, plantation equipment. This required extensive contacts not just with England, the source of manufactured goods, but with the empire's Caribbean colonies, who supplied their northern compatriots with sugar, rum, and molasses. Increasingly, these tobacco merchants came to finance industrial investments in the Clyde Valley in order to guarantee cargo for their voyages and supplies for their customers.[223]

In the seventeen-eighties and nineties, as a consequence of the end of colonial monopolies on trade and of intra-European warfare, the power of tobacco oligarchs declined. Sugar barons took up their place. Earlier, during the American Revolution, Glasgow's tobacco merchants had maintained their relationships with North American planters by relying on smuggling operations that were run out of the West Indies. These further developed the city's existing connection to the sugar colonies of the Caribbean. In their service as commission merchants, the city's sugar traders even came to own plantations themselves. Partners in these firms often began their careers as planters, before coming (or returning) to Glasgow as traders. In other cases, plantations were used as collateral to secure loans, and when they not infrequently went into default the trading firm became the proprietor. Many of the firms had substantial offices in the Caribbean, and in London, the center of the British sugar market and the supplier of insurance. Unlike the tobacco lords who re-exported their goods, West India merchants increasingly supplied the British demand for sugar and overseas demand for British manufactured goods. These merchants too, as a result, invested domestically in Clyde industry. The

223. T. M. Devine, "The Golden Age of Tobacco," in *Glasgow*, ed. T. M. Devine and Gordon Jackson (Manchester: Manchester University Press, 1995).

ventures they financed included sugar refineries in Greenock, just downriver from Glasgow, to add value to what they imported, as well as ironworks. In the last few years of the eighteenth century, they also funded the application of steam to textile milling, though for decades the city's mills still depended on the leading textile center of Manchester for its machinery.[224]

The Carron Company, for instance, one of the first and longest-lasting of Scottish ironfounders, depended on Glasgow merchants for its access to American and Caribbean markets. For the merchants, Carron specialized in items "which would not otherwise have been developed and which long remained important elements of the Company's output." Chief among these were iron parts for plantation sugar machinery, especially in demand as Glasgow merchants' interests moved, after 1776, to the West Indies. The company also made sugar-boiling pans, which were tested or "proved" using a cyclical process that echoed the heating and cooling to which the pan would be subjected when filled with cane juice from the mill: heating the finished iron object red hot, filling it with cold water, boiling it off, and filling with freezing water again.[225] Yet Carron's orders, writes Celina Fox in her recent work on industry and art, "came mainly through the recommendation of engineers," across Britain or even more distant. "The company itself disclaimed any specialised skill in design [and] was dependent on drawings to be able to

224. T. M. Devine, "An Eighteenth-Century Business Élite: Glasgow-West India Merchants, c. 1750-1815," *The Scottish Historical Review* 57, no. 163 (April 1, 1978): 40–67; R. H. Campbell, "The Making of the Industrial City," in *Glasgow*, ed. T. M. Devine and Gordon Jackson (Manchester: Manchester University Press, 1995).

225. R. H. Campbell, *Carron Company* (Edinburgh: Oliver and Boyd, 1961), 105.

produce the parts."[226] Carron was nervous, however, about supplying sugar plantations with cast-iron stills for rum, because they did not know the effect of the fermented sugarcane liquor, as opposed to the local whisky made from grain, on the iron itself, and the concomitant effect on the beverage. They had to be informed by an Edinburgh merchant and steam-engine designer that "there is some degree of acidity in Rum which acts upon the Iron, corrodes it and communicates an Iron colour to itself."[227]

Ex-Carron workmen also started the Falkirk Iron Works, which produced sugar pans as well, plus fountains bound for India, "tubular telegraph-posts for South America; grates, pots, and pans for the million," David Bremner wrote in his survey of Scottish industries in 1869. This wide array "testif[ied] alike to the wide connection of the firm and to the merit of Scottish workmanship." Yet such paeans to workmanship, as constituting Glasgow's global advantage, could be eulogies as well. Bremner wrote dismissively of the workmen themselves. He derided them as "little more than passive agents" who merely delegated their work to "ingeniously-constructed mechanism, which performs the work with unfailing accuracy and astonishing speed."[228] There was a tension between advertising to potential clients the virtues of Glasgow's handiwork, or the ways that its machines supposedly replicated the qualities of that handiwork, and effacing the fact that human hands did that work. Hence, Bremner also complained that trade unions, particularly the Amalgamated Society of Engineers that brought together millwrights,

226. Celina Fox, *The Arts of Industry in the Age of Enlightenment* (New Haven: London: Yale University Press for The Paul Mellon Centre for Studies in British Art, 2009), 98.

227. A century later, Carron's heavy foundry was still primarily supported by sales of open pans for sugar sales, but demand was collapsing. Campbell, *Carron*, 95, 214, 302.

228. Bremner, *Industries of Scotland* (1869), 48, 133.

smiths, and pattern makers as well as engineers, had robbed workmen of "a superior knowledge of the[ir] business." Of three hundred workers on a shop floor not one could be counted on to replace the organizational and comprehensive material know-how of the foreman.[229]

According to Robert Harvey, Jr., a leading sugar-machinery manufacturer at the turn of the twentieth century, the first steam-powered sugar mills produced in Glasgow were made by a Fife-born millwright named James Cook. As he built wind- and water-powered textile and grain mills, he was contracted by West India merchants to build equivalently-driven sugar mills for their clients.[230] In 1800, he proposed to one of these merchants that he attach a steam engine, and by 1805 he had so many orders that he was forced to move to a larger site on the south bank of the River Clyde.[231]

By 1820, Cook's were among the city's leading engineering workshops. So many of the city's engineers were trained there that it became known, Harvey recalled, as "The College." In the next half-century, through 1875, Glasgow's factories spread east from the center of the ever-more-crowded city. The winds of the city blow towards the east, so

229. Bremner was pleased that the defeat of ironmolders, in the lockout of 1868, had seen them accept employers' power over their own ability to set their work rules. Bremner, 134-135.

230. Despite Adam Smith's protests, by 1785, cotton, wool, and silk production equipment were banned from export, as were the tools for iron and steel. Mid-eighteenth-century restrictions on artisans' movement were repealed in 1824, but not those on machinery, though the Board of Trade was granted the power to issue export licenses. It was only the Select Committee on the Export of Machinery in 1841 that succeeded in repealing the laws. See Maxine Berg, *The Machinery Question and the Making of Political Economy, 1815-1848* (New York: Cambridge University Press, 1980), 205-206.

231. Robert Harvey, *Early Days of Engineering in Glasgow* (Glasgow: Aird & Coghill, Ltd., 1919), 8. In Harvey's telling, as with so many other industrialist hagiographies (a genre pioneered by Samuel Smiles), Cook triumphed over a doubtful chorus. "The works were of such an extensive character for those days that they were called Cook's Folly. James Cook knew it was a bit of an adventure; he therefore built the works in such a manner that he could convert them into dwelling houses, and had the fire-places, flues, and chimney heads all built in for the first and second floors, and also provision made in the walls for the beams to carry the second flooring. However, the business was a great success, and still further additions had to be made to the works." In such depictions of industrial genius, even hedging one's bets against failure represented a commendable moral virtue.

the city's affluent moved west, to the attractive wooded hills clustering above the River Kelvin, upwind of the effluent from the factories they owned.[232] But Cook's site anchored the growth of engineering works to the old city's south in the neighborhood that came to be known as Tradeston (**Figure 3.3**). Most of the city's sugar-engineering firms would eventually be sited here. In 1900, and indeed today, Cook's traces are still visible. Cook Street marks his workshop's southern boundary of the workshop, and the name of Commerce Street itself "commemorates the large shipping business done by Cook in exporting his sugar machinery." The street passed directly through the works.[233]

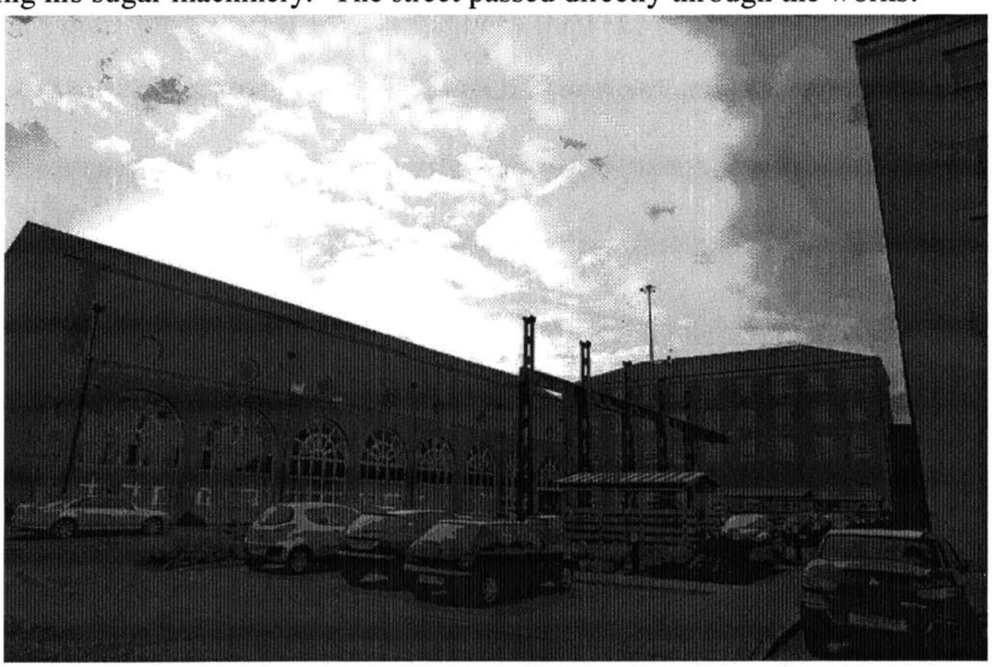

Figure 3.3: The only remaining sugar-engineering works structure in Glasgow is A. & W. Smith's Eglinton Engine Works, now converted into luxury condominiums. The developer has retained as color some of the works' own machinery.[234] (Photograph by the author)

232. Michael Pacione, *Glasgow: The Socio-spatial Development of the City, World Cities Series* (Chichester: J. Wiley, 1995), 75-77.

233. Harvey, "Early Days," 9.

234. John R. Hume, *The Industrial Archaeology of Glasgow* (Glasgow: Blackie, 1974), 244.

Cook was not the first to have tried to connect steam power to a sugar mill; in the late eighteenth century, steam-mill trials had been undertaken in Cuba, Jamaica, and elsewhere, but all had broken down or otherwise been judged unsuccessful. In particular, it was difficult to construct an efficient linkage between a steam engine and existing sugar mills, whose rollers were arranged and rotated around vertical axes.[235] But he appears to have been the first to do so in Glasgow.

Mirrlees and the other half-dozen firms that would come to dominate Glasgow's sugar-machinery business all began as joint ventures of a few partners, of whom some brought capital, others engineering expertise, and others familiarity with or connections to the West India merchant class. The uncle of James Buchanan Mirrlees, partner in what would become the city's largest firm, was a trader who retired in 1816 to live off his wealth. Partners' reputations, and those of their firms, depended on "long visits to the Carribean [sic] and Central America because of the business it would inevitably bring."[236] In the mid-1860s, the young engineer Duncan Stewart was offered the position of chief engineer by the owner of seven Demeraran estates.[237] He had recently started his own

235. John Daniels and Christian Daniels, "The Origin of the Sugarcane Roller Mill," *Technology and Culture* 29, no. 3 (July 1, 1988); María M Portuondo, "Plantation Factories: Science and Technology in Late Eighteenth-Century Cuba," *Technology and Culture* 44, no. 2 (2003): 231-257; Moreno Fraginals, *The Sugarmill*, 36.

236. Checkland and Slaven, *Dictionary of Scottish Business Biography*, 188-189.

237. The word "engineer" in Britain included those who acquired skills at working with metals and machines through praxis, and later, as well, those formally credentialed in academic engineering and members of professional disciplinary organizations. See Hobsbawm, *Industry and Empire*. In general much of the historical scholarship on British engineering as a profession—that is, on engineers, rather than machines—is focused on navigating this distinction, which is intimately related to the social, which is to say class, status of engineers themselves. Celina Fox writes, for instance, that drawings were meant to distinguish engineers from both the "dark trade secrets" of artisans as well as from "dilettante amateurs." But in doing so she presupposes a definition of professional. For university engineering in Glasgow see Ben Marsden, "Engineering Science in Glasgow: Economy, Efficiency and Measurement as Prime Movers in the Differentiation of an Academic Discipline," *The British Journal for the History of Science* 25, no. 3 (September 1, 1992): 319–346. Buchanan, in "Science and Engineering: A Case Study in British

London Road Ironworks. His calico-millwright father's former employers, the Crum family, were West Indian merchants in Glasgow, as were the Ewings who hired him.[238] Stewart accepted the appointment in order to "master the process of making sugar from the cane" to a greater extent than he could from visiting Scottish refineries. While there he made connections to some of the most powerful Spanish- and English-speaking factory owners as far away as Mexico, and, so his biographies claimed, thereby "placed himself in a position to contribute to the mechanical requirements of the respective establishments of his former employers."When he returned to Glasgow he brought "wider technical knowledge which proved to him of greater worth than the mere possession of capital."[239]

One of those planters' chief concerns, for instance, was to avoid what sugar-machinery treatises called "accidents." It was far less likely, with a steam-mill, that part of a slave or factory worker would get caught between the rollers, but Stewart set to work on hydraulic cylinders to prevent too damage when too much cane was fed into the sugar mills. His company's and his own reputation were built on a series of patents for these hydraulic rams, which would regulate the pressure applied to the rollers of a mill.[240] With fixed pressure settings, the roller's shaft or gudgeon might fracture. Stewart's devices

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Experience in the Mid-Nineteenth Century," chastises Isambard Kingdom Brunel and his generation for their "failure to provide for the sort of theoretical training which would be required for any successful engineering practice in the future." *Notes and Records of the Royal Society of London* 32, no. 2 (March, 1978): 215-223, on 221. For engineers' anxieties about class see also R. A. Buchanan, "Gentlemen Engineers: The Making of a Profession," *Victorian Studies* 26, no. 4 (Summer, 1983): 407-429.

238. Devine, "Eighteenth-Century Business Élite."

239. "The Implement and Machinery Review," September 1, 1886, in "Newspaper cuttings," TD185/5, Records of Messrs. Duncan Stewart & Co., Mitchell Library, Glasgow.

240. "The story of Duncan Stewarts, and their association with the British beet sugar industry," Address given by Mr. K. S. Arnold at the General Managers' Annual Conference of the British Sugar Corporation at Peterborough, 1st June 1955. UGD052/1/4/3, Records of Duncan Stewart & Co Ltd, UGA.

could apply a set load under normal circumstances, but they could also release the pressure if too many canes attempted to pass through the rollers at the same time. The resulting a catastrophic failure could have a serious impact on the output of a mill, and much of the correspondence between firms and their Caribbean agents was about these kinds of new rollers and shafts. Almost invariably, the reason given for the fears about roller breakages was what one treatise called "injudicious and unskilful feeding" on the part of the mill's workers. An "accident," in sugar parlance, therefore meant the breaking of a roller, not an injury to a worker. Stewart's patented hydraulics were called a "safety device" because they ensured the safety of the capital investment in machinery, not because they prevented a limb or worse from being milled.[241] To the planter and engineer, the sugar factory laborer's role usually became visible only when he erred, yet the description of problematic work as "injudicious and unskilful" implied that both judgment and skill were, ordinarily, necessary parts of the supposedly machinelike factory.[242] Eventually, Stewart's and other Glasgow firms produced crushers, a set of extra, grooved rollers positioned before the main mill, and chutes called cane-carriers, which funneled the canes to the rollers, that were designed precisely to regulate the flow of cane matter towards the powerful yet still-fragile rollers. The "technical knowledge" that Duncan Stewart brought back from his years overseas incorporated the whole complex of sugar production, human as well as mechanical.

241. A. J. Wallis-Tayler, *Sugar Machinery: A Descriptive Treatise Devoted to the Machinery and Processes Used in the Manufacture of Cane and Beet Sugars* (London: W. Rider and Sons, Ltd., 1895), 36.

242. Raphael Samuel noted that Victorian technical treatises omit the operators of machines. "Hammers rise and fall," he wrote, and "parts are jointed as if by an invisible hand." Raphael Samuel, "Workshop of the World: Steam Power and Hand Technology in mid-Victorian Britain," *History Workshop Journal* no. 3 (1977), 14.

By the latter decades of the century, boosters of Glasgow industry considered these links and voyages one of the chief advantages of the city's sugar firms, and advertised them as such. "By their long connection with the trade, and especially from the circumstance that principals of several of the firms engaged in it have travelled in the sugar-growing countries of both hemispheres, they have come face to face with the planters upon their estates, and acquired an exact acquaintance with their wants." It was these contacts that, it was argued, distinguished Glasgow's firms from all its rivals to the title of center of imperial engineering knowledge, chiefly London, Manchester, and Liverpool, but also Nottingham and Derby, where other major sugar-equipment manufacturers thrived.[243] Their success was a specific result of these interactions, and not just Glaswegian merchants' historical links to West Indian plantations. This was emphasized by John Mayer in his 1876 survey. "As it has for many years been made a sort of specialty," he wrote, the city's engineers had acquired "a degree of proficiency and technical skill in [sugar machinery] which cannot fail to be of prime importance to sugar planters; and as a rule, where the competitors meet on equal terms...competition is almost certain to terminate in favour of the Glasgow sugar engineers." Glasgow's longstanding mercantile connections to the Caribbean were essential, but only, it was claimed, because that tradition gave them the personal knowledge through which they could acquire knowledge about the supposedly new nature of the labor of sugar-making. Travel, witnessing, and personal experience, as opposed to inherited knowledge, were argued by

243. In Nottingham, Manlove & Alliot; in Derby, Fletcher.

sugar engineers to be foundational to that line of business in ways that distinguished it from others. The machinery business, "like the sugar plantations themselves...has been anxiously, intelligently, and enterprisingly cultivated."[244] What was true of the manufacturing of sugar machines was true of the making of sugar itself.

3. Traveling engineers, tracking machinery

The engineers who traveled back and forth between the Caribbean and Britain played crucial roles as go-betweens, mediating the relationship between sugar estates and the firms that manufactured their machines.[245] One engineer, who apprenticed with Duncan Stewart in 1876, immediately "began his life of wandering," which took him to the company's clients, in Argentina, Barbados, and Cuba, as well as international exhibitions similar to the Philadelphia centennial.[246] In the Cuban context, Jonathan Curry-Machado has recently explored the work and lives of the Britons and North Americans who traveled to the island in order to operate these new apparatus. Cheaper and faster oceanic travel meant these engineers could easily spend the grinding season supervising a factory in the Caribbean, and the rest of the year elsewhere, sometimes in

244. Mayer, Principal Manufactures, 116. For human intermediaries see Simon Schaffer et al., eds., *The Brokered World: Go-Betweens and Global Intelligence, 1770-1820* (Sagamore Beach, Mass.: Science History Publications, 2009).

245. For the entrepreneurial dispersal of British engineers overseas, though neglecting the kinds of networks that produced the movement of engineers in sugar, see R. A. Buchanan, "The Diaspora of British Engineering," *Technology and Culture* 27, no. 3 (July 1986): 501-524.

246. From the Beardmore News, November 1923, Records of Duncan Stewart & Co, Ltd., UGD052/1/4/2, UGA.

the cane fields of Louisiana, which harvested their cane on a different schedule, or in beet-sugar factories.

The increased speed and ease of overseas communication did not obviate the need for human contact. Planters came to rely on these engineers as crucial intermediaries between themselves and the firms from whom they wished to purchase new equipment. London purchasing agents were better placed to place orders, but these itinerant engineers were uniquely positioned to understand how sugar factories actually worked.[247] Many itinerant engineers found jobs as consultants for Glasgow firms while still working for one or more sugar estates, where an engineer could thus earn a commission for placing the order and then get the plum job of installing it. Those who tried to simply set up shop in Britain, however, frequently found themselves out of work.[248] Thus W. H. Ross, an ordering engineer for Cuban estates, traveled back and forth between Havana and Lanark.[249]

These processes held true elsewhere as well. In 1883 the Manchester merchants N. P. Nathan's & Sons paid the firm of Duncan Stewart £7304 for a full sugar production arrangement, to be shipped to an estate in the Canary Islands. According to the company's surviving cost-price book, that price included everything they needed for a factory: a horizontal engine with double gearing, a sugar mill with hydraulics, a fifty-foot cane carrier, clarifiers, filter presses, a triple-effect evaporator, vacuum pan, four centrifugals, and molasses tanks, plus piping, mounting, staging, spares, and tools for

247. Curry-Machado, *Cuban Sugar Industry*, chapter 3.
248. Ibid., 87-90.
249. Job No. 386, Mirrlees Watson Order Book, UGD118/2/4/10, UGA.

erecting, all of which cost the firm £6649 plus seven pence. Labor appears to have been folded into the cost of each individual item. The firm's profit on the order therefore amounted to a hair under ten percent.[250]

Robert Gilbert, one of the firm's engineers, went along to supervise. Although he traveled as its official eyes and hands, Gilbert was legally an independent contractor. In November of 1883, he signed a contract directly with Nathan's; the clerk and manager at the Duncan Stewart works were present only as witnesses. Once in Las Palinas "or any other place in the Canary Islands," Gilbert was responsible for the machinery once it arrived, including its unloading from the ship. The main task for which he had been hired, at £5 a week plus "suitable Board and Lodging," was to supervise "the erection of and fitting and putting into working order, of Cane Crushing and Evaporating Machinery." That became his job for the next several years.

The process of erecting such machinery was not simple, and it had to take place in the same way twice: once in Glasgow, and once in the sugar factory itself. After the parts had been produced in the works, the entire machine was assembled next door in the erecting shop, and tested in action insofar as was possible, before disassembly, packing, and shipment. Particular "erecting tracings" were sent to be sent along with the engineer in charge of reassembly.[251] Photography provided further instruction, but also documentation of progress towards completion and insurance against future

250. Duncan Stewart Cost Book 1881-1901, page 18, UGD052/1/1/1, UGA.

251. Unfortunately, the archives of the University of Glasgow do not contain erecting tracings sent abroad with the equipment themselves (it is hard to imagine why such tracings would have been returned). I was not able to locate any in Puerto Rico, but on further archival visits to Puerto Rico, Cuba, and Hawaii in the near future, locating the outbound communications of Glasgow firms will be a priority.

nonpayment.[252] Such progress photographs served, on the one hand, to communicate to customers the status of their long-awaited orders, and on the other, to protect the firm against later complaints by those customers. When complete, the erected assembly was photographed, and copies sent along to the installation site to be given as instructions for proper assembly to the engineer responsible for recreating it **(Figure 3.4)**.[253] Once erected in place on a factory, photographs of a firm's installations could, of course, serve publicity purposes elsewhere as well. "The photographs which we have reproduced in this book are largely of installations made for the island of Cuba, and of the most modern type," wrote the specialist centrifugal firm of Watson, Laidlaw & Co. in one of their early-twentieth-century catalogs, sent to a central factory in Puerto Rico. "It is our system to send a photograph of the installation [i.e., the machine, rather than the activity] of centrifugals to the planters who order from us, so that they may serve to guide their erection on the plantation, and, at the same time, so that it may be seen that we have erected and tested them in our works as is our usual practice."[254] Especially in the twentieth century, when competitors in the United States benefited from mutual tariff reductions between Washington and Havana, Glasgow's firms needed to assert and reassert their reliability as suppliers.

252. It is not clear when firms began using progress photographs; Volume 1 of A. & W. Smith's photograph albums is dated 1907. UGD118/1/5/1, UGA.

253. Moss and Hume, *Workshop of the British Empire*, 163-164.

254. My translation: "Las fotografías que reproducimos en este libro son en su mayoría de instalaciones hechas para la isla de Cuba y de los tipos más modernos. Tenemos por sistema mandar á los hacendados una fotografía de la instalación de las centrífugos que nos ordenan, para que sirva de guia al armarlas en la finca, y al mismo tiempo se vea que las hemos armado y probado en nuestros talleres según es nuestra costumbre." Watson, Laidlaw, & Co. catalog, "Centrifugas", in Colección Central Mercedita, caja "Católogos Comerciales 1920s-1940s," AGPR.

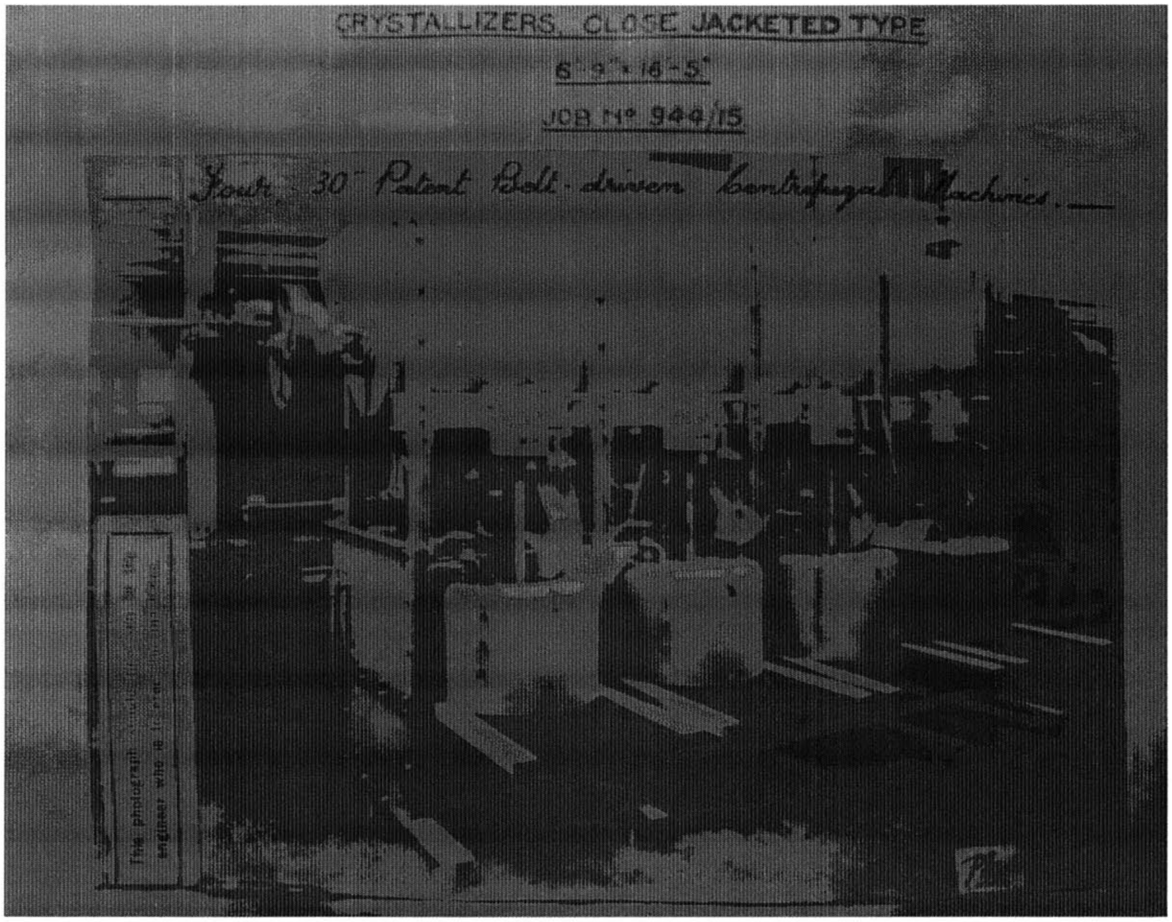

Figure 3.4: A. & W. Smith centrifugals, 1915, with note affixed: "this photograph should be given to the engineer who is to erect the machines." (UGD118/1/5/1)

The terms of Gilbert's contract as a traveling erecting engineer emphasize the difficulty of the task at hand. While he was to obey orders from Nathan's, their manager in the Canaries, or their attorneys, Gilbert was also obliged to "devote his whole time and attention to and employ his whole art and skill in the said erection and fitting up of the said machinery, and in getting the same in to proper and satisfactory working order."[255] Yet Gilbert could not, while he was on site, rely on quick or frequent communication with

255. Copy minute of agreement between N P Nathan's Sons and Robert Gilbert (Nov. 1883)—Forbes and Bryson, writers, Glasgow, UGD052/1/7/2, UGA.

those who had designed the machines. At the same time, his suppliers and erstwhile employers at Duncan Stewart themselves were stifled in their efforts to understand what was going on. Gilbert was still in the Canaries in July 1884 and the personnel of Duncan Stewart were not even sure of how the work was getting on. In his letter early that month, the manager of the works in Glasgow asked Gilbert to "kindly write to us on receipt of this and let us know when you expect to come home." Their ignorance of his status had begun to rankle; moreover, they wanted him back in Glasgow because he was needed on another mission to Brazil, accompanying "a large Sugar Plant which will be ready for shipment early next month."[256] But in mid-September he was still in the Canaries and still waiting for necessary parts. The sugar factory was still not finished. "We have sent as much of the details as you have ordered...as we possibly could in the short time they gave us before the ship sailed." But the company was still pleading for information from him, too, and for updates on the status of the construction.[257] In May 1885, a year and a half after he had left, Gilbert was still there, and still needed parts. These had at last shipped from Liverpool, just in time to be installed for the next grinding season. "We hope therefore all will reach you in good time so that you may be able to start the factory to [crush] the greater part of the crop satisfactorily," the firm wrote him. Contracted erecting engineers sent as agents of a firm did not necessarily keep their principals apprised of their activities. Despite the delays and frustration, however, an engineer's presence could serve a firm's interests in other ways. During Gilbert's time in the Canaries he had been

256. Letter, 7 July 1884, from David H. Andrew, UGD052/1/7/4, UGA.
257. Letter, 15 September 1884, to Arucas, Canary Islands, UGD052 1/7/5, UGA.

in contact with other planters and was on the verge of securing orders for two further factories. By this point, though, the relationship may perhaps have been more cordial, as the letter was signed not by the works manager, whom Gilbert knew, but by an anonymous representative of the firm as a whole.[258]

Company order books from the 1840s and 1850s show how plantation owners rarely ordered more than one or at most two mill-and-steam engine combinations at the same time. Milling equipment was a capital expense plantations hoped to undertake only once or twice a century. The phenomenal cost and mass of these machines also shaped the strategy of both sugar plantation and engineering firm. Once emplaced in the mill, such a machine was extremely difficult to move. And planters had good reasons to keep them in good working order. If properly maintained and repaired, a mill and its steam engine might still compete with a new product fifty years later in its ability to efficiently extract juice.[259]

The bulk of the work of the engineering firms, therefore, was not on new machines but on extensions, additions, and repairs to old ones. In the absence of reliable information about which of their products survived, heavy engineering firms were reluctant to part with paper plans.[260] They were essential to providing timely and accurate repairs. "To request spare parts it is sufficient to give us the number of the centrifuge, which is inscribed in the vertical axis of each one," wrote the specialized centrifuge firm of Watson, Laidlaw & Co. in a brochure sent to the Spanish Caribbean in the nineteen-

258. Letter 21 May 1885 to Arucas, Canary Islands, UGD052/1/7/6, UGA.
259. Sugar Department Letterbooks, Mirrlees Watson & Co., UGD062 1/3/1, UGA.
260. Moss and Hume, *Workshop of the British Empire*, 162.

twenties and retained by a Puerto Rican central. "We hold designs and plans of every centrifugal made by us, from the beginning of our firm in 1870 until the present, in order to be able to respond to any request for spares."[261] Yet, on the same page, they also suggested that their products were sufficiently interchangeable, and that they could "always maintain a large stock of the most important spare parts for centrifugals of various sizes," just in case they needed to respond to urgent requests for spares during the grinding season. They suggested, surely accidentally, that this consistency and interchangeability of their products was related to the scale of their market and the pressures of filling all the orders they were receiving: "Due to a large number of orders, we have recently had to double our works' capacity to erect the most modern equipment, so that we can permit ourselves to fill orders as rapidly and as perfectly as possible."[262]

Moreover, engineering firms made it their business to know the fate of their machines many decades after they had been originally manufactured, in order to be able to fulfill requests for repairs. The annotations in the margins of the Mirrlees Watson mill order book, above, record not just the kind of information they wanted, but also the process by which they acquired it **(Figure 3.5)**.[263]

261. "Tenemos diseños y plantillas de todas la centrífugas fabricadas por nosotros desde la fundación de nuestra casa en 1870 hasta la fecha, así que podemos atender á cualquier pedido de repuestos." Watson, Laidlaw, & Co. catalog, "Centrifugas", in Colección Central Mercedita, caja "Católogos Comerciales 1920s-1940s," AGPR.

262. "Debido al gran número de órdenes, hemos tenido que duplicar ultimamente la capacidad de nuestros talleres instalando maquinaria la más moderna que nos permite ejecutar las órdenes con la mayor rapidez y perfección posible." Watson, Laidlaw, & Co. catalog, "Centrifugas", in Colección Central Mercedita, caja "Católogos Comerciales 1920s-1940s," AGPR.

263. Mirrlees Watson Mills and Krajewskis Book no. 1 1841-1912 and no. 2 1883-1964, UGD118/2/4/37 and /2/4/38, UGA.

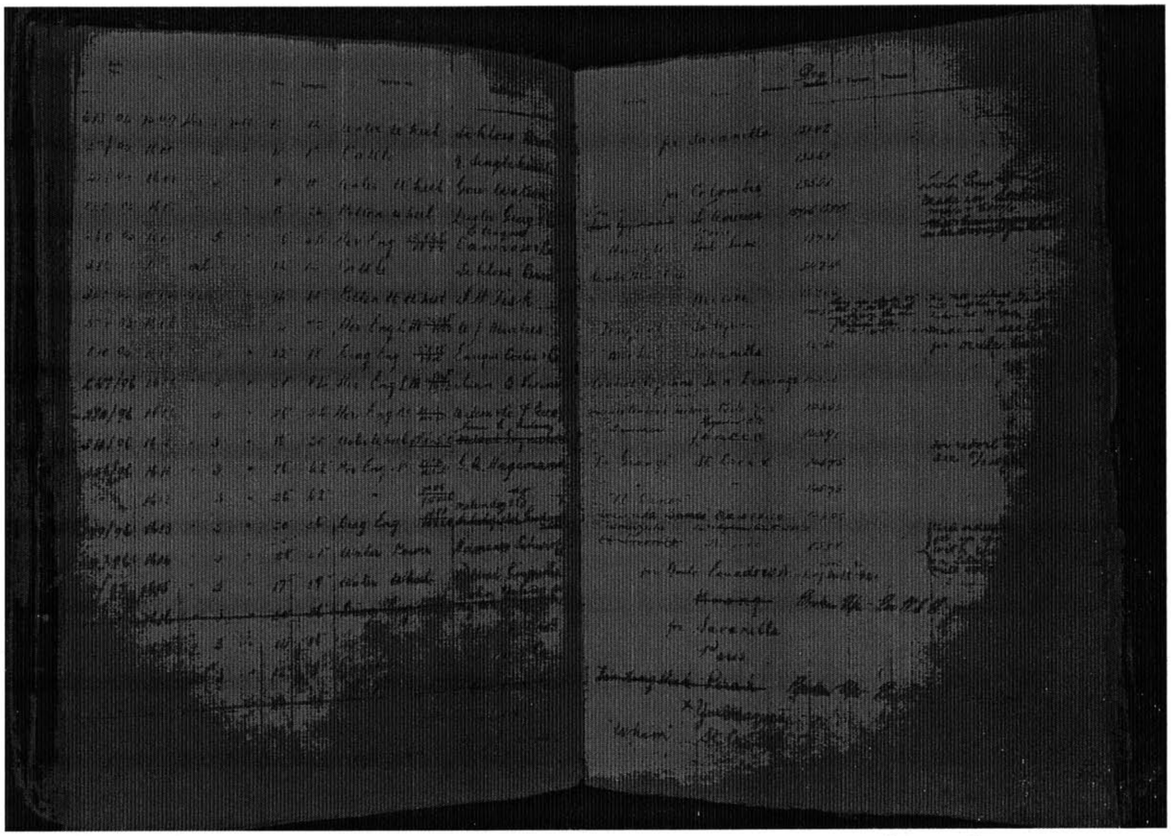

Figure 3.5: Mirrlees Watson mill order book, showing annotations where new information was received. (UGD118/2/4/37)

For example, Mill No. 360, a horizontal mill driven by Engine No. 281, was originally purchased for the Caledonia estate in Cuba in March of 1859. It was recorded in the margin that in 1886 the mill was transferred to San Isidro. The employee who recorded the movement of the unit also noted the number of the letter by which the information had arrived: 9367 of 1904, fifty-five years after the machines were first bought, though the letter itself no longer survives. Mill No. 449 was a horizontal mill sent, with Engine No. 365, to the Armonia estate in Cuba in June 1861. In 1903, the company received word that the mill unit had been transferred to La Reglita on the same island. But the next year, they received conflicting information: perhaps it was only the engine that had been moved. Other entries note the company's own modifications, like the one for Mill 723: built in 1869 for Demerara as a three- or four-roller mill, it was expanded in 1889 to five rollers, "reverted" to three rollers some years later, and was finally sold to Bradford estate.[264]

Examining individual cases can demonstrate how fragile these edifices of knowledge really were. In December of 1857 the Cuban owner of a plantation called Soledad had purchased a 30"x84" mill from Mirrlees Watson, number 257, with engine number 211. Mill number 445, purchased in June of 1861 for the San Antonio estate, was transferred to Soledad at some indeterminate point. In 1882, Edwin Atkins, a Boston merchant, came into possession of Soledad by foreclosure. When he took possession of the property he found its Mirrlees apparatus to be older than he wanted. His new mill had significantly larger rollers—thirty-eight inches in diameter, the largest that Mirrlees then fabricated. "[W]e replaced it with more modern machinery," he recalled, but "it was still in good condition and we sold it to another estate."[265] The property of the estate when Atkins took it over also included mill 1406, which Mirrlees had just shipped there in February 1883. But it might take Mirrlees Watson years to find out about activity in this secondary market, despite yearly contact between Atkins and Mirrlees's agent. In fact they might never find out. The last time the books record Mills 257 and 445, for example, they are at Soledad. If Atkins sold them, the engineering firm never knew. Mill 1406,

264. Ibid.
265. Atkins, *Sixty Years*, 93.

purchased in February 1883, was definitely sold: to Central Rey, according the annotation in the margins. But either this was a much later sale, or else Mirrlees heard the news four decades late. The information was taken from letter 6223, sent from the firm's Cuban agent, in 1929.[266]

More than just which plantation owned which mill, the Glaswegian firms sought to know how their apparatus were being fitted together. Number 1745, ordered in 1907 through the ubiquitous purchasing agent Victor Mendoza, was a standard 3-roller unit, "making with mills 1405, 1712 & 1713 a 12-roller train" at Central Mercedita in Cuba. Knowing the position of the unit in the "train" was essential to predicting its wear and the pressures it was subjected to as the passing cane was gradually pulped. They cared about how their engines and mills interfaced. Mill 1326, made in 1882 for Dos Hermanos in Cuba, according to "Mr. Gaskell's Estate Report" of 1909, was "driven by new engine 1820 (26x45) & gearing," an engine which had been delivered in 1892 with mill 1555. Mill 1555, meanwhile, was now being turned by the earlier engine, 1336. This mattered because the earlier engine's rollers were both longer and wider than the newer ones, and thus subjected to different pressures and volumes of cane, and therefore had different patterns of wear, demanded different amounts of power, and had different projected lives.

In many cases, sugar factories were agglomerations of machines from not just different vintages but different companies. It was the rare factory that had the wherewithal to replace its production line at the same time. Mirrlees's number 1503, as a

266. Mirrlees Watson Mill & Krajewskis Book no. 2, UGD118/2/4/38, UGA.

water wheel-powered mill ordered in 1889 for a Mexican factory called Raboso, was unusual in the first place. According to a letter of 1922, however, the mill was at that point "working with a Fawcett Preston mill of same size," built by that engineering firm in Liverpool, driven and geared by a Fawcett engine, "and preceded by a crusher made by D. Stewart & Co."

An engineer in Puerto Rico, at the end of the 1864 sugar season, sent Mirrlees Tait a request for two new mill cheeks on behalf of the estate of Señors Patxot and Polidura in Mayaguez, "as they have split the two this last crop across by the centre brass." He told them where to look in their own books. "Knowing that *you have always your plans and models of the machines at hand in case any accident such as above should happen*, for that reason I only send you the number of mill 374, and year 1859, thinking that is quite enough." He merely felt the need to attach a "small sketch" to show where the original pieces had failed. But he also wanted to make sure that the new cheek would be identical in crucial respects, "finished so that the same brasses will suit when necessary." A few weeks later they received another letter on the same subject. A different correspondent identified the estate as "Ysabel for which you have executed before this several orders." He was not the plantation's own engineer, but had "been told" that plates of wrought iron were used to strengthen the cheeks in typical fracture points. "Should you consider advisable to adopt [sic] the plates Messrs. Patxot & Polidura beg you will adopt them for their order."[267] According to the company's books the mill was still being driven by a water wheel, and they had produced a greater-than-usual number of drawings for it.[268]

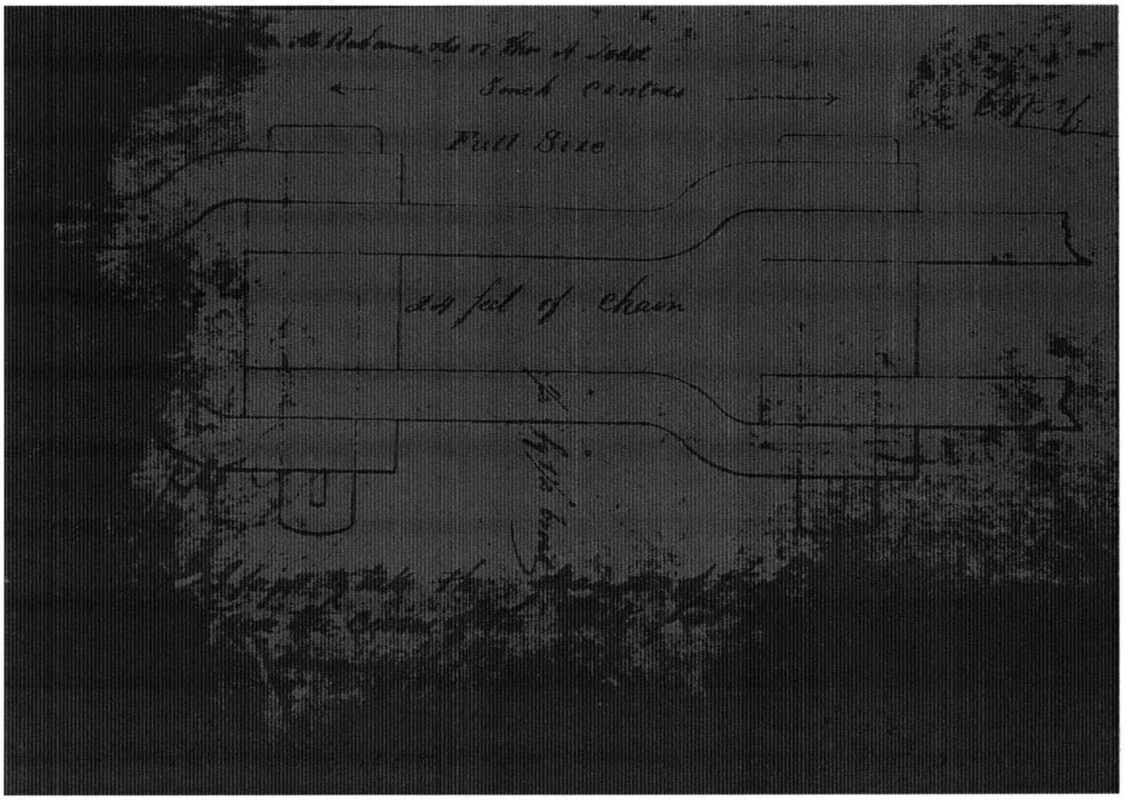

Figure 3.6: Full-scale drawing of chain links for Estate Florida, sent to Glasgow by Thomas Dodd in Puerto Rico (UGD202/1555)

The engineer Thomas Dodd, writing for Estate Florida near Ponce, on the southern coast of Puerto Rico, enclosed a drawing of the links of a driving chain of which he needed twenty-four feet. "I forgot to take the diameter of the pitch wheels to give the curve of the links," he wrote, "but you will have it in your dimension Books" (**Figure 3.6**).[269] Dodd's relationship with Mirrlees lasted decades; he still ordered from the company in 1891.[270]

267. Drawing from C. A. Hasche in Mayaguez, dated 8 July 1864,, UGD202/2430, UGA.
268. UGD118/2/4/37. See also Descriptive Drawings Index, "Horizontal Sugar Mills," p. 502, UGD118/2/7/12, UGA.
269. Chain link drawing from Thomas Dodd, 16 September 1859, UGD202/1555, UGA.
270. Mirrlees Order Book, 1891, Job no. 304, UGD118/2/4/10, UGA.

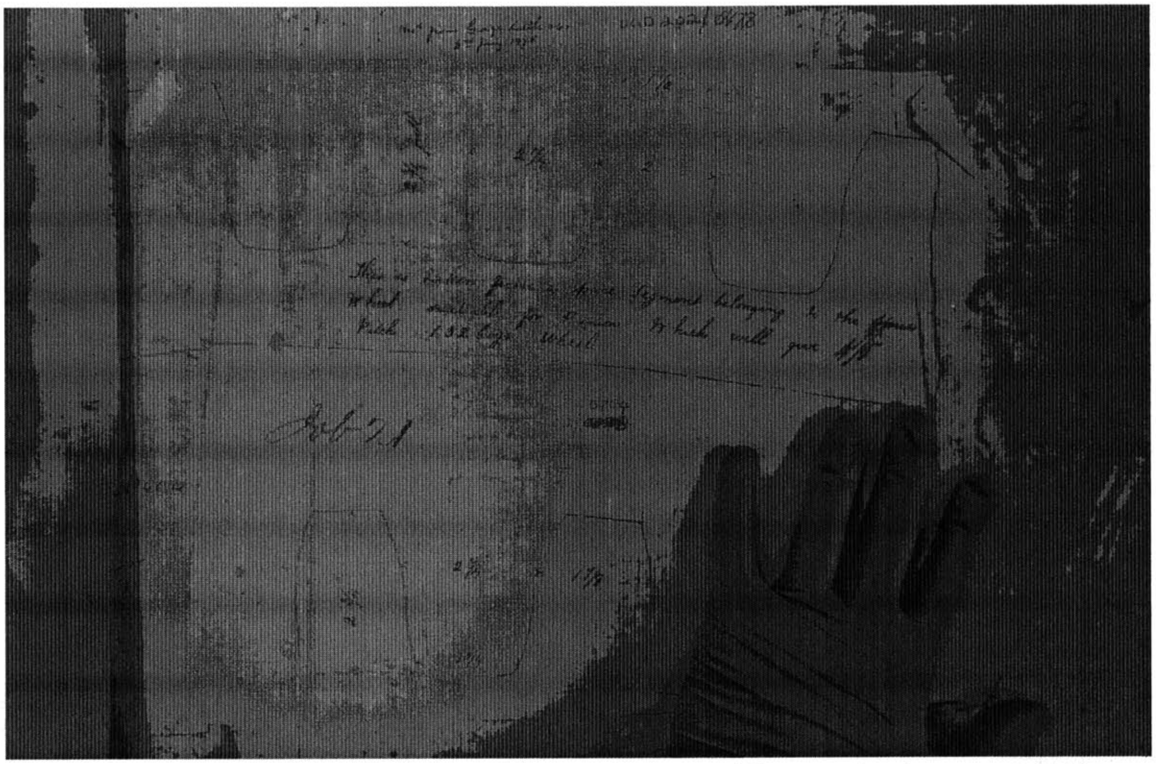
Figure 3.7: Full-size tracing of gear teeth of a sugar mill spur wheel sent to Mirrlees Watson, with hand for scale (UGD 202/0704)

In their elliptical references to the firm's practices of record-keeping, these engineers were also, in some ways, testing Mirrlees's reliability as a manufacturer and credibility as a supplier of spare and replacement parts across great lengths of time and space **(Figure 3.7)**.

4. Plans and designs

The exchange of drawings and tracings was the medium by which firms maintained their relationships with overseas clients. In 1838, the failed locomotive engineer Peter McOnie wrote to a friend in the West Indies seeking work on an estate. He was advised to set up a repair shop in Scotland instead.[271] When this friend needed spares for his Cook-made mill, he needed to have "sent home such complete sketches with all sizes carefully marked" before McOnie could produce working patterns for the forge.[272] Later, when the plantation needed a new mill, the friend "made careful drawings of the set he required and sent them home to McOnie, who started at once to make working drawings from the sketches." The estate's owners were skeptical of McOnie's ability to complete the order, and only signed the deal "on Mr. McOnie explaining that he had working drawings already made to sketches from D. Cook's engine and sugar mill in Trinidad."[273]

Drawing sugar machines required knowledge that was particular even within the world of engineers world. The story of Robert Harvey encapsulates the way that draftsmen could be powerful figures in a sugar engineering firm. Harvey had begun as a 6-foot-2-inch, 220-pound iron turner in the works of James Cook, and his lathe was so productive that it made him Cook's best-paid employee. He was working sixty hours a week for 21 shillings when, in the late 1830s, the sole draftsman of the works departed. Harvey was a talented artist, around whom his fellow workmen had formed a subscription club for portraits, and he asked for and received a trial as draftsman, though it entailed a pay cut of 1s. per week. After serving twelve months as draftsman, he asked for a raise, just enough to return to his previous salary. But David Cook, James Cook's

271. Moss and Hume, 31.

272. Harvey, Robert, "The history of the sugar machinery industry in Glasgow," *International Sugar Journal* 19 (1917): 57-61, 112-117, on 112.

273. Harvey, "History of the sugar machinery industry," 113. Emphasis added.

(unrelated) manager, who had entered into a new partnership after his employer's death, refused. As Harvey's son later related, David Cook had "never paid more than 20s. per week for a draughtsman, and he was not going to do so now." So Harvey left for a competing foundry, which promised him a 50% raise.

Harvey's experience also is the prime example of the way that expertise in sugar-machine drawings was distinct from more general engineering draftsmanship. He was hired by the Neilson general engineering works, which had received an order for an engine and mill from Cuba. But the works manager, William Tait, told Neilson that he could build a locomotive but not a sugar mill, even from scaled-up patterns, "as it was all strange to him."[274] So Neilson sought out Harvey—as a draftsman and turner—to advise his works manager. That conveyed expertise, in turn, later brought Tait into business with James Mirrlees in the largest and longest-lasting of the Glasgow sugar partnerships. Harvey wound up returning in triumph to his old firm as managing partner in the 1850s. Though Harvey's case is clearly exceptional, a sugar draftsman's skill was clearly prized, and he could sometimes retire a wealthy man.

In the late 1830s, when Harvey's predecessor as draftsman in Cook's business had quit, "there were no drawing classes [so] no one could be found to take his place."[275] Self-trained draftsmen assembled techniques from many exemplars and sources, from drawing manuals to magazines. A decade or so later, however, the evening classes that Harvey began to teach were among an increasing number of such courses at Anderson's and the

274. Ibid., 59.
275. Harvey, "Early Days," 11.

Mechanic's Institutes. The demand testified to the attraction of the potentially more "gentlemanly" nature of draftsman's occupation than that of even skilled factory work—as, indeed, did Harvey's willingness to take a pay cut.[276] At the same time, however, the professionalizing elements among British engineers hoped to make draftsmen into "invisible technicians" of engineering workshops.[277]

When he began work as a draftsman Harvey also began to teach mechanical drawing to supplement his income: first at home in the evenings, then in the Mechanics' Institute, and at the Government School of Design, which later became the Glasgow School of Art.[278] The Mechanics' Institute had split in the 1820s from Anderson's Institution, created by the 1796 will of a late, irate Glasgow professor of natural philosophy. Anderson's, the model for the Royal Institution in London, offered both intensive and "popular" courses to a target audience of "young gentlemen designed for manufactures or commerce, who are too often sent from the grammar school to the counting house, without acquiring that knowledge which will...enable him [sic] to make those improvements in his business he would do, if acquainted with the principles on which his different operations depend."[279]

276. Peter Jeffrey Booker, *A History of Engineering Drawing* (London: Chatto & Windus, 1963), 134.

277. See Steven Shapin, "The Invisible Technician," *American Scientist* 77, no. 6 (November 1, 1989): 554–563, and Larry Stewart, "Assistants to Enlightenment: William Lewis, Alexander Chisholm and Invisible Technicians in the Industrial Revolution," *Notes and Records of the Royal Society of London* 62, no. 1 (March 20, 2008): 17–29.

278. Harvey, "Early Days," 11.

279. George Emmerson, *Engineering Education: A Social History* (Newton Abbot, England: David Charles, 1973), 91-100, 184-5. Steven Shapin and Barry Barnes argued that these institutions' courses of instruction, in natural philosophy and other scientific pursuits, were tools of socio-industrial discipline. Such education, their backers expected, would render workers and artisans, individually and as a class, "more docile, less troublesome, and more accepting of the emerging structure of industrial society." Anderson's soon began offering lectures to the city's "craftsmen" as well, first for free and then for five shillings. Shapin and Barnes suggest it is misleading to think they were oriented at the "working class" as a

Harvey's classes were part of a broader reconfiguration of the labor and status of mechanical drawing in British industry in the early nineteenth century. At the same time, the relationship between the production of drawings and the production of finished metal goods was also being altered, part of a nineteenth-century struggle between those who performed the "artisan coordination" that defined the work of large-scale construction and design, and those who wanted to calculate and thereby control it.[280] Bruno Latour has famously argued for the concept of "immutable mobiles": drawings or other inscriptions that are not purely verbal and thereby acquire the power to project knowledge at long ranges, unmolested by its changed circumstances.[281] Likewise, Celina Fox, for instance,

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whole, rather than targeted specifically at the famous "labor aristocracy", those craftsmen or mechanics who were thought to possess sufficient moral and intellectual characters worthy of education. Steven Shapin and Barry Barnes, "Science, Nature, and Control: Interpreting Mechanics' Institutes," *Social Studies of Science* 7 (1977), 31-74. By contrast, Maxine Berg argued that such institutes sought to create an "ingenious artisan," one who was nonetheless compatible with flexible labor forces and new hierarchies of skilled labor. The founders of such institutes hoped for workmen "imbued with creative and innovative instincts," but the rhetoric of "persons from who little beyond ordinary handicrafts would have been expected" does not dispel the already-extant disdain for "mere" craft. Berg, *Machinery Question*, 147-155.

280. First and most notoriously waged in the royal naval yards during the Napoleonic wars, these struggles produced the rhetorical battles between science and art, customary practice on the one hand and experiment on the other. See Simon Schaffer, "'The Charter'd Thames': Naval Architecture and Experimental Spaces in Georgian Britain," in *The Mindful Hand: Inquiry and Invention from the Late Renaissance to Early Industrialisation*, ed. Lissa Roberts, Simon Schaffer, and Peter Dear (Amsterdam: Koninkliijke Nederlandse Akademie van Wetenschappen, 2007), 279–305, on 288. Self-styled reformers advocated experimental trials and insisted on the superiority of formal mathematical theory. The goal was to replace the informal ingenuity and "artisan coordination" that defined the way that ships and other pieces of high technology were built. Ashworth, "System of Terror."

281. Latour, *Science in Action*, 227; Bruno Latour, "Visuaization and Cognition: Drawing Things Together," *Knowledge and Society: Studies in the Sociology of Culture and Present* 6 (1986): 1–40. For the important ways in which mobiles are in fact mutable, and the ways those mutabilities shape the disciplines that depend on them, see David Kaiser, *Drawing Theories Apart: The Dispersion of Feynman Diagrams in Postwar Physics* (Chicago: University of Chicago Press, 2005). For the rituals of inscription, see Simon Schaffer, "'On Seeing Me Write': Inscription Devices in the South Seas," *Representations* no. 97 (Winter 2007), esp. 92-93. More radically, the anthropologist Matthew Hull, in his book *Government of Paper: The Materiality of Bureaucracy in Urban Pakistan* (Berkeley: University of California Press, 2012), points out that, contra Latour, "the producer of graphic artifacts may have much less control over her text than a speaker." A speaker much more firmly controls the context of the speech and the audience, despite the ability to record and disseminate, while the author of a document faces the fact that its "perdurance...affords more radical recontextualizations and allows them, in Latour's terms, to translate a wider array of interests than that allowed by speech" (24).

argues that the increasing sophistication of engineers' drawings "exuded an air of authority yet [?] were grounded in reality," and therefore "reconciled clients, guided progress, secured co-operation, settled disputes and forestalled mistakes."[282] Within the industrial engineering workplace, art historians of drawing have argued that mechanical drawings had a disciplinary, almost panoptic power, regulating the behavior of those charged with enacting their dictates. But supposed power of technical drawing to compel or indoctrinate workers was not a power inherent to images themselves.[283] Instead, the Glasgow School of Art historian Frances Robertson has analyzed the rhetorical role of drawing among Glasgow's nineteenth-century engineering firms. In establishing relationships with their customers, she writes, "the claim to be able to reliably execute known geometrical forms in the real world" was a marketable asset. Control over the shapes of parts meant tighter tolerances and higher efficiency. "Superhumanly neat inscriptions on paper functioned as a promise to deliver the goods in the material world."[284]

Robertson argues that, in a technical drawing, "a ruled line is a command to produce a straight edge or flat plane surface" in more permanent materials. Yet if this was the message to potential clients, then firms themselves recognized that the simplest forms

282. Fox, *Arts of Industry*, 48, 132.

283. As Frances Robertson writes, it is problematic that "we are asked to believe in shadowy but all-powerful forces coercing passive workers, where the activity 'drawing' is given an agency denied to its hapless minions." Robertson, "Manufacturing the visual economy in nineteenth century Britain," International Society for Cultural History, Luneville 2012, 2-5 July, shared privately with the author. The architect and propagandist of machinofacture himself, Charles Babbage, learned the hard way that drawings required the interpretation of a specially knowledgeable craftsman. Babbage wanted drawings that, in so minutely defining his desires, would enable him to leave the workshop, but found that no such drawings could be made. See Schaffer, "Babbage's Intelligence."

284. Robertson, "Delineating a rational profession: engineers and draughtsmen as 'visual technicians' in early nineteenth century Britain" (3 Societies Meeting, Philadelphia, July 11-14, 2012)

on paper, like a straight edge, could be the trickiest to execute in less compliant materials. Of his father's work in James Cook's sugar-mill works the early decades of the century, the junior Robert Harvey recalled that "The flat surfaces of the various parts of engines or other machinery which had to be made fair and straight, were all done by hand chipping and filing, and [firms] selected good men from the joiner and mason trades, until they had young men trained as apprentices for the work."[285] Hand work had been prized, and visitors to the machines in 1876 had commented on its absence, for good reason. Fitters could reportedly file a surface so smooth that one piece of wrought iron would cling to another merely "by the force of molecular attraction, as if glued to it."[286]

Between paper and iron, the crucial intermediaries in foundries were the patternmakers.[287] They were responsible for translating draftsmen's exterior designs into wooden forms that incorporated understandings not just of the wood from which they were made, but of the fluidity of the sand molds they were supposed to shape, and the heat shrinkage of the metal objects that the process was ultimately intended to create. In constructing a pattern, from multiple cross-grained layers of glued wood, the maker had to consider how useful the pattern might be in the future, and build it accordingly: cheaply to be discarded, or solidly to last, with layers of shellac to protect it from moisture warpage and precisely designed joints which would not alter with age. In addition to predicting the interactions of materials with each other they had to understand

285. Harvey, "Early Days," 11.
286. Samuel, *Workshop of the World*, 41.
287. Sarah Fayen Scarlett, "The Craft of Industrial Patternmaking," *The Journal of Modern Craft* 4 (2011): 27-48.

the workings of others within their factory. Molders had idiosyncratic ways of removing patterns and machinists had to remove rough edges from the mold. Patterns were embodiments of time and skill, a company's key intellectual property.

In the nineteenth century both idealists and opponents of craft began to define it as creative, unlike the work machines performed. Yet craft, as Glenn Adamson argues, is fundamentally imitative. Conversely, imitation demands immense craftsmanship. In the eighteenth and early nineteenth century, however, "variation from a norm was seen as a mark of poor quality, not human affect." Creating an exact copy of an existing object or drawing is both an act of craft and also, crucially, was always part of the craftsman's training, from apprenticeships to mastery. Drawings often depicted only one half of an object and left it to shop know-how to fill in the symmetric remainder. In the production of machinery, the patterning and prototyping stages were intensely copy-heavy. Patterns had to be made of wood from drawings or existing pieces, after which the model was made into a negative mold for the part.[288] "Workmen were often left to mark out the job and settle the details of machining operations themselves," writes the economic and labor historian Jonathan Zeitlin. "Manual skills and long experience were also needed to produce reliable castings from wooden patterns, and hand labor played an extensive part in fitting and erecting the final product."[289]

288. Adamson, *Invention of Craft*, chapter 3.

289. Charles F. Sabel and Jonathan Zeitlin, eds., "Between Flexibility and Mass Production: Strategic Ambiguity and Selective Adaptation in the British Engineering Industry, 1830-1914," in *World of Possibilities: Flexibility and Mass Production in Western Industrialization* (New York: Cambridge University Press, 1997), on 247.

A firm's patterns were its most crucial assets, even more than physical plants. When the firm descended from James Cook finally dissolved, the managing partner sold the works, but "bought all the patterns and drawings."[290] Duncan Stewart's patterns were made of Canadian yellow pine and new space continually had to be found to accommodate them.[291] In 1896, Mirrlees Watson had a three-story pattern shop that "communicates directly with the drawing office, as well as a separate four-story pattern storehouse that had been made fireproof.[292] The following year, insurance assessments of the firm of A. & W. Smith pegged the value of the patterns at £6,000. These were worth more than any other part of the works, including the erecting, boiler, and turning shops, and nearly one-fifth the value of the company's entire physical plant.[293] Nonetheless, patterns did not dictate the construction of sugar machines, as William Tait understood when he needed Neilson to bring in Harvey. Instead, engineering shop-floor workers had both the room and the need to figure out how to produce metal from drawings and patterns, and the cooperative and interlinked processes of design and construction meant that dimensions themselves might necessarily be left to the judgments of those working with the final material.[294]

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290. Harvey, "Early Days," 60-61.

291. Recollections of Mr. Adam Stirling, Messrs. Duncan Stewart (1902) Ltd., later Davy United, AGN 429, Mitchell Library, Glasgow.

292. "Mirrlees," *Engineering*, 534-5.

293. "Inventory and Valuation of Machinery Plant, and Tools at Eglinton Engine Works, Cook Street, Glasgow, made by Messrs John Turnbull Jr. & Sons, Consulting Engineers, 18 Blythswood Sq. Glasgow, 20th February 1897," UGD118,1/7/1, UGA.

294. David McGee, "From Craftsmanship to Draftsmanship: Naval Architecture and the Three Traditions of Early Modern Design," *Technology and Culture* 40, no. 2 (April 1, 1999): 209–236, 6.

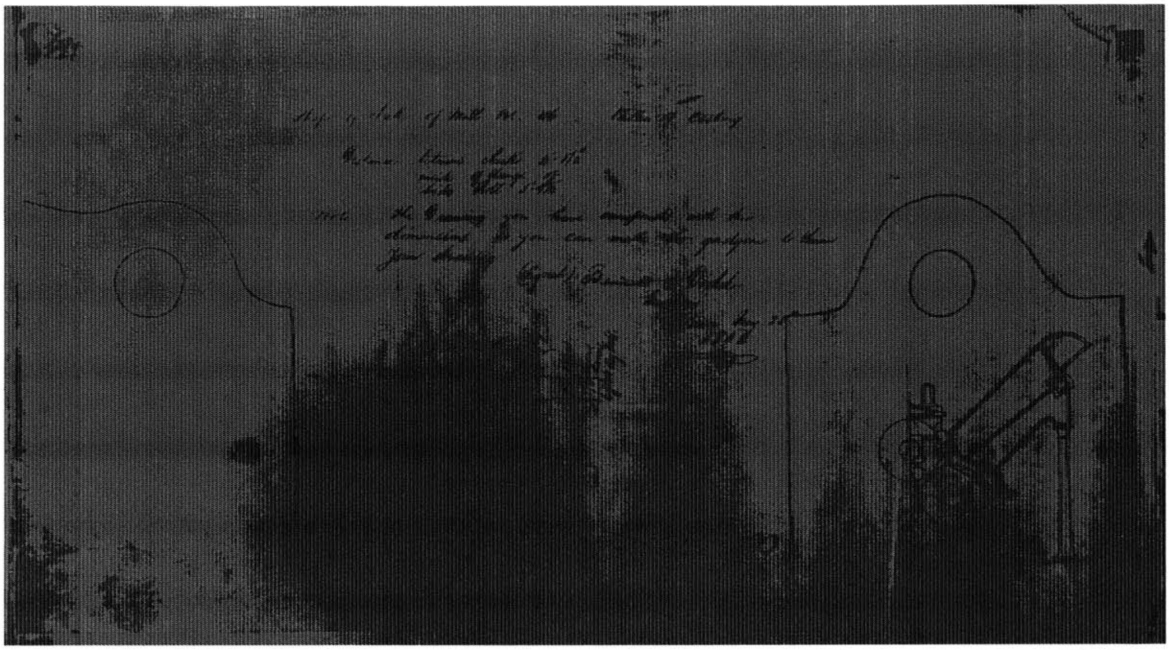


Figure 3.8: Sketch of mill cheeks sent by Robert Bennett and Thomas Dodd to Mirrlees Watson, 1862 (UGD202/1890)

The ability of a company to classify, store, retrieve, and reuse patterns was key to its fortunes. The Puerto Rico engineers Robert Bennett and Thomas Dodd sent many orders to the Mirrlees firm in the late 1850s and early 1860s. "As I am not exactly acquainted with your patterns" for juice clarifiers, wrote Bennett in 1857, "I have sent you a sketch of the position they are to be placed with regard to the engine and you can make any other alterations that may be required to fit your patterns."[295] They wrote again on the eve of the 1861 grinding season to order a new engine, cane carrier, and shafts for Estate Vista-Alegre. "Cane carrier sides to be fitted to your mill No. 116," but "if the patterns have been altered since [the mill was made] let us know & we will send you a sketch, as we have not had time to do so."[296] The next year they ordered new cheeks for

295. Drawing dated 24 June 1857, UGD202/0044, UGA.
296. Drawing dated 24 December 1861, UGD202/2148, UGA.

the mill, but seemed to trust the company's records less, sending them the "shape of cheek...taken of casting." They added that "the drawing you have corresponds with these dimensions so you can make the gudgeons [to] your drawing" **(Figure 3.8).**[297]

By the end of the nineteenth century, most reasonably-sized engineering firms, whether producing large custom items or mass-manufacturing consumer goods, boasted large drawing offices, which included individuals of differing skills, training, background, and status, including apprentices **(Figure 3.9).**[298] Some were themselves designers of machinery, while others worked to translate those designs into practicably-manufacturable shapes. Still others were tasked with producing fine images for customers and publication. The offices therefore produced both presentation materials, intended to advertise the firm to potential clients, and working drawings for the factory floor. In June 1893, a new firm called Pott, Cassels and Williamson was established in Motherwell, southeast of Glasgow, specifically to make centrifugals and other sugar machinery. Pott was the former assistant manager of Watson, Laidlaw, & Co., J. H. and D. Y. Cassels had managed the general-purpose Glasgow Iron and Steel Company, and Robert Williamson had been Watson and Laidlaw's "chief of the drawing office and designing department." Even before the company announced that it had acquired land for a works and foundry, it

297. Drawing dated 25 May 1862, UGD202/1890, UGA.

298. John Laidlaw of Selkirk was offered a position in Mirrlees, Tait, & Watson's drawing office in March 1874. He had been employed by Simeon Bathgate, a wool millwright, who wrote that "Although [he] is the youngest of the squad, from the way in which he has been engaged in planning the arrangements &c. [of a woolen mill at Portree], it naturally devolves upon him to take the principal charge in carrying out the plans and executing the work." When Mirrlees hired him on Bathgate's reference, they paid him "25/- per week to commence with which will be increased ascending as you render yourself valuable to us." Laidlaw's trade, however, was listed as "millwright." Laidlaw letters T-HB 72, Mitchell Library, Glasgow. For apprentices at Duncan Stewart and their salaries see TD 158/11, Apprenticeship Book, Mitchell Library.

had already placed an advertisement for a "first class Mechanical" draftsman in the pages of the Glasgow Herald.[299] The largest group of "draftsmen" worked as tracers, skilled at multiple reproductions. The more complex process of manufacturing itself now demanded multiple copies of drawings where just one had previously been necessary.[300] What counted as an adequate copy, of course, depended on for whom it was being produced, their place in the workshop, what information they needed from a drawing and what other resources they would deploy.[301] Indeed the spread of drafting knowledge meant that drawing office came to resemble the works itself, at least in the eyes of higher-status engineers striving to differentiate themselves from its new inhabitants. They complained of noise, crude jokes, and proletarian laziness—hardly making it a site for centralizing and disciplining the factory, as Charles Babbage, among others, hoped it could be.[302]

299. Glasgow *Herald*, 31 May and 1 June, 1893.

300. Moss and Hume, *Workshop of the British Empire* 160.

301. Booker, *History of Engineering Drawing*, 133.

302. Frances Robertson, "Manufacturing and the visual economy in nineteenth century Britain" (Intl Soc for Cultural History, Luneville 2012, 2-5 July).

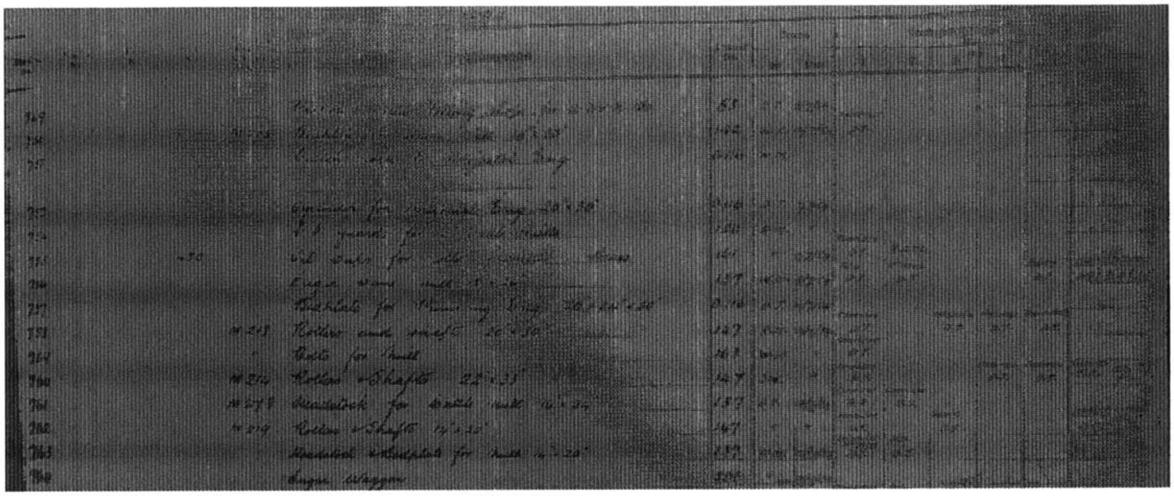


Figure 3.9: Section of 1884 drawing-office register from the firm McNeil Aitken, showing order numbers, mill and vacuum pan serial numbers, draftsman, date, copies, and where stored. (UGD118/5/4/1)

Many hundreds of the orders sent by Bennett, Dodd, and others to Mirrlees are extant in the University of Glasgow's archives, though only from the eighteen-forties to the eighteen-nineties. It seems likely that, when the University's archivists were canvassing the business records of the West of Scotland in the nineteen-sixties, drawings received as far back as 1895 could not safely be archived because the machines they represented were still, in all probability, grinding cane.

5. 1900 and after

By the end of the century and the beginning of the twentieth, when Caribbean sugar factories became more complex, the locus of expertise in sugar production had shifted. Glasgow firms were frequently called upon to design and construct the new, technologically sophisticated "central factories" from the ground up. The Harvey

Engineering Company advertised, in the back pages of one of the many late-nineteenth-century sugar machinery treatises, that it produced fourteen between 1905 and 1909 alone **(Figure 3.10).**[303]

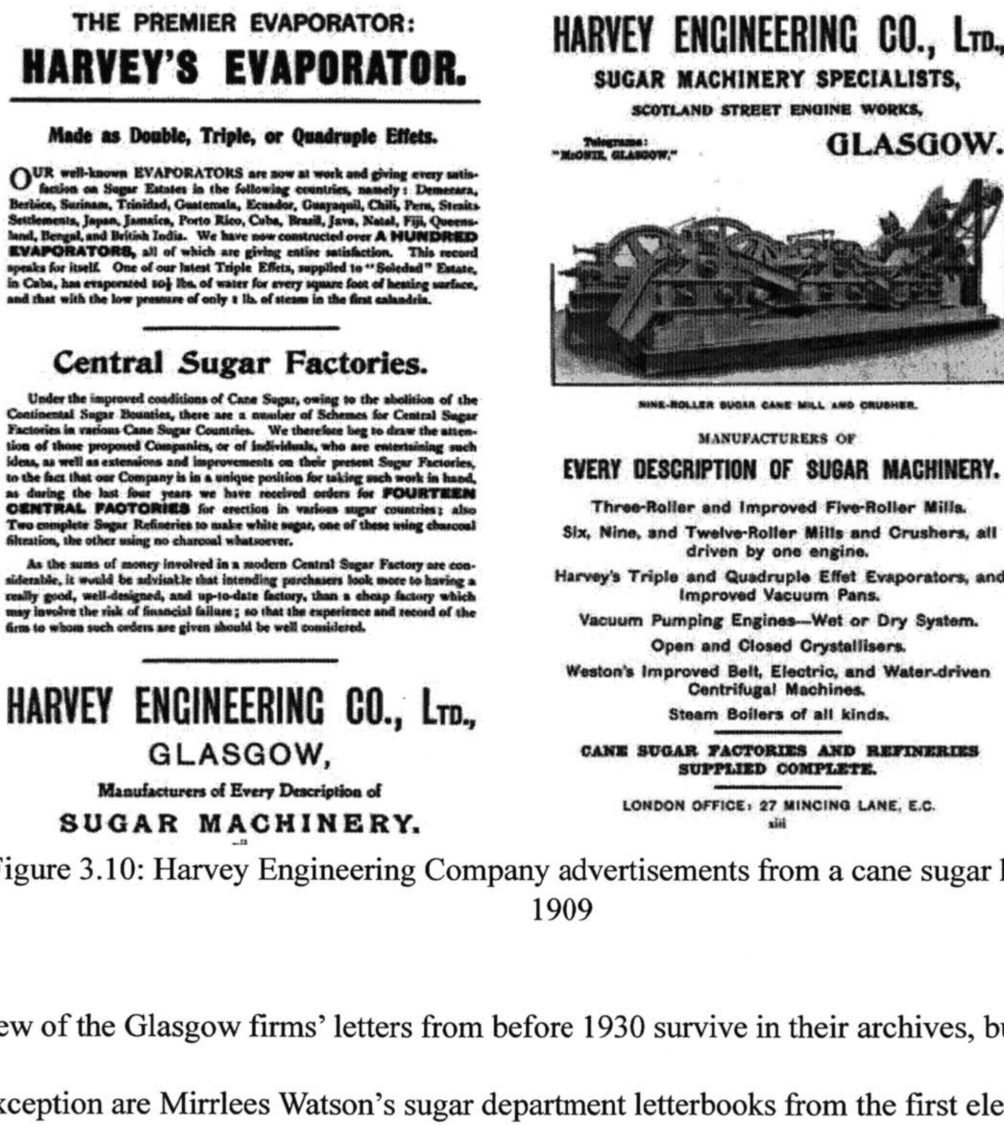


Figure 3.10: Harvey Engineering Company advertisements from a cane sugar handbook, 1909

Few of the Glasgow firms' letters from before 1930 survive in their archives, but an exception are Mirrlees Watson's sugar department letterbooks from the first eleven months of 1903. These show the firm's reliance on the nuances of communication with its clients, agents, collaborators, and competitors, particularly in a period of renewed

303. Harvey Engineering Company advertisement at the end of Llewellyn Jones and Frederic I. Scard, *The Manufacture of Cane Sugar* (London: Edward Stanford, 1909).

business from Cuba and Puerto Rico following their respective independence and annexation by the United States.

Agent-engineers remained the firm's source of sales as well as intelligence in purchasing countries. In Havana, Victor G. Mendoza was one of the agent-engineers through whom Mirrlees Watson worked in the early 1900s. He is listed as the person through whom many owners ordered their mills. He also kept the company up to date with the latest movements of the mills they had shipped years before.[304] Thus number 1692 was a 36"x78" three-roller mill, ordered by Mendoza for J. P. Baroso for the Conchita estate in Cuba in 1904. In 1909 they received a letter from "VGM" indicating it had been transferred to La Julia, and then in 1914 more of letters indicated it had gone to Santa Rosa. Mendoza did not only apprise them of the movements of his own purchases. Mill 1326 and engine 1336 had been ordered for Dos Hermanos in 1882; in 1909 Mendoza told Mirrlees Watson that the mill had been attached to a newer engine, while the newer mill had been hitched to the old engine. The sources for this information were listed as an "Estate Report", and a 1909 letter from Mendoza."[305] Placing an order for large pieces of sugar-producing equipment was not a momentary transaction but a lengthy, drawn-out negotiation.

Mendoza also informed Mirrlees when one of their potential customers was "using our letters to our disadvantage." It is unclear whether this meant their technical advice rather or their cost estimates, since the latter were routinely conveyed by

304. UGD118/2/4/37, UGA.
305. UGD118/2/4/38, UGA.

customers shopping for the best bargain. Rather than end negotiations, however, Mirrlees instead sent their official quotation through Mendoza, and wrote the customer that Mendoza "is well acquainted with our work [and] will be able to give you any further information that you may require."[306] When they were outbid by Fletcher's for generosity of terms of payment, Herriot asked Mendoza to find out the identity of Fletcher's own agent.[307] Rival firms, who were neighbors in the same quarter of a Scottish city, used customers in the Caribbean as sources of information on each other's activities.[308]

The minute books of A. & W. Smith, which survive only from 1909, show that much of that company's concern in the prewar years was with securing agents abroad, especially in the Caribbean islands that had fallen further into the American embrace. Once an agent resigned—often after demanding a higher commission—it was difficult to find another whose "experience of Sugar Machinery and knowledge of the Planters was of value."[309] In autumn 1911, a year after appointing a new agent, A. & W. Smith had to raise the commission rate from 5% to 7½% on orders, and to likewise increase the minimum commission by half.[310] This did not stop the agent from resigning the next summer. They too were replaced by a new agent after references were received both from

306. Correspondence with Victory Mendoza, 10 August 1903, UGD062/1/4, UGA.

307. Mendoza correspondence, 5 August 1903, UGD062/1/4, UGA.

308. For late-eighteenth-century steam-engine makers "profit[ing] from personal interaction, written correspondence, reading reports, viewing diagrams and models, visiting installations and the circulation of gossip," see Lissa Roberts, "Full Steam Ahead: Entrepreneurial Engineers as Go-Betweens in the Late Eighteenth Century," in *The Brokered World: Go-Betweens and Global Intelligence, 1770-1820*, ed. Simon Schaffer et al. (Sagamore Beach, Mass.: Science History Publications, 2009), 193–238, on 197.

309. A. & W. Smith Minute Book, UGD118/1/1/1, UGA, 14 February 1910.

310. In the cost books examined for this chapter, such as that of Duncan Stewart, agents' commissions were not listed as part of the cost of an individual order. Presumably agents' payments were therefore made and accounted for from the general accounts, but it is also plausible that different firms operated their agents in different manner.

the National Bank of Cuba and "others such as Merchants & Planters."[311] One of Duncan Stewart's former London agents was later approached, but "he personally would not do any spade work" but would instead send his assistant, and "only call personally after it had been ascertained that business might result." Smith wanted more diligent representatives than this.[312] Their agent in Natal, South Africa, for instance, Henry Dunsmore, appointed at the same time, was also their agent for Mauritius in the Indian Ocean. He was to "pay a visit to Mauritius annually, at the time planters were prepared to place Orders for Sugar Machinery," but "owing to the conditions existing in this Island" the partners decided to pay Dunsmore a flat fee rather than a commission.[313] The contract of their agent in Java expired at the end of 1915, but they were unable to get hold of him by letter or telegraph, so they found a new one.[314]

The agents and traveling engineers were essential as well because large orders for central factories or for substantial amounts of equipment were accepted only after long discussions among a firm's partners or directors. Even after careful consideration of their correspondents' recommendations, and even given frequent rejections of orders on grounds of creditworthiness, not all such investments were wise ones. Glasgow firms faced difficulties recovering their debts. In 1907, Duncan Stewart was owed £183,835 on one Cuban contract, but had been paid only £134,984. The next year, they took an enormous loss. At a meeting between their bankers and the sugar company's

311. A. & W. Smith Minute Book, UGD118 1/1/1, 6 November 1911, 29 July 1912, 27 September 1912.
312. A. & W. Smith Minute Book, UGD118 1/1/1, 15 September 1913.
313. A. & W. Smith Minute Book, UGD118 1/1/1, 6 March 1911.
314. A. & W. Smith Minute Book, UGD118 1/1/1, 1 November 1915.

representatives in New York it had been concluded that the almost seventy thousand pounds now due would be "written off as irrecoverable."[315] A. & W. Smith's prewar minutes are full of special pleadings from sugar mills. Having ordered several tens of thousands of pounds of machinery in the summer of 1911, by 1913 Beattie & Company were "unable to pay their indebtedness at present, but as prospects for the approaching crop were very bright they hoped to be able to sell out at an early date." Two years on they sent £3000, "all they can do for us this season, hope to pay off balance next crop," but they only received another £3000 eighteen months later, and then a further £2000 in August 1917, with the balance of £1958 promised February 1918—all within the midst of high wartime sugar prices.[316] Ferdinand Pons of Guantanamo "regrett[ed] his inability to pay installment due 30th June 1913, but hoping to do so during the approaching year." Sugar companies frequently offered mortgages to their own property as security.[317] In extreme cases, equipment might even be paid for in cargoes of sugar itself. The employees of the Derby-based firm of Fletcher founded the Derby Pure Cane Sugar Association in 1885, whose goal was to turn public opinion against the bounties that stimulated the production and import of beet sugar. They combined both advocacy and fundraising in the setting up of a shop selling cane sugar at the Fletcher works itself. For the next seven years they sold an average of one ton of sugar every week.[318]

315. Duncan Stewart profit and loss accounts, TD158/14, Mitchell Library.

316. A. & W. Smith Minute Book, UGD118/1/1/1, 11 August 1913, 7 July 1915, 6 December 1916, 14 August 1917.

317. 15 September 1913, 19 January 1914.

318. D. Bradley, "Fletcher & Stewart Ltd: A Business History" (MPhil thesis, University of Nottingham), UGD118/11/1/48, UGA.

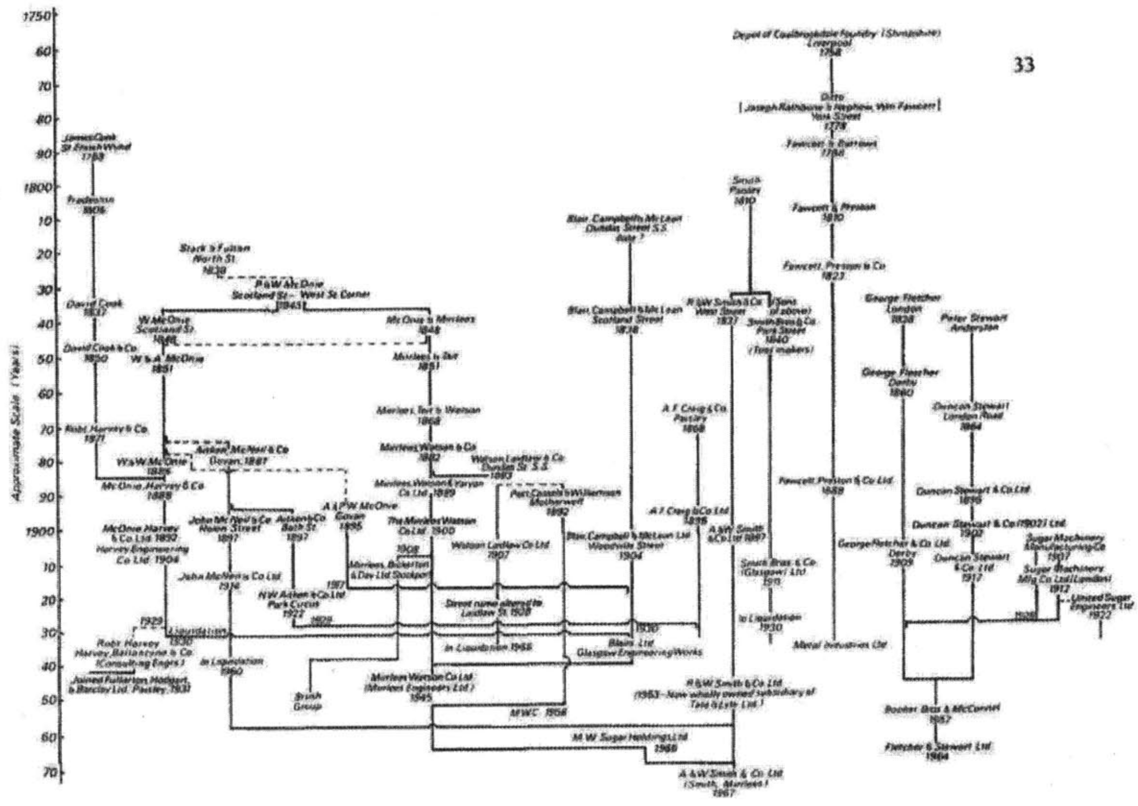


Figure 3.11: Evolving partnerships of Glasgow sugar firms (from Moss and Hume, 33)

On larger, more complex orders, firms frequently collaborated with their local rivals. The partnerships of Glasgow sugar engineers were evolving and interlinked **(Figure 3.11)**. McOnie Harvey, for example, was the British licensee of a patented apparatus to feed syrup into the vacuum pan, for which Mirrlees had received an order. They asked McOnie for an estimate and for "a sketch or litho. showing exactly what you include in your offer." Representatives of the firms might meet in person to discuss terms, as James Harvey and W. S. Herriot, one of Mirrlees's chief engineers, did a few weeks later.[319] Making working iron devices from drawings required close coordination, even from firms next door to each other. Watson, Laidlaw & Company had been spun off of Mirrlees two decades earlier specifically to produce centrifugals under the license of the Weston patent.[320] "The drive from Molasses Pump is not coming in exactly as we expected and as arranged with your Draughtsman," Herriot wrote, and asked to have him "sen[t] over here on Monday morning, when we can no doubt arrange to overcome the difficulty."[321] All but the most straightforward orders required multiple exchanges. The ability to send estimates on time depended on capacity in the drawing offices.[322]

Even where a firm subcontracted out parts of its orders, its management was very concerned to maintain their name in the front of a distant customer's mind. Theodore Brooks was a purchasing engineer for the Guantanamo Sugar Company, but not one who seems to have been tied to Mirrlees.[323] Upon receiving Brooks's orders of crystallization equipment for Los Caños, Mirrlees sent nine tracings, and expected to be able to send the devices themselves in three months, since Herriot, on a recent visit to the island, "took particulars" of their dimensions and design.[324] For delegated orders, Mirrlees asked that drawings be supplied without the subcontractor's name on them. The same, more importantly, went for the machine itself, for which the firm supplied the brass plate.[325]

319. Mirrlees Watson to E. A Brooks, UGD062/1/4, 29 July and 17 August 1903.
320. "Mirrlees," *Engineering*.
321. Mirrlees Watson to Watson, Laidlaw & Co., UGD062/1/4, 22 June 1903.
322. Mirrlees Watson to Theodore Brooks, Esq., Guantánamo, UGD062/1/4, 4 July 1903.
323. "This tracing [of a spur wheel for Soledad] is sent to enable you to judge of the superiority in design and strength as compared to the wheel at present in use." UGD062/1/4, 6 July 1903.
324. Mirrlees Watson to Theodore Brooks, Esq., Guantánamo, UGD062/1/4, 3 August 1903.
325. Mirrlees Watson to Pott, Cassels, & Williamson, UGD062/1/4, 15 June 1903. They also insisted that erecting tracings be supplied on cloth and demanded the same from their subcontractors. UGD062/1/4, Mirrlees Watson to Watson, Laidlaw & Co, 22 June 1903.

Collaboration or not, it was still in a firm's interest to have its name identified with the final product as solidly as possible, not least to guarantee repair business in the years and decades to come. As it was sold and resold from plantation to plantation, the only documentation that was sure to accompany a machine was the lettering forged into the iron itself **(Figure 3.12)**.

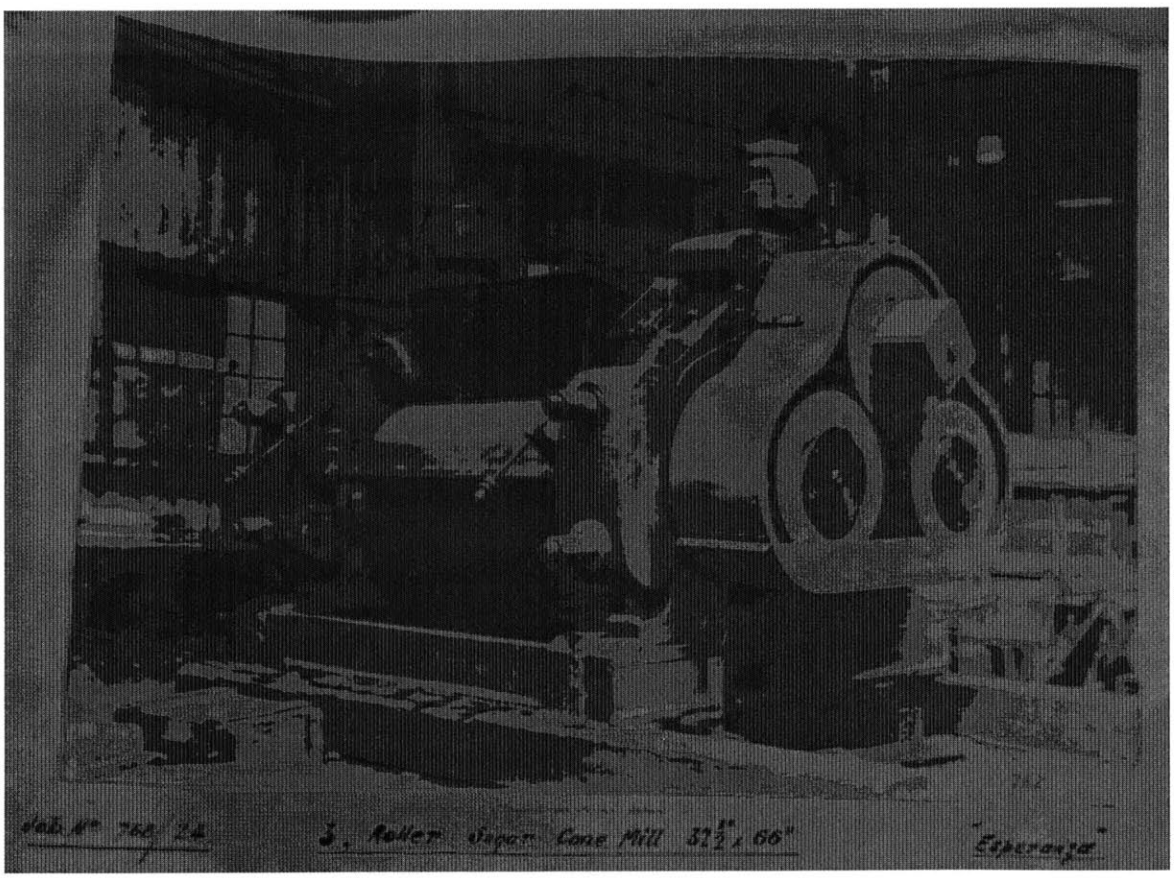


Figure 3.12: Mill unit made and photographed by A. & W. Smith in 1924, showing the company's name on the mill cheek in the foreground (UGD 118 1/5/1/35)

Inscriptions going the other way, meanwhile, were increasingly scrutinized. Forwarding a customer's supplied drawing on to the specialist firm of Pott Cassels and

Williamson, as part of an order for a set of centrifugals, Mirrlees commented that the distributing trough "is shown unnecessarily large."[326] In another case, a photograph from a Cuban estate showed a pulley where the drawing did not, which the firm understood to mean "that you intend to make the necessary arrangements yourself."[327] In 1881, Mirrlees Watson had sold Mill 1273 to Ingenio Matilda, and 1276 to Esperanza. Now in 1903 Mendoza was transferring them to Santa Gertrudis. Mirrlees sent along two tracings containing the "general arrangement and foundation plans" for both mills, nearly identical except where specified on the drawings. They cautioned that "as these drawings were made so many years ago we cannot guarantee their correctness," a warning not about the inexactitude of the draftsmanship but more about modifications made in the intervening two decades. "Before the foundations are built from them all dimensions of bolt holes, etc. should be checked from the actual machinery."[328] Two decades later Mendoza informed Herriot that the mills had been separated, and were being sold again.[329]

At the same time, purchasers depended on the firm's records of their own estate. An estate-owner from St. Croix commissioned rings to extend his four cylindrical crystallizers in order to accommodate the higher strike capacity of his vacuum pan. The crystallizers were seven years old in 1903, having been built by Watson, Laidlaw, & Co., while the rest of the plant had been supplied by Mirrlees. The latter accepted Watson's

326. Mirrlees Watson to Pott, Cassels, UGD062/1/4, 23 June 1903.
327. Mirrlees Watson to Sr. Don Ramon Palayo, UGD062/1/4, 21 August 1903.
328. Mirrlees Watson to Pott, Cassels, UGD062/1/4, 14 July 1903.
329. Mirrlees mill book no. 1, UGD118/2/4/37.

bid for £35 per cylinder, but commissioned only three, having observed that, in 1896, they had built "a column in the way of the 4th Crystallizer which prevents its being lengthened."[330]

In those sugar-producing regions that had now been absorbed into the American tariff zone, British firms faced a suddenly more competitive market. A Hawaiian client of Mirrlees requested an estimate for centrifugals of various sizes, the cost of delivery in Glasgow and in Honolulu. The customer added bluntly that "as the Hawaiian market is now under the American flag," they expected "you will give us a special cut to enable us to meet the competition of American made machines."[331]

Though linked to all of its local peers and rivals by webs of contracts and subcontracts, Mirrlees nonetheless had closer ties to some than to others, and sometimes tried to keep business from certain competitors. A Mexican estate wrote asking for spares for its centrifugals, which Mirrlees also forwarded to Pott, Cassels, and Williamson. The quality of sugar itself and its intermediate products was of particular concern for the builders of centrifugals. Devices for first and second sugars—the latter being the product of syrups which had been recharged with first-sugar molasses—were distinguished, as were centrifugals for other types of refinery product, such as powdered sugar.[332n]"Please let us know whether you can identify the machines in question, which we think were probably supplied by Messrs. McOnie, Harvey & Co.," they asked, "and whether you

330. Mirrlees Watson to Watson, Laidlaw, UGD062/1/4, 27 June and 25 July 1903.
331. Mirrlees Watson to Pott, Cassels, UGD062/1/4, 24 August 1903.
332. Mirrlees Watson to Pott, Cassels, UGD062/1/4, 23 June and 14 August 1903.

could supply the spares correctly without further information."[333] The firm was invested in being able to supply a positive answer to queries about any provider's machinery, and to "execute [an] order without further particulars" in time to cast, erect, and deliver.[334] Thus, on the one hand, sugar engineers emphasized the "taking of particulars," the specific knowledge of a customer's wants and detailed knowledge of the business itself. On the other hand, they also needed to be able to claim to execute an order precisely without more information, any more, that is, than what they had been supplied by the overworked engineer of a factory.

At the same time, however, a new development in Glasgow itself signaled the degree to which the ideology of chemical control—that making sugar was not a human but a technical process—allowed for new claims to be the source of knowledge of sugar production. The fall 1911 term at the Glasgow and West of Scotland Technical College—the descendant of Anderson's Institution—saw established a new post of Lecturer in "sugar manufacture", financed by "firms and individuals interested in this industry."[335] Among the donors were several representatives of Glasgow's wealthy community of West India traders, estate owners and commission merchants, but more than 75% of the donations were given by the city's sugar engineering firms. The Harvey Engineering Company promised £50 for two years, Mirrlees Watson gave £25, A. & W. Smith and

333. Mirrlees Watson to Pott, Cassels, UGD062/1/4, 14 July 1903.
334. Mirrlees Watson to Watson, Laidlaw, UGD062/1/4, 30 June 1903.
335. Glasgow & West of Scotland Technical College annual report 116th session (1912), p. 20. OE/4, University of Strathclyde Archives. For the Audubon Sugar School in Baton Rouge, see Heitmann, *Modernization of the Louisiana Sugar Industry*, chapter 10.

Duncan Stewart gave £20 apiece.[336] These were tiny sums by the scale of the engineering business, of course, yet all the other firms together gathered just half of the lectureship's £250 salary.[337]

But it was not cash that the college wanted from the city's engineering firms, but machines. The centerpiece of the sugar school was to be a model of a sugar factory itself, so that the first lecturer, a former factory chemist in the West Indies named Thomas Heriot, could claim, to the readership of the *International Sugar Journal* in 1916, to have constructed a "complete factory in miniature." This boasted small versions of a modern sugar factory's equipment, all supplied by the city's prominent sugar-machinery makers **(Figure 3.13)**. Over the next year, Mirrlees Watson provided a vacuum pan, Duncan Stewart delivered crystallizers, and Watson Laidlaw furnished its specialty centrifuges.[338] Once these had been installed, the college felt comfortable claiming that "the equipment for the demonstration of all the important processes in the treatment of sugar juice is now complete." This terminology carefully and intentionally excluded the crushing of cane—the operation which, in cane-growing regions, connected the relatively controlled inside of the cane factory to the fields and world beyond.[339]

The machines were part of a package deal: the firms sent apparatus, and they also sent students. Although only four came to the first course of daytime lectures, the cheaper

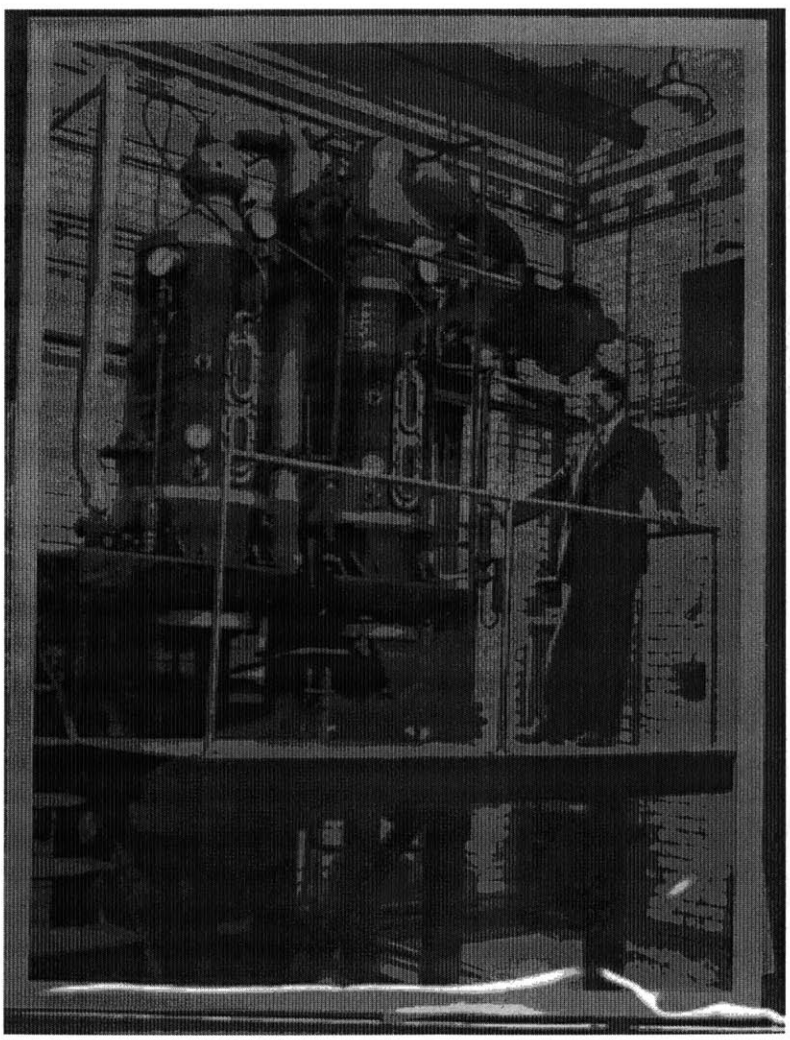
336. Glasgow & West of Scotland Technical College annual report 116th session (1912), p. 64, University of Strathclyde Archives.

337.Thomas H. P. Heriot, "Technical training for the sugar industry," *International Sugar Journal* 28 (1916), footnote 1. The salary for 1911 is found in OE/6/1/1, the GWSTC staff card index, University of Strathclyde Archives

338. I was unable to find entries for these donations in the relevant books of the various companies.

339. Glasgow & West of Scotland Technical College annual report 117th session (1913), p. 24, University of Strathclyde Archives, OE/4.

evening course was packed by almost sixty, nearly all of whom were employees of the local sugar machinery works. The lecture topics followed sugar from its agricultural beginnings as "raw material" through milling, diffusion, clarification, concentration to syrup and then massecuite, crystallization, drying, and packing, all before "chemical control of manufacture."[340] Within a few years, demand was sufficient to add a new laboratory course, at a cost of thirty shillings, that included "analysis of sugars, juices, &c."



340. University of Strathclyde Archives E10/2/2, prospectus of day classes 1912-13, 29, and E10/2/6, "Guide to Evening Classes in Science and Technology," 1912-13, University of Strathclyde Archives.

Figure 3.13: Evaporator, School of sugar manufacture, Glasgow and West of Scotland Technical College (University of Strathclyde Archives, OP4/145)

It was intended as a course to teach local sugar-machinery-making students how factories worked. But over the next decade it grew to become a model of a factory that taught colonials how their factories were supposed to work. The course's enrollment shifted during that period to include many more students "from cane-growing districts in the West Indies and elsewhere." They had come in the hope, according to the college, "that their work [here] will do much to increase the knowledge of modern methods of sugar production and manufacture which they have come to this country to acquire."[341] In other words, to understand how to make sugar, a tropical commodity, one was supposed to leave the tropics. This was a peculiar inversion, one which ran counter to the main flows of movement, of people, paper, and ideas, that had defined the sugar-machinery trade for a hundred years. Now Glasgow was claiming to be an alternative and indeed the superior site for knowledge about how sugar was made.

In Scotland, Heriot claimed, "every essential feature of the factory plant is reproduced." With the help of the manufacturers and instrument makers, he had installed "conveniences for exact experimental work which are lacking in the sugar factory." This allowed him to perform "technical training in a more direct manner than by practical

341. Glasgow & West of Scotland Technical College annual report 116th session (1912), p. 20; E10/2/2, Glasgow & West of Scotland Technical College Prospectus of Day Classes 1911-12, University of Strathclyde Archives.

experience."[342] Thus, in this factory-laboratory, chemical control could teach these trainee managers of sugar factories abroad how the human, technical, and environmental complex of a such a factory worked.

It was the very fact that its miniature machines were just like the real ones, produced by the same engineers at the same factories in Glasgow, that gave this model factory credibility as a real one.[343] More than that, what gave Glasgow's school credibility as a sugar school, so distant from sugar islands, was its proximity to the engineering firms themselves. Heriot's was a huge image of a sugar factory in steel, rather than ink. As he himself lectured in 1918, "Teach the student all essential principles outside the factory, by means of lectures and laboratory experiments, so that, when he first enters the factory, he understands what he sees, and needs no other instructor than his own eyes and intelligence."[344] This was a marked shift in how knowledge was expected to be acquired: from hands-on training, a miniature model had come to be seen as superior.

At the same time, companies continued to emphasize the importance of sending members of their own technical staff abroad. These itineraries were often tortuous. An A. & W. Smith engineer named Samuel Irvine, for instance, spent nearly all of 1910 chasing orders around the Atlantic. In February the directors dispatched him to Cuba to acquire orders and to interview new candidates for the company's agency. He returned to Glasgow in early summer, after drumming up a contract for a new central factory. In July,

342. Heriot, "Technical training," 173.

343. For models' power to inform and persuade in the sciences, see Soraya de Chadarevian and Nick Hopwood, eds., *Models: The Third Dimension of Science* (Stanford, California: Stanford University Press, 2004).

344. Thomas H. P. Heriot, "The Sugar Industry after the War," *Proceedings of the Royal Philosophical Society of Glasgow* 49 (1918): 31.

the company decided to send him back to Argentina in September, thence to return via Jamaica and Cuba. But in mid-August they decided to send him back sooner than planned: a crisis had arisen when a Cuban central, with whom terms had already been agreed, wanted to change the terms of its payment plan for the £72,000 worth of machinery it had ordered. By the end of the month there was a cable waiting for Irvine in Havana that the revision was to be rejected and a new contract offered for three installments, with any late payments guaranteed by the National Bank of Cuba. Over the course of August and September, as Irvine served as A. & W. Smith's agent on the island, the partners held frequent and often special sessions devoted to this individual contract.[345] Even with telegraphic communications and in countries with longstanding agents, Glasgow's firms still considered it highly profitable to send valuable engineers on fatiguing personal voyages.

The sugar engineering business in Glasgow relied heavily on information gathered in mediated exchanges between firms and their markets. That information was then put to use by draftsmen, engineers, and shop-floor workers. Yet that very mechanization of the production of sugar also led to institutions like the "factory in miniature" at Glasgow's engineering college, which were meant to direct the flow of knowledge the other way.

6. The view from 1943

345. 14 & 25 February, 25 April, 4 July, 15, 16, & 26 August, 29 September 1910, A. & W. Smith Minute Book no. 2, UGD118 1/1/1, UGA.

The status of Glasgow as the world's dominant heavy-engineering city diminished as the twentieth century wore on. The First World War and its immediate aftermath were boom times, as Glasgow engineering works were commandeered by the state to produce armaments and other matériel. Subsequently, the crop of 1920 brought the highest sugar prices in a century; the influx of cash produced heady effects collectively known in Cuba as *la danza de los millones*, the dance of the millions. Mountains of unfilled orders rose in the sales offices of sugar engineering companies, yet profits rose too. Such remarkable harvests of capital were driven by the absence of European beet sugar from the market. When that crop returned in 1921, sales vanished. Some firms received no new contracts until 1923. More problematically, in addition to the United States's preferential tariff treaties with Cuba, many of the island's central factories had failed in the 1921 collapse and fallen into the hands of American creditors who strongly preferred to buy from domestic engineering firms. From the perspective of British manufacturers, the tariff discount should only partly compensate for the commercial advantage gained by their own longstanding relationships with engineers and owners in the Caribbean, and thus they were disappointed when, in 1921, there was only a single order of centrifugals placed to Scotland.[346] As the price of sugar remained low through the 1920s and into the Great Depression, the language of Glasgow newspapers reporting on their city's sugar firms changed: they spoke of "moderate activity," business that was "fairly active," with

346. Bradley, "Fletcher," 118, 122.

"work not so plentiful as in the years past."[347] Sugar prices remained low through the 1930s, and while the sixteen sugar-machinery firms began 1929 in operation in Glasgow, a decade later, after mergers and failed partnerships, only eight had survived. This difficulty perhaps explains why, in October 1921, the board of A. & W. Smith dispatched the appropriately-named Martin Ironside to Cuba "for the purpose of gaining knowledge of the most modern practice." They judged that "such a visit would be advantageous [and] a similar visit on the part of a member of the Works Staff would be even more so." He returned six months later, en route to South Africa via Glasgow, having toured not just "the Sugar Factories of Cuba" but also Trinidad, Louisiana and elsewhere in the United States.[348] When business flagged, it was especially important to remind past, current, and potential customers of Glasgow's longstanding expertise.

Within the once again centralized command economy of the Second World War, the Glasgow engineering firms converted anew to making armaments and aircraft. By 1943, the government was already plotting its postwar return to normal peacetime production. The Board of Trade, Britain's wartime economic governors, had sent letters to firms throughout the country asking what they would need to return to ordinary work. In early December 1943, a delegation from the Sugar Machinery Export Group, a trade association comprising engineering firms from Liverpool and Derby in addition to those from Glasgow, came to meet with a committee representing the Board. These managers of the country's major makers of sugar-factory equipment took trains to London to plead

347. Quoted in ibid., 211.
348. 24 October 1921 & 3 May 1922, A. & W. Smith Minute Book no. 2, UGD118 1/1/1, UGA.

what they claimed was their unusual case. "Sugar machinery work is all of a special nature," they argued. Their requests laid out in detail their claims about how sugar-machinery engineering differed from other kinds of heavy industry. These documents show how remarkably similar the work of such firms in the mid-twentieth century was to their work many decades before. Just as significantly, they demonstrate how the identity of this subset of engineering firms was bound up with the particularities of the biographies of the objects that they produced, and how distinct they considered themselves to be from other seemingly similar lines of manufacture.

The most senior government official present at the meeting in December 1943 was Richard Pares, in peacetime life an Oxford don and economic historian of the British empire. Pares knew in detail how the sugar industry operated, at least in the seventeenth and eighteenth century. After the war, he would write his best-known work, *A West-India Fortune*, about a firm of sugar merchants and planters on the Caribbean island of Nevis.[349] Within the civil service, as a departmental Priority Officer allocating scarce material and human resources, one of Pares's roles was to grant export licenses to engineering manufacturers.[350] Here too the sugar business was unusual. Repair requests were piling up from customers around the globe, but these could not yet be translated into

349. Richard Pares, *A West-India Fortune* (London: Longmans, Green and Co., 1950).

350. Reflecting in 1951 on his role in the wartime economy, he observed that planning for peacetime within the civilian production departments was not fully determined by wartime production needs. As a result, "priority officers" like Pares had to incorporate an industry's "value in morale and politics" into their allocations. "The official who allowed or obliged the manufacturers of grain-milling machinery to export their entire output, so that the British flour mills broke down, would be incurring a political risk, but that he would not be incurring any risk if he did the same thing to scent-making machinery." Richard Pares, "The Work of a Departmental Priority Officer," in *Lessons of the British War Economy*, ed. Daniel Norman Chester (Cambridge: University Press, 1951), 154–166, on 164-165.

orders. "Machinery cannot be built in large quantities to stock by repetition methods," the manufacturers explained. Instead "all new units are made to suit the requirements of each customer, and details and negotiations frequently require visits of a consulting character to factory sites abroad."[351] They requested the release from armed service of their draftsmen, whom they described as their firms' "key men." Not just any draftsmen would do, but only those who had specific experience working with and on sugar machines.[352] Only if draftsmen from war service returned could promissory notes be put on the books. Their absence held everything up. The order process was lengthy and required the communication of many drawings and designs between British companies and overseas sugar producers; as the delegation claimed, it "entails a considerable amount of drawing office and estimating work in preparing alternative suggestions for consideration, and involves, in some cases, discussions by correspondence with customers several thousand miles away." In addition, cost-estimating staff, and even the ranks of "sales engineers," were customarily drawn and trained "from draughtsmen with sugar machinery drawing office experience."[353]

The work of producing sugar machines likewise placed particular demands on the factory floor. Sugar machines were not standardized products, and so the "work was not repetition work." The consequent "varied and special nature" of sugar-machinery production, argued Duncan Stewart's representative, made it impossible to use the

351. Letters to Board of Trade from the Sugar Machinery Export Group (1944) - Board of Trade and the Sugar Machinery Export Group, UGD052/1/3/4, UGA.

352. Papers Relating to Post-War Production, UGD052/1/3, UGA.

353. Ibid., emphasis original.

younger and largely female "dilutee" labor that had been drawn into the workforce.[354] They asked for the release, in particular, of their special patternmakers, but they also wanted back their machinists and fitters, who like other workers had to be capable of working without "close supervision of all operations." Most important, they "must be able to read drawings," which the wartime "unskilled operators" could not do.[355] In the absence of these skills, production and repair of sugar machinery had come to a halt. Pares and the Board accepted these claims for the peculiarity of the sugar machinery business. But in the 1940s, these manufacturers were claiming a status for their business that was singular because it was in many ways remarkably old-fashioned. These were working practices that had continued since the middle of the nineteenth century, and which lasted as long as the machines themselves.

7. Conclusion: Skilling and deskilling

Much has been written about Glasgow's connections to the commodity riches of the New World, but primarily in the city's earlier incarnation as an eighteenth-century mercantile entrepôt, before its metamorphosis at the turn of the nineteenth century into a city whose largest and most powerful industries were central. As a global commodity, sugar has features that differentiated it from the arenas for whom much of Glasgow's heavy industry built capital goods. At the same time, they distinguish it from the

354. Ibid.
355. Letters to Board of Trade, UGD052/1/3/4, UGA.

“peripheral” areas of the globe that produced raw materials for the industrialized “center.” Machines for the milling of grain into flour, for instance, or the spinning of cotton into thread only had to be sent as far as other metropolitan cities or to novel agglomerations of industry in mill towns, where they would spend their lives toiling in human and physical environments not unlike Glasgow itself. But the crucial fact that cane juice quickly spoils meant that the pieces of Victorian high technology meant to facilitate the transformation of sugar from a harvested crop into an exchangeable commodity, unlike those built for wheat, flesh, or cotton, were uniquely required to operate in taxing tropical zones, immediately proximate to the plant itself, its agricultural environment.

To the manufacturers of these pieces of sophisticated sugar machinery, this meant that their products were unlike the others that Glasgow was more famous for sending around the world. The different climate, labor and management regimes, and rhythms of production required their engineers, designers, and craftsmen to pay constant attention to the particular human and material environments where sugar was produced, and to the individuals who would construct, operate, and maintain them. The city’s specialized sugar engineering firms faced singular challenges for both the design of their products and the transoceanic management of information. Expensively customized mills, evaporators, and other devices of sugar production had to survive many decades in taxing environments hostile to mechanical apparatus. So these companies built decades-long relationships with sugar plantations and central factories abroad, sending specially trained draftsmen and engineers for consultations, inspections, and follow-up visits. The knowledge acquired from these journeys, and through communication by the transmission of plans and designs, helped them track their creations for decades, recording changes of owners, plantations, and islands.

It was not just that Glaswegian engineers, draftsmen, fitters, turners, laborers, and apprentices enabled the central-factory workers of the Caribbean to produce sugar of dazzling quality. In the Caribbean, as the previous chapter has demonstrated, new machines and new techniques of sugar production were the terrain on which managers and chemists of sugar factories battled the artisans of sugar to construct an ideal of consistency, interchangeability, and chemical purity, an ideal that was allied to efforts to discipline and routinize the craft labor of those very same workers. This chapter has argued that it was the explicit sustainment of custom, craft, and ingenuity in Glasgow's machinery workshops that allowed such attempts at discipline and standardization elsewhere in the sugar economy. The success of the new machines built by these Glasgow firms, machines which, it was claimed, would replace the need for independent-minded labor, depended on these same firms' continued reliance on older methods of design and construction.

The sugar machine builders, more than any other Glasgow engineering concerns except perhaps shipyards, built their reputation on capital goods made bespoke to customers' desires. They thus epitomized certain conservative tendencies of firms whose business models relied on large, complex, and custom products, and which were nestled within a Clyde Valley teeming with skilled workers. By 1900, 40% of Scottish male workers were employed in heavy industry. These facts served, in the words of the Glasgow labor historian Ronnie Johnston, to discourage "any radical break with tried and tested craft-centred production."[356]

Highly skilled engineers benefited from British market dominance that was based on heavy and custom products.[357] The nature of demand in the British overseas marketplace and the needs of clients for custom designs often determined the kind of labor control that domestic engineering firms could adopt. Firms who attempted to produce standard products to make inventory, spares, and repairs easier found that their customers demanded more design control. Only a few industries, like textile engineering, were able to impose standardization on their customers in order to make the delivery of spares and repairs easier on themselves. In those sectors, "so vast an amount of repetition work," as one survey wrote in 1894, contrasts particularly with the claims sugar engineers made for themselves, and for the ways that their workshops operated, as late as the nineteen-forties.[358]

In large part the labor history of Glasgow in the last decades of the nineteenth century and the first of the twentieth has involved digging for the "roots of Red Clydeside," as one compilation of essays is called, the search for explanations of the radicalism and militancy. [359] Recently historians have concluded that it was the boom in

356. Ronald Johnston, *Clydeside Capital, 1870-1920: A Social History of Employers* (The Mill House, Phantassie, East Linton, East Lothian, Scotland: Tuckwell Press, 2000), 139.

357. Jonathan Zeitlin, "Craft control and the division of labour: engineers and compositors in Britain 1890-1930," *Cambridge Journal of Economics* 1979, no. 3: 263-274, 264-269.

358. Zeitlin, Between flexibility and mass production, 248.

359. For analyses questioning whether Glasgow and its environments were really more radical than England and Wales, as well as other sites on the Continent and in America; the degree to which Red Clydeside reflected a deeper Edwardian unrest; and whether it was syndicalist, truly revolutionary, or

the immediate prewar years that led to tight labor markets, the intensification of work, and industrial actions demanding labor prerogatives, rather than deeper currents of radicalism. In 1897, the nationwide engineering union, the Amalgamated Society of Engineers, demanded a forty-eight-hour work week. A dispute that began over the counting of hours quickly became a more fundamental struggle about whether workers or managers had the right to manage shop-floor practices, pitting the ASE against the Engineering Employers' Federation. The members of the EEF locked their skilled workers out, much to the fury of the unorganized laborers, and of the elements of the ASE, like boilermakers and patternmakers, who had not supported the Society's stand. Moreover, the EEF had not singlemindedly sought a lockout, since its members depended on their skilled workforces to widely varying degrees. Industries with which sugar machinery makers were in many ways comparable, and whose lines of businesses often overlapped, such as marine and armaments engineers, strongly favored the hard stance. They felt threatened by German and American competitors who had more aggressively subdivided their labor, and wanted to wrest control from the craftsmen.[360] Yet not a single sugar-machinery engineering firm is listed among the seven hundred and two who locked out their employees.[361]

"merely" interested in higher wages, see William Kenefick and Arthur McIvor, eds., *Roots of Red Clydeside, 1910-1914: Labour Unrest and Industrial Relations in West Scotland* (Edinburgh: J. Donald, 1996).

360. Zeitlin, "Craft Control," 268-69.

361. Engineering Employers' Federation, *List of the Federated Engineering and Shipbuilding Employers Who Resisted the Demand for 48 Hours' Working Week* (Glasgow: Engineering Employers' Federation, 1898); Johnston, 137-139.

Between 1910 and 1914 there were 53 strikes by engineering and shipbuilding works, including a huge 1911 strike by the employees of the Singer sewing machine works.[362] The minutes of A. & W. Smith make no mention of large inter-war labor actions such as the 1919 Battle of George Square, in which as many as ninety thousand of strikers, seeking a forty-hour week, fought off police assaults but were defeated by the tanks and howitzers of the army.[363] The company did insure itself the following year against fire and other damage "through Riots and Civil Commotion, Strikes &c.," but the following year they chose not to renew the policy even at half the previous price. Yet a lockout, in March 1926, of the members of engineering unions by the Engineering Employers' Federation threatened delivery dates for A. & W. Smith's upcoming orders to South Africa and Brazil. "It might be advisable for the Company in its own interests to secede from the Fedn. rather than risk the alienation of their [sic] customers through failure to deliver the machinery in time for the respective Crops in the countries," the directors considered. "Several of the most important" of their competitors, they noted further, "are not members of the Fedn. & are therefore unfettered by its policy."[364] The city's sugar firms seem, therefore, largely to have been exceptions to the tendency for antagonism between employers and employees in engineering.

The nineteenth century witnessed consistent and increasing efforts to deride craft as unscientific and then define it as the opposite of industry. Indeed the very notion of

362. Kenefick and McIvor, eds., *Roots of Red Clydeside*, 7-12, 22.

363. "The battle of George Square (Bloody Friday) 1919," Glasgow Digital Library, University of Strathclyde, http://gdl.cdlr.strath.ac.uk/redclyde/redclyeve14.htm.

364. 28 December 1920 and 27 December 1921, A. & W. Smith Minute Book, UGD118/1/1/1, UGA.

"craft," in its sense as the antithesis of mass production, is a rhetorical and intellectual product the early nineteenth century and the glorification of engineer-entrepreneurs. The supposed authenticity, tradition, and unmediated creativity of craft were also ways of denigrating it and its practitioners, both in Britain and in the empire. Yet in fact craftsmanship was a requisite of nearly all forms nineteenth-century industry. It was the particular knowledge that workers and only workers possessed that frustrated their employers into designing schemes to capture that knowledge, control it, or render it irrelevant. Most of all they did not want to have to pay a premium for it.[365] "Progress," Glenn Adamson writes, "is always located elsewhere—in political radicalism, machinery and technology, organizational structures—but never in skilled hands themselves."[366] Yet sugar machinery design and production that was held to be highly advanced lay precisely in "skilled hands" of various individuals with a network of interdependent forms of knowledge.

The exclusion of Glasgow from histories of the sugar world has led to neglect of the close link between the precision and craftsmanship of the design and production of sugar machines, on the one hand, and on the other, the quality of what those machines were supposed to do or produce. As the market for sugar itself became standardized and commodified—as sugar was reduced to sucrose—the building of sugar machines remained a personal business. The process of bespoke orders and customized design let

365. David Montgomery wrote of steel production that "The steel managers and owners sought to "attack the menace of collective workers' control over any part of those operations and ultimately to search for ways in which to cut the taproot of nineteenth-century workers' power by dispossessing the craftsmen of their accumulated skill and knowledge." Montgomery, *The Fall of the House of Labor*, 45-46, and *Workers' Control in America*. See also Adamson, *Invention of Craft*, xix.

366. Adamson, *Invention of Craft*, xvii.

sugar producers, their engineers, managers, and their chemists implement the ideal of chemical purity. Attempts to control the production and trade of sugar were intended both to elevate the purity of sugar to unprecedented levels and also to achieve a consistency that was hitherto impossible. To do so, the machines on which sugar was produced had to be more efficient as well—in terms of the losses of sugar in production, in terms of the fuel consumed, and in terms of their robustness and resistance to breakage. Building machines to the specifications of overseas producers meant maintaining knowledge of the way those producers turned the sugarcane into cane sugar. The irony was that maintaining that knowledge depended on workshops full of visual technicians and metalworking craftsmen, whose labor was closely analogous to that which the machines they made were meant to erase.

The previous chapter showed how the labor of two kinds of experts in the sugar factory was required to make sugar seem a chemical commodity, even as the expertise of one, chemists, largely was devoted to efforts to suppress the labor of the other. This chapter has shown how those efforts and the reinvention of sugar as sucrose, might be connected to a different story of expertise on the other side of the Atlantic, in a city not ordinarily associated with the sugar trade yet crucial to it. The next and last of this dissertation's core chapters shows how the accountability of sugar experts was central to the greatest issues in the political economy of the late-nineteenth-century United States.

Chapter 4:

The "safe practice of fraud" in the New York sugar trade, 1877-1907

1. Introduction: Sugar tariffs from the custom house to the White House

At the beginning of February 1877, a small-time Republican politico named William Grace began work as a customs inspector in Brooklyn. His assignment placed him in charge of customs collection along Sugar District No. 13, a section of the Williamsburg waterfront.[367] In this important position, Grace lasted fewer than three months. On 23 April, he was dismissed on charges of drunkenness by the Surveyor of the Port of New York, George Sharpe, one of the chief officers of the Custom House.[368] On 20 July, Grace got his revenge: passing Sharpe on a Lower Manhattan street, Grace punched him in the face. Well over six feet tall and "burly as an ox," Grace pounded away until policemen hauled them both to jail at the Tombs.[369] The press rushed to cover the story, because more was at stake than the fate of a lowly customs officer. Sugar refining was the city's largest manufacturing employer, and District No. 13 included the largest and most profitable refineries in the country, owned by the firms of Havemeyers & Elder and De Castro & Donner. Grace's firing marked the beginning of three decades during which public accusations of fraud and corruption would swirl widely around the

367. "A Sweet Fraud: The Alleged Rascalities in Sugar," Brooklyn *Daily Eagle*, 23 January 1879.
368. "Gen. G. H. Sharpe Dead," The New York *Times*, 15 January 1900.
369. "Ruffianism in Broadway," The New York *Times*, 21 July 1877; "A Custom House Fracas," The New York *Tribune*, 21 July 1877.

importation and valuation of sugar in the New York Custom House. These accusations, this chapter shows, reveal the political and economic power wielded by those who could take advantage of sugar's "thickness" as a substance.[370] Participants in sugar commerce valued its substance in a multiplicity of ways. The difficulty of reducing its value to a number, of reducing sugar to sucrose, could be put to work by parties to commercial transactions and in relations between private actors and the state.

Grace and Sharpe both had political allies who went to work on their behalf. As a former Union intelligence officer and confidant of President Grant, Sharpe's were the more potent: the former and current United States district attorneys, the police commissioner, and the head of the Custom House, Chester Arthur, all of whom showed up in the courtroom. The Brooklyn *Daily Eagle* noted after the trial that these friends, and the state prosecutors, "belong to a political faction, of which the members fit into one another as closely as a glove fits the hand."[371] This faction publicized Grace's story as one of simple insubordination and ruffianism. The management of De Castro & Donner had written to Sharpe to complain that Grace was drunk, while Havemeyers & Elder called him "a nuisance and a loafer." Both firms accused Grace of trying to "blackmail" the captains of the vessels that unloaded sugars on their wharves, and of demanding "perquisites of sugar...or its equivalent" in cash. When Sharpe investigated, Grace threatened to retaliate by publicizing charges of fraud against the refiners.[372]

370. Following Ken Alder's use of the term in "Making Things the Same."
371. "A little case which only begins a big one," Brooklyn *Daily Eagle*, 25 Sept 1877.
372. "Four months in jail. Ex-Inspector Grace convicted," The New York *Times*, 25 September 1877.

According to Grace's friends, however, he had discovered illicit activity on De Castro & Donner's docks soon after taking his post. His side of the story emphasized how refiners exploited the political and physical spaces of the sugar trade in the United States. Refinery employees were collecting the "sweepings" of sugar that had come loose from their containers aboard ship, and bringing them on shore without paying duties.[373] Further, the refinery was using its own scales to take official weights, contravening rules that required them to use the scales provided by the government. The company's scales were built into the refinery walls: the weighing apparatus itself was outside on the wharf, while the beam, from which the weight was read, was inside the building. Thus, wrote the increasingly Grace-sympathetic Brooklyn *Daily Eagle*, those working indoors "could not tell whether the trucks carrying the sugar were properly on the scales or not, and those outside could not tell whether the proper weights were recorded by the men inside."[374] But when Grace notified the Surveyor of his concerns, it became clear that Sharpe was in on the scheme. When the inspector "would not connive," Sharpe himself had asked a refiner to submit the written complaints of inebriation, in order to provide a pretext for the sacking.

Grace had not kept quiet, however, testifying before Treasury officials and writing to the Secretary himself, and declaring that his "vindicat[ion] by the authorities at

373. "A Dismissed Officer's Revenge. Wm. H. Grace, a Brooklyn Politician, Assaults Lawyer Sharpe," Brooklyn *Daily Eagle*, 21 July 1877. For "sweepings", see Linebaugh, *London Hanged*, 405.

374. "A Sweet Fraud," Brooklyn *Daily Eagle*.

Washington" was imminent.[375] By September, when he was sentenced to four months in jail, De Castro & Donner was already in trouble. Its president had resigned, and its treasurer had fled to Cuba with $14,500 in gold and, peculiarly for one trying to flee, was carrying a number of the company's ledgers with him.[376] The firm fell completely under the control of the city's largest refiners, the brothers Theodore and Henry Havemeyer.[377] Meanwhile, Sharpe had lost the support of the new President, Rutherford Hayes, and though he refused to resign, he withdrew his name from consideration for reappointment.[378] And indeed, in November, things began to look up for Grace. After serving only two months in prison, he was pardoned by a Democratic governor grateful for the opportunity to needle his Republican opponents, and obtained an official order from the Treasury entitling him to his back pay from the date of his dismissal through the July day he socked Sharpe. "Mr. Grace's official vindication is about as complete as it could be made," exulted the *Eagle*.[379]

In pursuit of further government employment, Grace tried to take credit for revealing the existence of sugar frauds, and, with his claims of a "Sugar Ring" masterminded by Theodore Havemeyer, invoked the ghost of the recent "Whiskey Ring"

375. "Four months in jail," The New York *Times*, 25 September 1877. On the day of the assault itself, Grace had been on his way to see a Treasury agent downtown assigned to investigate sugar frauds, and then he was to have met Lawson Fuller, a refiner and importer who again and again accused the Havemeyers of corrupting the customs.

376. "The Schmidt Defalcation," The New York *Times*, 2 September 1877. The firm publicly dismissed the documents as worthless, but the *Times* noted drily that "it is hardly customary for a fugitive...to burden himself with useless account-books."

377. "A little case which only begins a big one," *Daily Eagle*.

378. John Sherman, *Recollections of Forty Years in the House, Senate and Cabinet: An Autobiography* (Chicago: Werner, 1895), 680.

379. "Grace's Vindication," Brooklyn *Daily Eagle*, 18 December 1877.

scandal that had tarnished Grant.[380] Grace insisted that there were false weighings, sugars artificially colored, sugars wrongly classified, overvalued drawbacks, and the "most criminal" use of harmful substances as adulterants in the Havemeyers' refineries. He demanded Congress rewrite the tariff to beat back their emerging monopoly. But, attributing the demise of the Whiskey Ring to the appointment of incorruptible officials, Grace insisted that the new tariff had to be enforced by "competent" appraisers, chemists, and samplers, and "a thoroughly honest collector" at the head of the city's Custom House.[381]

The collectorship was a position of such importance because the tariff on imports was the overwhelming political issue of the Gilded Age. It has consequently been a classic topic in the study of late-nineteenth-century American political economy.[382] Of all the period's protectionist tariffs, that levied on imported sugar was among the most

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380. For a contemporary account, see H. V. Boynton, "The Whiskey Ring," *The North American Review* 123, no. 253 (October, 1876), 280-327.

381 The New York *Sun*, 20 November 1878, reprinted in Charles [Carlos] Rebello, *The Pith of the Sugar Question* (New York: Macgowan and Slipper, 1879). In 1879, Grace's friends attempted to get him reappointed to the custom house based on his supposed good work exposing fraud. President Hayes was unhappy to learn from George Curtis, of the New York Civil Service Reform Association, that "a man named Grace, who was convicted a year or two ago of a flagrant assault upon Surveyor Sharpe," had been put forward again. Hayes was less concerned about Grace's violent temper than he was about the idea that Grace might get the position ahead of candidates recommended through the newly-instituted and still-fragile civil service examination system, so Sherman made clear he was not to be reappointed. "Ex-Inspector William H. Grace. An Order Revoking his Appointment Received at the Custom-House," The New York *Times*, 3 July 1879; Hayes to Sherman, 30 June 1879, in *The Diary and Letters of Rutherford B. Hayes, Nineteenth President of the United States*, digital edition, http://ww2.ohiohistory.org/onlinedoc/hayes/Volume03/Chapter37/EXECUTIVEJune301879.txt.

382 See, for example, Richard Franklin Bensel, *The Political Economy of American Industrialization, 1877-1900* (New York: Cambridge University Press, 2000); Lewis L. Gould, "Tariffs and Markets in the Gilded Age," *Reviews in American History* 2, no. 2 (June 1, 1974): 266–271. Andrew Wender Cohen places the sugar importing scandals within the much more widespread Gilded Age fascination with smuggling, which expressed America's ambivalent relations to the rest of the world. Tariffs, he argues, were an expression of nationalism and an attempt to forestall globalization of identity by severing ties between immigrants and homelands and by extra scrutiny of women, Jews, African-, Mexican-, and Asian-Americans. Andrew Wender Cohen, "Smuggling, Globalization, and America's Outward State, 1870-1909," *The Journal of American History* 97, no. 2 (September 1, 2010): 371–398, on 373, 376.

controversial. Its effects were almost universally felt: sugar was consumed by nearly every American in increasingly large quantities, and sugar duties were by far the largest single item of Federal revenue. In 1879, for instance, the national government earned $274 million from all its sources of revenue. More than half of that—over $137 million—came from customs, and of that half, nearly $40 million came from sugar alone. The sugar tariff was as big as the Army, and more importantly, it was as big as the pensions obligated to the veterans of the Grand Army of the Republic. Securing the loyalty of these predominantly rural voters was crucial to the electoral power of the era's national Republican coalition.[383]

Just as it had done for the French and the British, the differential in the tariff between sugar judged raw and that judged refined served to insulate domestic refiners from foreign competitors.[384] As the largest manufacturing employer in the North's urban centers, the refining industry was politically powerful, and consistently pushed for a greater differential between raw and refined to protect its profits at consumers' expense. These efforts infamously culminated with the greatest political triumph of the Gilded Age monopolists: the Sugar Trust's rewriting of Congressman Wilson's 1894 free-trade bill into the Wilson-Gorman Tariff, which raised rates on refined sugar and protected the Trust's own profits instead. Such a blatant demonstration of political "friendship,"

383. Bensel, *Political Economy of American Industrialization*, chapter 7; *Annual Report of the Secretary of the Treasury on the State of the Finances for the Year 1879* (Washington: Government Printing Office, 1879), iii-iv.

384. This distinction had been first established during the reign of Louis XIV, France established a higher tariff on refined sugar to encourage the creation of domestic refineries in an attempt to halt the outflow of gold to Holland. James Pritchard, *In Search of Empire: The French in the Americas, 1670-1730* (Cambridge University Press, 2004), 164.

including supposed secret agreements between the Secretary of the Treasury and the Trust's executives, alarmed the editors of *Harper's Weekly.* "The tariff question is not a mere question of schedules and rates," they wrote in September 1894. "It does indeed involve the integrity of republican government."[385]

As it tied sugar tariff provisions to the fate of American democracy, *Harper's* gestured to the materiality of the sugar itself. In the cover cartoon accompanying that editorial, the protectionist Senator Gorman drives the chariot of the triumphant Trust, pulled by the Democratic donkey, dragging the chained and defeated free-trader President Cleveland, and crushing Wilson and his bill into the dust. But, on closer inspection, the chariot is not a chariot. Instead, it is a hogshead, the kind of barrel in which sugar was shipped around the world, and on the complexities of whose measurement, as this chapter will show, many sugar-tariff scandals had turned. That material detail points to an equally material history of the sugar tariff: a history of how it was enforced, and how it was subverted. So does the following joke, printed as "Contemporary Humor" in the Brooklyn *Daily Eagle* later that same month:

> "Name some of the qualifications for a United States senator," said a professor to a young man who was being examined for admission to college.
>
> "He must be 30 years of age, be above sixteen, Dutch standard, and be able to stand the polariscope test," replied the applicant.
>
> He got marked 100.[386]

385. "The True Issue," *Harper's Weekly: A Journal of Civilization*, 8 September 1894.
386. "Contemporary Humor," Brooklyn *Daily Eagle*, Thursday, 27 September 1894.

The dark humor built on obscure references to the actual instruments of tariff enforcement might have been lost on the public at large, were it not for the fact that Brooklynites, New Yorkers, and Americans elsewhere had consumed two decades of detailed coverage of sugar scandals within and surrounding the custom house. Indeed, it was not even originally a Brooklyn joke: the *Eagle* had picked it up from Pittsburgh's *Chronicle-Telegraph.*[387]

Paying attention to such a material history of the tariff lets us see how the sugar tariff of the 1870s and 1880s was an arena in which refiners and importers, locked within their fiercely competitive business, sought advantage over each other as well as over the government. In fact, this chapter argues, for much of this period, the government was only an incidental and unintended victim of whatever illicit activity took place in the importation and valuation of sugar. Despite the fact that almost all of the press and public attention—not to mention that of the government—was focused on ways the Federal coffers were being drained of their rightful income, the primary aim of those who sought to influence the official measurements of sugar was not to siphon money from the state but to gain even minutely more leverage in the vicious sugar market. These contests took place as much on the underbelly of the "tariff question" as on its surface, and were fought not over its rates, but its material means of enforcement. In those struggles, as in other battles between Gilded Age industrialists, Congress was a battlefield and legislation was

387. The *Eagle* cited the "Pittsburgh Chronicle" but that paper had been succeeded by the *Chronicle-Telegraph* since 1884 (http://chroniclingamerica.loc.gov/lccn/sn84026126/).

a weapon.[388] But just as tariff rates were only part of the fights among refiners, so too was Congress just one arena among many. Just as important, but far less well understood now, were the country's major ports in Boston, Philadelphia, Baltimore, and above all New York and Brooklyn.

In the decades following the Civil War, the sugar trade in the United States was plagued by charges that the largest and most powerful sugar importers and refiners exercised undue influence on how sugar was sampled, weighed, measured, and valued.[389] During a time of falling refining profits, these charges were leveled primarily by smaller firms outmuscled by newer, larger, more efficient competitors, and their claims have been dismissed as resentment at being outcompeted in the marketplace.[390] This chapter takes these allegations seriously, but not in order to prove or disprove the existence of corruption in the collection of sugar duties.

In this respect, the analysis here differs from Richard White's recent work on corruption and the building of transcontinental railroads.[391] White shows how competing roads used their influence with legislators to write and rewrite laws to help themselves and harm their competitors. In privately acknowledging the danger should their covert exchanges of gifts and political favors become public, he argues, these officials and

388. Alfred S. Eichner, *The Emergence of Oligopoly: Sugar Refining as a Case Study* (Baltimore: Johns Hopkins University Press, 1969), 55.

389. As Raphael Samuel wrote, the economic growth of the nineteenth century depended upon not just new machines and new systems of labor "a promiscuous variety of profit-making devices," of which two of the most common were adulteration and artificial coloration of everything from soot to smoked fish. Samuel, "Workshop of the World," 8.

390. Eichner, *Emergence of Oligopoly*, 51.

391. Richard White, *Railroaded: The Transcontinentals and the Making of America* (New York: W. W. Norton, 2011).

businessmen implicitly revealed their society's rules about what was acceptable behavior for political participants, rules which more or less resemble our own.[392] But government officials or energetic private citizens confronted a murkier situation when they attempted to discover corruption on the part of those who possessed intimate knowledge of how a commodity's substance related to its value. They discovered instead that it was exceedingly difficult for non-experts to point to exactly how and where the corruption of the "proper" exercise of judgment in the assessment of duties had taken place. Rather than providing evidence of corruption, therefore, such allegations become valuable to historians in other ways. They allow us to see how the definitions of corruption and of proper judgment were themselves at stake in the contests over the value of sugar, and thus how some forms of knowledge came to be seen as legitimate while others became illegitimate.[393] Thus we can better understand the work required to reduce a complex

392. To White, the consequence of battles between railroads for Federal land grants and subsidies meant that "what might have been done relatively methodically, efficiently, and cheaply"—the building of transcontinental lines—"would be done badly [and] expensively" (26). The problems of such a retrospective interpretation are apparent not just to historians of science and technology. As the political scientist Gerald Berk noted of these same railroads, there was no "metarule of efficiency" to be uncontroversially or nonpolitically employed. The outcome behavior of this period's officials and businessmen was not a deviation from some alternate, imaginary, objectively "rational" course. See Gerald Berk, *Alternative Tracks: The Constitution of American Industrial Order, 1865-1917* (The Johns Hopkins University Press, 1997), chapter 1.

393. I am drawing on the work of Simon Schaffer and Peter Linebaugh, among other scholars. In his analysis of Benthamite reforms of British shipyards around 1800, Schaffer argues that that the power of terms like "theory" and "experiment," and dichotomies like "science"/"art" and "reason"/"tradition" were not the causes of the struggle between management and labor but instead its results. Linebaugh demonstrates a similar conflict over the terms of criminality and fraud in London in the seventeenth and eighteenth centuries. See Schaffer, "'The charter'd Thames'," and Linebaugh, *The London Hanged.* The editors of *Corruption: Anthropological Perspectives* note that because people are much more likely to talk about corrupt acts by others, anthropology and other social sciences are "perhaps better placed to deal not so much with corruption per se as with allegations of corruption and their effects." Dieter Haller and Cris Shore, eds. *Corruption: Anthropological Perspectives* (Ann Arbor: Pluto, 2005), 14.

natural substance to a single economic value, and how that work was tied to the relationship between government and private power in the late nineteenth century.[394]

The gravest charges centered on the Federal Custom House in Manhattan, already the focus of American politics as the juiciest plum in the spoils system of political appointments, and thus the target of civil service reformers. It was also where half the tariff revenue was collected and where the fruits of empire arrived.[395] Yet while the nineteenth-century American custom house in general has recently been the subject of historians' renewed interest, none have investigated how the physical and spatial organization of these crucial institutions affected how they operated or how revenue was actually collected in the world of the port.[396] This is in spite of the fact that, as Will Ashworth points out of the eighteenth-century English excise, it was on "officers'

394. For the nature of the Federal government, see Brian Balogh, *A Government Out of Sight: The Mystery of National Authority in Nineteenth-Century America* (Cambridge: Cambridge University Press, 2009).

395. Stephen Skowronek, *Building a New American State: The Expansion of National Administrative Capacities, 1877-1920* (Cambridge: Cambridge University Press, 1982), especially Chapter 3, "Patching civil administration: the limits of reform in the party state." For the custom house as "policeman of republicanism," see Wender Cohen, 385.

396. Gautham Rao, "The Creation of the American State: Customhouses, Law, and Commerce in the Age of Revolution," (Ph.D., University of Chicago, 2010); Robert E. May, "Culture Wars: The U.S. Art Lobby and Congressional Tariff Legislation During the Gilded Age and Progressive Era," *The Journal of the Gilded Age and Progressive Era* 9, no. 1 (January 1, 2010): 37–91. Nicholas Parrillo, in his new book *Against the Profit Motive: The Salary Revolution in American Government, 1780-1940* (New Haven: Yale University Press, 2013), conducts a detailed analysis of the "moiety" incentives, in which customs officials were given a percentage of the value of seized property, that structured the work of the customs house in New York City until 1874. Parrillo identifies four factors in the movement against moieties in the late 1860s and early 1870s: the national-politicization of the customs house, the increase in tariffs, the increasing severity of forfeiture rules, and new seizure powers. The mercantile community was disturbed not just by the higher tariffs but by the aggressive searches for "intentional" fraud on the part of customs officials and Treasury special agents. But while his analysis of these factors is convincing, his conclusion is not as persuasive. In framing Congress's passage of the Anti-Moiety Act of 1874 as an attempt to inspire willing compliance with regulations on the part of merchants, he is too credulous of claims that the abolition of moieties would "make every honest importer and merchant a watchman for the Government" (249).

everyday activities that the fiscal future of the state ultimately rested."[397] Such an investigation reveals the central role of particular spaces, individuals, and types of knowledge to the collection of customs on commodities. Yet there is a surprising scarcity of evidence, writes Akhil Gupta in the context of modern India, on "what lower-level officials actually do in the name of the state," and on how where they do their work affects the ways they do it.[398] In the late-nineteenth-century custom house, the crucial spaces were refinery docks, appraiser's stores, and chemical laboratories. The government relied on its expert agents to work in these settings, but they were also secluded places where that same expertise made it hard to hold such agents accountable.[399]

In elucidating how the power to assign values to sugar was wielded by samplers, appraisers, chemists, and others who actually manipulated the sugar itself, this chapter argues that the introduction of chemical testing into the New York custom house made it more, not less, difficult to locate and define the sources and methods of corruption. The fact that sugar refining was a high-volume, low-margin business created particularly strong incentives, in the eyes of contemporaries, to manipulate the collection of tariffs: even a small saving in the duty paid could amount to a significant proportion of the profit

397. William J. Ashworth, "'Between the Trader and the Public': British Alcohol Standards and the Proof of Good Governance," *Technology and Culture* 42, no. 1 (January 2001): 27–50.

398. In the case of local officials in India, Gupta explains that while Western standards emphasize "historical experience has been built on states that put people in locations distinct from their homes...to mark their 'rationalized' activity as office holders in a bureaucratic apparatus....One has a better chance of finding [lower-level officials in India] at the roadside tea stalls and in their homes than in their offices" (384). Akhil Gupta, "Blurred Boundaries: The Discourse of Corruption, the Culture of Politics, and the Imagined State," *American Ethnologist* 22, no. 2 (May 1, 1995): 375–402, 376.

399. For a detailed investigation of the ways certain places are associated with the legitimate exercise of skill, see Schaffer, "Golden means."

on a pound of sugar, which never rose above a few fractions of a cent. But the polariscope, the instrument that was claimed to render the valuation of sugar objective, instead highlighted the extent to which that process of valuation depended on the trust vested in experts.

The first section shows how the attention paid to the samplers and appraisers of sugar reveals the importance and difficulty of government supervision of its expert employees. The second discusses a new instrument meant to substitute for the subjective grading of sugar by color, and how its introduction exacerbated the problems of supervision rather than resolved them. Finally, two episodes from 1907 together indicate the power refiners had over the assessment of sugar values. Ultimately, this chapter suggests, control over the means of customs valuation and control over the meaning and nature of sugar were essential to the consolidation of the power of the Sugar Trust, and its opponents knew it.

2. The colors of sugar, the judgment of samplers, and the morals of labor

Upon becoming Treasury Secretary in early 1877, the Ohio senator John Sherman assigned three-man commissions, made up of Treasury agents, lawyers, merchants, and civil-service reformers, to investigate the employment practices at the Federal custom houses in Philadelphia, Boston, Baltimore, New Orleans, San Francisco, and most of all New York. These were an appealing political target, the last in particular. "More than any other single office, the New York Customhouse [sic] symbolized the fusion of party and state, and more than any other single office, it focused the interests of merchants and gentlemen against spoils administration," Stephen Skowronek writes. "Spoils and industrial combinations were linked by reformers and merchants in a single system of governmental corruption and collusion."[400] Yet while the newly elected President Hayes himself may have been most interested in reform, Sherman was more attracted by the fact that the Manhattan custom house was the deepest reserve of patronage power for the New York Republican machine, let by his intraparty rival in the Senate, Roscoe Conkling. Sherman and Blaine led a faction of the party that sought to nationalize its structure and fundraising and ally it more closely with industrial and monied interests. The commissioners in New York, therefore, included the lawyer John Jay and the Democrat Lawrence Turnure, of the trading firm of Moses Taylor & Co., among the most influential sugar merchants in the country.[401] At the same time, Sherman assigned panels specifically to investigate the sugar drawback—the amount of import duty refunded upon re-export, which depended on the government's calculation of how much raw sugar was lost in the refining process. This made the drawback for sugar trickier to assess than for other goods that were reexported without being modified. The reports of these panels began to arrive in late spring.[402] The reports of the commissions on sugar and on custom-house employment were transmitted to Congress in the same document, with the drawback

400. Skowronek, 51-52.
401. Hartman, "Politics and patronage," 203.
402. "Commissions to Examine Certain Customhouses of the United States," House of Representatives Executive Document 8, 45th Congress, 1st session (October 25, 1877).

reports printed first. Thus, problems of the reliability of government employees and of the qualities of the sugar itself were already closely related.

The drawback commissioners reported that the trouble with the sugar tariff dated to 1861. That year, Congress had passed new tariffs to pay for the cost of the Civil War. The section of the bill pertaining to sugar specified the use of the "Dutch standard" for levying duties in rough proportion to sugar's value. This standard was a series of jars produced and certified by the government of the Netherlands, which contained samples of sugar of different colors. These were arranged, from lowest (6 or 7) to highest (about 25), by order of lightness—and thus, supposedly, by quality, value, and sweetness.

> On raw sugars, commonly called muscovado or brown sugar, and on all sugars not advanced above number twelve Dutch standard by claying, boiling, clarifying, or other process, and on sirup of sugar or of sugar-cane, and concentrated molasses...two cents per pound; and on white and clayed sugar when advanced beyond the raw state above number twelve Dutch standard by clarifying or other process, and not yet refined, two and a half cents per pound; on refined sugars whether loaf, lump, crushed, or pulverized, four cents per pound ; on sugars after being refined, when they are tinctured, colored, or in any way adulterated, and on sugar candy, six cents per pound.[403]

These jars of sugar would prove less stable than legislators hoped. The text of the instruction suggested that the customs officer had to know something about how the sugar was produced and how that production related to its color, not merely the color

403. Gideon E. Moore, *Statement Relative to the Artificial Coloring of Imported Sugars* (U.S. Government Printing Office, 1881), 14.

itself. And the relationship among color, value, and kind was almost immediately destabilized. In December 1861, the government seized a shipment of sugar that it claimed had been falsely labeled as "quebrado," a type of raw sugar. But witnesses for the accused importer testified that in Cuba, the source of the cargo, "quebrado" could mean anything from dark brown to bright white.[404]

In an attempt to align the tariff categories more closely with the actual value of sugars of different hues, in 1870 a Congress added several further grades, so that less costly sugars would not be unduly penalized. That bill created categories for sugar below 7 on the Dutch scale, from 7 to 10, 10 to 13, 13 to 16, 16 to 20, and a final one for sugar above 20.[405] The drawback commission warned that this profusion of categories since 1861 had made the Dutch standard all too easy for samplers and examiners to manipulate and all but impossible for anyone above them to effectively supervise. In 1872, moreover, tariffs were lowered by 25%, but three years later, faced with a revenue shortfall, Congress repealed that reduction. By raising the rates it made the duty on higher-grade sugars more costly as a proportion of the value of the sugar itself.[406] Over the following years, the Treasury had received increasing reports that sugar was being under-classified to evade these new and higher duties, both by having their color manipulated in production, and through the efforts of samplers, appraisers, and others in the custom houses who were friendly to those in the sugar business. The worried commissioners

404. "Important to Sugar Dealers," The New York *Times*, 6 July 1862. See Moreno Fraginals, *The Sugarmill*, 34, for more on "quebrado" sugar as "of intermediate color" from the middle of the drained loaf.

405. Moore, *Statement*, 16.

406. F. W. Taussig, *The Tariff History of the United States, Part I*, 5th ed. (New York: G. P. Putnam's Sons, 1910), 142.

credited the testimony they had taken from sugar refiners and importers in Boston, who claimed that American firms had already placed massive orders with European beet-sugar producers. These cargoes would be delivered in the autumn, tinted to evade all but the lowest rate of sugar tariffs. The commissioners proposed an extra 33% levy on sugar judged artificially colored.[407] In August, Sherman issued a circular to the all custom houses, instructing them to seize and declare forfeit all sugar which the officers there deemed to have been colored specifically to evade the tariff.[408] At the same time, he told appraisers to find chemists who could conduct tests in cases of disputed coloration. The newly appointed appraiser in New York, Silas Dutcher, quickly sought help from Charles Chandler, the Columbia chemistry professor and president of the New York City Board of Health.[409] At the end of 1877, in his first annual report to Congress, Sherman admitted that "Embarrassment has occurred during the past year in the collection of duties on sugar." He again referred to the work of the Jay Commission "to investigate generally the manner in which the customs business has been conducted" with the alteration of the sugar tariff. While his report admitted that he had yet uncovered no proof of artificial coloration, he insisted that "the suspected sugars...were of a higher intrinsic grade in many cases than those paying higher rates of duty." He called for the abandonment of the Dutch standard, "which bears no definite relation to the value of the sugar" and thus could be subverted by "foreign substances." But he acknowledged Congress might not

407. "Commissions to Examine Certain Customhouses," 6-7.

408. "Washington: The Duty on Sugar," The New York *Times*, 1877 August 21.

409. Dutcher to Chandler, 11 September 1877, Box 260, Folder 10, Charles F. Chandler Papers, Rare Book and Manuscript Library, Columbia University (hereafter RBML).

wish to abandon the system and thus recommended a simpler tariff containing only three rates, one for sugars up to No. 13 on the Dutch scale, one between 13 and 20 and one "for all sugars above No. 20, including all refined sugars." The Treasury calculated this would produce the same revenue and be simpler to enforce.[410] In his own annual message, President Hayes explicitly linked judgment, corruption, and the tariff, arguing that "so far as practicable the rates of taxation should be in the form of specific duties, and not ad valorem, requiring the judgment of experienced men to ascertain values and exposing the revenue to the temptation of fraud."[411]

Yet the forfeiture policy had already encountered difficulty—but in the eyes of those subjected to it, this was just what Sherman wanted. In November 1877, a shipment of 712 bags of dark sugar from Demerara was seized at the port of Baltimore. The Federal attorney, suing for forfeiture, charged that the sugar had been darkened after its production specifically to evade American tariffs and that W. H. Perot, the importer, was well aware of this fact.[412] Perot did not deny that the sugar was dark, but did protest that there was nothing "artificial" about the color since nothing had been added. Instead he insisted its hue came from the presence of molasses and other impurities which had remained during the boiling and cooling process. A month later, another Demerara cargo was likewise confiscated, this time in New York. This second seizure forced Sherman

410. *Annual Report of the Secretary of the Treasury on the State of the Finances for the Year 1877* (Washington, D.C.: Government Printing Office, 1877), xxvi; *Review of the Efforts of the Forty-Fifth Congress of the United States for the Revision of the Sugar Tariff, together with Speeches Made by Members of the House of Representatives* (New York: n.p., 1879), 3-4.

411. "President's message," The New York *Times*, 4 December 1877.

412. *A Review of the Case of the United States vs. 712 Bags of Dark Demerara Centrifugal Sugars, A.W. Perot & Co., Claimants: Tried at the September Term of the District Court of the U.S. for the District of Maryland* (Baltimore: Lucas Brothers, 1878), 4.

into an awkward position. The furious importers, Maitland, Phelps & Co., "not wishing to be involved in any controversy on the subject with your department or its agents," insisted to Sherman that they had specifically advised their suppliers against any extraordinary coloration whatsoever. Moreover, the appraiser in New York ruled that the sugar was not artificially colored at all. But Sherman, overruling his Manhattan subordinates' judgment, replied to Maitland that their sugars were "found to be of the same character as other sugars heretofore seized, as being artificially colored." He declared that "the individual opinion of the Customs officers at New-York cannot control the action of the department," yet it was his officers' "individual opinion" that he depended on for seizures, and indeed had "found" the sugars' "character."[413] In these two incidents, barely a month apart, the Treasury was already dangerously stretched between seemingly contradictory official positions on its own employees' expertise and competence.

The mercantile community of Baltimore argued that the government confused theoretical and practical expertise, and that, in the evaluation of sugar, the latter was both superior and necessary. The government's witnesses at trial consisted of chemistry professors and sugar refiners from New York. None of them, Perot's laywers pointed out, had ever actually seen sugar being made in the Caribbean, nor tried the processes in use there, nor least of all made sugar for any purpose other than ones "wherein clarification and lightness of color are the great objects."[414] The defense, by contrast, traced the path of

413. "Colored imported sugars," The New York *Times*, 26 January 1878.
414. For geographies of skill and tropical commodities see Schaffer, "Golden Means."

the sugar for the jury, from canefield to plantation to vessel to American port, identifying the owners and sugarmasters.[415] They also cited Henry Morton, professor of chemistry and president of the Stevens Institute of Technology in Hoboken, to whom the government in September 1877 had submitted "suspicious" samples and asked for analyses. Morton had replied in November that he had not found any extrinsic substances, but that his analysis could not determine whether it was just a "peculiar" process that had created the colored sugars or something else. That could "only be established," he argued, "by actual observation of the process employed."[416] Perot, like Dutcher, attempted to solicit the advice and help of Charles Chandler, but much to Morton's irritation, these pleas were ignored.[417] The city's *Evening Bulletin* assailed the Treasury for its ignorance of the effect of the tariff on the producers of the Caribbean.[418] It wondered why, rather than fixing its own means of tariff assessment, "the Treasury Department has insisted on finding fault with the sugars."[419] Editorials accused him of having ignored pleas and petitions from sugar importers since entering office. His only goal was "to procure a change in the tariff, by so persecuting the trade as to compel Congress to listen to its cries."[420] At heart, the paper insisted, this was a campaign of

415. *Review of the Case*, 7, 27.

416. Ibid., 11.

417. For correspondence among Perot, Morton, and Chandler, see Chandler Papers, Box 260, RBML.

418. The *Evening Bulletin* had been edited and published by William Laffan, but by this point had left to edit the conservative New York *Sun* for Charles Dana and, subsequently, J. P. Morgan. Library of Congress, "Baltimore Bulletin.," Chronicling America: About Baltimore Bulletin, accessed July 22, 2014, http://chroniclingamerica.loc.gov/lccn/sn84026777/.

419. Editorial review, 14 December 1878, quoted in *Review of the Case*, 1-2.

420. *Review of the Case*, 59. Such statements by merchants and their representatives in the press cast doubt on Nicholas Parrillo's arguments in *Against the Profit Motive*. In his discussion of anti-moiety legislation, Parrillo argues that Congress was attempting to "rescue the mutual trust between government and merchants" (248). The *Evening Bulletin*'s assessment of the relationship among Congress, the Executive, and commercial interests would strongly suggest that Congress was not an independent actor

Federal aggression against private industry, and Sherman was merely interested in demonstrating his power to crush merchants at will.[421]

Though the jury concluded that the sugar had, somehow, been manipulated to avoid the tariff, they were persuaded by Perot's attorneys that the innocent importer had not known about it.[422] Following the trial, Sherman dispatched three Treasury special agents to the Caribbean, who presented samples of seized sugars from American ports to local planters and sugar-boilers for evaluation.[423] Contrary to the testimony of Perot's witnesses, the agents reported that the sugars had indeed been engineered to circumvent the tariff. The samples' quality was unquestionable: they had been "made with care, to eliminate the impurities, and, as a rule, are superior in their character."[424] In the near-universal judgment of the planters and masters Chamberlin's expedition encountered, the seized sugars were all "firm and well defined," properties only producible by skilled and patient clarification. The pan-boiler on one Demerara estate examined a sample brought from New York and declared that it had been boiled for three days: first to create a fine-

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with its own interests to balance against those of merchants (and thus "Congressional intent" is not a useful analytical framework), and just as importantly, that no one at the time thought that it was thus independent.

421. Having remained in the Union, Maryland had not been subject to Reconstruction, but as a slave state it had only been kept from joining the Confederacy by unprecedented exertions of Federal power. The year after Reconstruction's inglorious termination in the Congressional deal that had brought Hayes and Sherman to executive office, the complaints in Baltimore of such "scandalous" tactics and "practices upon the citizen" were politically freighted.

422. Deborah Jean Warner, "How Sweet It Is: Sugar, Science, and the State," *Annals of Science* 64, no. 2 (2007): 147-170, on 153 and 158.

423. The report did not explain how the agents had selected their sources, though they did note that they began in Dominica because that island "exhibits the manufacture of sugar in the crudest form, thereby affording us an opportunity to commence our investigations, by becoming familiar with the simplest process of making muscovado." From there they planned to gradually learn the "most improved methods now in use, in the manufacture of vacuum-pan sugars." *Report on the Methods of Manufacturing Sugars in West India Islands and British Guiana*, United States Treasury Department (Washington, D.C.: Government Printing Office, 1880), 3.

424. *Report on Methods*, 28.

grained crystal, then to build on those crystals, and finally "burning the molasses over the crystals after they had been formed much lighter." These sugars were "an unnatural dark color...even darker than the crudest muscovado," and had thus transparently been produced to evade American customs duties. Yet the investigators could still point to nothing "artificial" about the way they had been made.[425]

The way such mercurial qualities would be assessed in American ports was a question before the drawback commission. One of their chief answers revolved around the labor of the custom-house sampler, and the place he worked: not in the custom house itself, but on the docks of the sugar refinery. Docks under refineries' exclusive control were still a relative novelty in the 1870s. Since the early eighteenth century, New York's sugar refineries had been located in lower Manhattan, but not along the waterfront. Instead, refineries had paid to cart their hogsheads of sugar from the wharves into the city streets.[426] In the 1840s and 1850s, however, Congress permitted merchants to store imports in bonded warehouses, where they would not have to pay tariffs before finding a buyer or re-exporting the goods. The liminal status of these warehouses, physically onshore and yet legally offshore, with easy access to the waterfront but out of reach of the Treasury, made large waterfront properties suddenly more desirable.[427] Taking advantage

425. Ibid., 16.

426. Eichner, 26-30; James Bradley, "Sugar," in Kenneth T. Jackson, ed., *The Encyclopedia of New York City* (New Haven: Yale University Press, 1995); Robin Shulman, *Eat the City: A Tale of the Fishers, Foragers, Butchers, Farmers, Poultry Minders, Sugar Refiners, Cane Cutters, Beekeepers, Winemakers, and Brewers Who Built New York* (New York: Crown, 2012), 156.

427. Gautham Rao, "Cities of Ports: The Warehousing Act of 1846 and the Centralization of American Commerce," *Thresholds: The MIT Department of Architecture's Critical Journal of Architecture, Art, and Media Culture* 34 (Autumn, 2007): 34-37; Daniel Margolies, "'Factors of Universal Commerce:' Bonded Warehousing and the Spatialities of Mid-Nineteenth Century American Foreign Trade Policy," *World History Bulletin* 21 no. 1 (Spring 2013): 22-30.

of the fact that even a refinery could be declared a bonded warehouse, William and Frederick Havemeyer, German immigrants who were then the largest refiners in the city,[428] moved their company to a site on the Williamsburg waterfront in the mid-1850s.[429] There, at the cost of nearly a million dollars, they built a huge new refinery, boasting its own docks on the East River.[430] Having independent access to the water allowed the Havemeyers to unload cargo directly into their refinery, saving on middlemen, storage, and transport.[431]

Smaller rivals, however, argued that the true advantage given by private docks was the fact that collectors of customs duties would now have to work on the refiner's property rather than on public wharves. Nineteenth-century observers of other private or enclosed docks likewise admired the protected space they offered. American travelers to England marveled at the huge "wet docks" of London and Liverpool, noting the "security" the docks afforded to the activities inside their walls. In London, as Peter Linebaugh shows, that security had meant regulating the labor of dock workers, eliminating the customary takings of sugar and other goods that had long supplemented their income.[432] In the case of the customs in Brooklyn, however, the labor in question was that of the sampler, the lowest-ranking official in the customs administration. It was

428. Jack Mullins, "The Sugar Trust: Henry O. Havemeyer and the American Sugar Refining Company" (Ph.D., University of South Carolina, 1964), 3-4.

429. Eichner, 40-41.

430. Ibid., 39; Betsy Bradley, *Tribeca North Historic District Designation Report* (New York City Landmarks Preservation Commission, December 1992).

431. Harry Waldron Havemeyer, *Merchants of Williamsburgh: Frederick C. Havemeyer, Jr., William Dick, John Mollenhauer, Henry O. Havemeyer* (New York: Privately Printed, 1989), chapter 4.

432. Linebaugh, *London Hanged*, chapter 12, "Sugar and Police," especially 425; Tamara Plakins Thornton, "Capitalist Aesthetics," in *Capitalism Takes Command: The Social Transformation of Nineteenth-Century America*, ed. Michael Zakim and Gary John Kornblith (Chicago: The University of Chicago Press, 2012), 169–198, on 180.

his task to extract a representative sample of each cargo.[433] The commissions investigating the custom house, Sherman himself, and importers "frozen out" of the private dock system all agreed that at $100 a month, the poor wages of the sampler rendered them easy targets for bribery.[434] In practice, however, samplers were entrusted with enormous authority.

This was because the packages of sugar they were responsible for sampling were themselves accepted to be highly variable. Most of the sugar arriving in the United States landed in huge hogsheads of up to fifteen hundred pounds apiece, "and any one familiar with these sugars must be aware that samples can be drawn from different sections of the same cask that will vary from four to five [Dutch scale] numbers in color" (**Figure 4.1**).[435] The tool of the sampler was the trier: a long, thin metal tube with handle at one end and a sharp edge at the other, which he thrust into the package of sugar. The regulations on the books left the manner of its use to the sampler himself, specifying only that "samples from packages of sugar shall be taken by the proper Officers, in such manner as to ascertain the true quality."[436]

433. *Annual Report of the Secretary of the Treasury on the State of the Finances for the Year 1878* (Washington: Government Printing Office, 1878), xxviii.

434. "Freezing out refiners," The New York *Times*, 23 February 1880, and "The Custom House System," The New York *Times*, 2 May 1877.

435. "Commissions to Examine Certain Customhouses of the United States," 7.

436. Quoted in Henry Alvin Brown, *Sugar Frauds and the Tariff: Their Relations to Home Product, Consumption, Industry, Imports, Duties and Revenue, Analyzed and Exhibited. Duty & Drawback, Sampling & Grading. Adulterations and the Polariscope. Official Statistics, Remedies, &c.* (n.p.,1879), 24.

Certificate of polarization, showing variations in polariscope test in a single hogshead of muscorado sugar No. 10 Duch Standard in color.

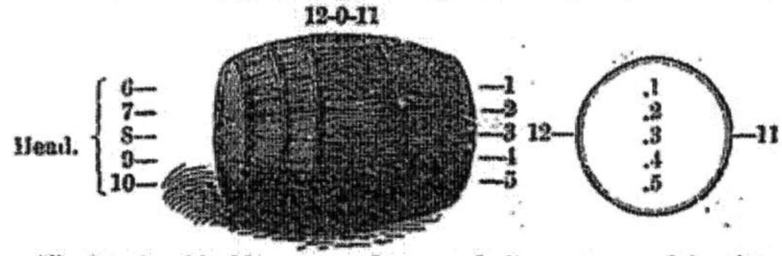
[P. de P. Ricketts, E. M., Ph. D., assayer and chemist, corner 50th street and Fourth avenue, New York city. Jan. 19, 1880.]

NEW YORK, *January* 27, 1880.

CERTIFICATE OF ANALYSIS.

DEAR SIR: The samples of "Porto Rico" sugar taken by me from hogsheads, as indicated below, and marked No. 1 to No. 12, inclusive. "H. 1548," submitted to me for examination, contain, by polariscope test:

	Cane sugar. Per cent.		Cane sugar. Per cent.
No. 1	83.40	No. 6	76.70
No. 2	86.30	No. 7	82.00
No. 3	86.60	No. 8	84.10
No. 4	87.00	No. 9	84.80
No. 5	87.20	No. 10	83.80
No. 11	82.20	No. 12	79.90



The hogshead had been turned over and allowed to stand five days before sampling, in order to let the moisture mix evenly through the mass. The same instrument, apparatus, &c., was used for all the tests.

Very respectfully,

[SEAL.] P. DE P. RICKETTS, *Ph. D.*

Figure 4.1: Tests of samples taken from different parts of a hogshead (Searles, 1880)

Silas Dutcher, a longtime Custom House employee promoted to Appraiser in 1877 and therefore in charge of all shipboard and dockside customs officers,[437] defended before a House of Representatives committee hearing the prerogatives each sampler enjoyed to do his job. Such liberty was especially necessary when the sugar arrived after a voyage during which the molasses had drained, creating a "foot" of wetter, darker sugar at the bottom and a lighter portion up top. As Dutcher put it, "it requires a good deal of judgment on the part of the Sampler, and whoever is supervising the Sampler, to get at

437. William Jay Hartman, "Politics and Patronage: The New York Custom House, 1852-1902" (Ph.D., Columbia University, 1952), 15-16.

the exact proportions of the dry and wet sugars in a hogshead where there is a foot...they may have to bore two or three times before they can ascertain satisfactorily [the foot's] depth."[438] If a sampler was inclined to help the purchasing refinery, he might take from the darker portion and thus lower the duty; if, on the contrary, he was of a mind to favor a competitor, he could sample from the lighter part of the barrel. By doing so he could add or subtract large fractions to the duty owed.

The more testimony Congress and the Treasury heard, the more sampling seemed an obscure art. It took six months to train "an intelligent man" to be a sugar sampler, but even after thirty years of work, a pair of samplers could strongly disagree on what constituted a "representative" extract of a cargo or even of a single hogshead.[439] One ex-Customs agent, Henry Brown, mocked Dutcher's "charming naivette" [sic] in trusting his samplers' judgment. Brown compared American regulations unfavorably to those in effect in Great Britain, which had specified not just the positions of the hogshead as they were removed from the hold, but also the precise bodily actions of the sampler himself: "the sampling iron should be driven in by a hammer or mallet if necessary, till it strikes the bottom stave; and that after giving the iron two or more turns it should be withdrawn...*[N]o discretion in assessing the duty should be exercised* on account of the larger quantity of 'foot' that some sugar...generally contain[s]."[440]

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438. *Testimony in Relation to the Sugar Frauds, Taken by the Subcommittee of the Committee of Ways and Means of the House of Representatives, New York, September, 1878* (Brooklyn: Brooklyn Daily Times Print, 1878), 7.

439. "The Custom-House Inquiry: Further Evidence By Examiners," The New York *Times*, 23 May 1877.

440. Brown, *Sugar Frauds and the Tariff*, 26. Emphasis added.

The claimed checks on the "discretion" of samplers were their superior officers, the examiners. But only four examiners were employed to monitor over a dozen samplers along "the whole Brooklyn river front, from Greenpoint to Red Hook," a distance of about six miles.[441] Samplers were also supposed to rotate to other parts of the harbor after two weeks, but in practice this did not often happen.[442] Outnumbered, faced with his lengthy patrols, and with samplers who had plenty of time in their absence to work unsupervised, all that the examiner could do was take a quick sample himself. Even then, Dutcher testified, he too merely "forms his opinion, his general judgment regarding the character of that cargo." Frustratingly for the higher-ranking customs officials, here too they seemed to have no way of checking the estimations of their deputies. Some examiners did not even bother with "personal direction and oversight" at all.[443] The outspoken refiner Lawson Fuller, a fierce critic of the private docks, testified to the House Ways and Means Committee that no such partial surveillance could prevent manipulation by samplers so inclined. "I sampled for three years myself," he said, "and if I were in the business now I believe I could cheat the government out of a quarter of a million dollars...and I believe anybody else could do it."[444]

Once a sampler on the dock had extracted what he claimed to be a representative sample of the cargo, an official messenger was supposed to convey the tins of sugar to the

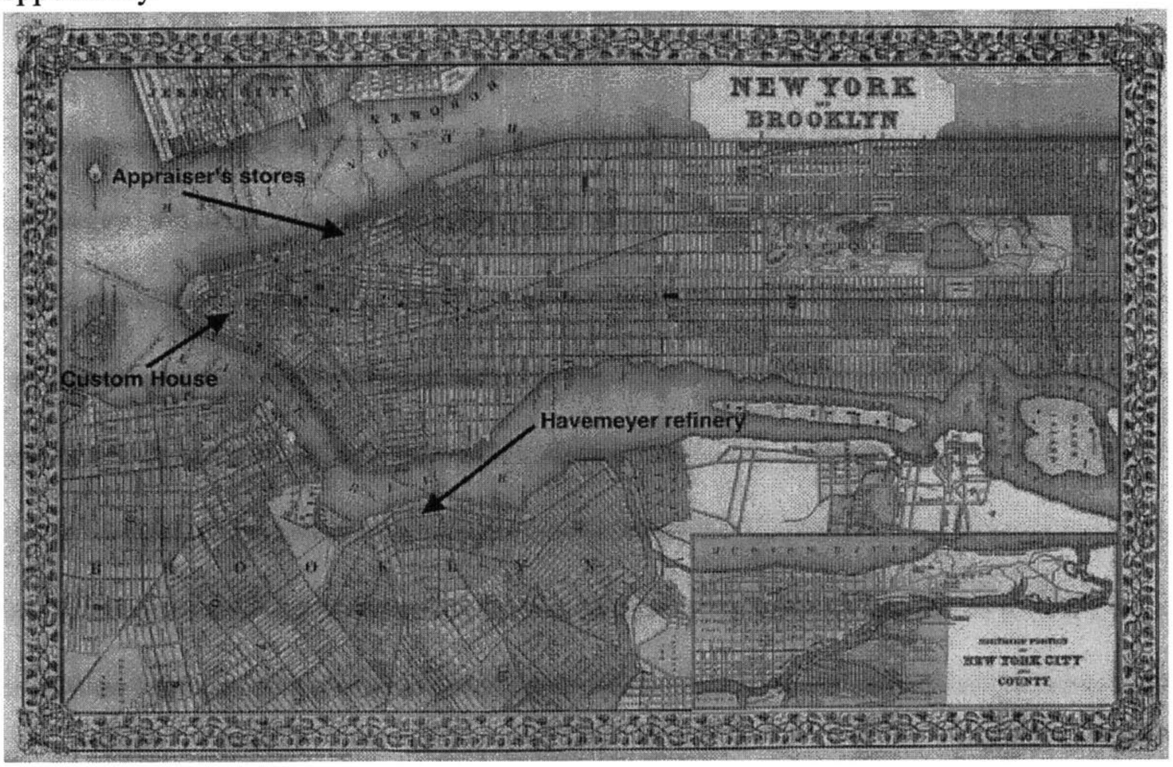
441. In 1890, six customs districts covered New York Harbor. The first encompassed Manhattan, Yonkers, Jersey City, and Hoboken, while the second through sixth districts divided up the Brooklyn waterfront from Greenpoint to Bay Ridge. "No sand in this sugar," The New York *Times*, 27 July 1890.

442. *Testimony in Relation to the Sugar Frauds,* 4.

443. "Commissions to Examine Certain Customhouses of the United States," 91.

444. *Testimony in Relation to the Sugar Frauds*, 4, 39.

appraiser's stores (**Map 4.1**).[445] That facility, a division of the Custom House, had moved north in 1874 from lower Manhattan, to an old sugar refinery at the intersection of Laight and Canal Streets. It was near the bonded warehouses that were springing up along the Hudson, but it presented the large Brooklyn refiners with another exploitable opportunity.[446]



Map 4.1: Geography of the sugar trade, 1870s-1890s

Sugar importers complained that the new location forced them to incur both licit and illicit costs. The merchant Royal Phelps petitioned Collector Arthur in July 1877 for a relocation of the appraiser's division. Phelps explained how the distances between the appraisers and Custom House downtown prevented effective supervision of the

445. Ibid., 3.

446. "The Appraiser's Department," The New York *Times*, 1 July 1874; Bradley, *Tribeca North Historic District*, 3, 18.

appraisers, and how the distance to Brooklyn kept appraisers from watching over samplers and examiners:

> ...[M]erchants are put to great inconvenience and expense by having the appraisers so far away from the custom-house, to say nothing of the greater facilities the appraisers have for committing fraud, if they should be so inclined, by being, so to say, isolated from easy contact with the collector and deputy collectors of the custom-house...In the appraiser's office there are more opportunities for frauds than in any other department of the customs. Then why have the appraiser's office so far away from the observation of the revenue officers of the port?...[I hope] you agree with me in the absurdity of having to cart our samples of sugar two miles away from the custom-house to get them appraised, thus practically preventing the appraiser from testing the correctness and honesty of the sampler.[447]

Even Appraiser Dutcher himself thought his office was "well adapted to its purposes, but too far from the Custom-house."[448] Those miles made a difference to the physical matter of the sugar itself, and to the manipulability of that matter. "I should put my sugar office over where the sugar was," suggested the importer Henry Hitch. "If they are on the dock, and the sun is hot, [then the sugar] has got to go up to Laight street [sic], and won't probably be opened for a day or two, and, then, very often it has changed in color." The heat might evaporate the moisture in the sugar, lightening its color and making it seem more refined than it really was.[449]

447. "Commissions to Examine Certain Customhouses," 70.
448. "The Custom House System: Continuation of the Inquiry," The New York *Times*, 2 May 1877.
449. *Testimony in Relation to the Sugar Frauds*, 28.

Domestic monopoly, overseas empire, immigration, and the skill of labor of all kinds were always intertwined in sugar tariff questions, sometimes as subtexts, but sometimes explicitly. Before the Civil War Americans had feared a conspiracy of the Southern slave power; now they saw the same devil coming from abroad. These new concerns were linked to the tariff and the ways it was being subverted.[450] Large refiners, in particular, claimed that their business would be subverted by a uniform tariff. Part of the premise of such a tariff was that particular refiners and importers were colluding with suppliers to adjust the color of their sugars—in other words, that these domestic businessmen were too closely tied with planters in the Caribbean. But the opponents of the uniform tariff inverted the very same charge. Its advocates, they claimed, were a devious fifth column: the single rate would throw open the gates to an invasion of the products of cheap Cuban slave labor and the destruction of domestic industry.

Lawrence Turnure, partner in the merchant firm of Moses Taylor and Jay commissioner, cautioned the Ways & Means Committee in the fall of 1878 that a single tariff rate up to 16 Dutch Standard would make Cuba "the grand refinery of the world."[451] But Cuba's domestic and foreign positions were turbulent. In 1878 the Ten Years' War was coming to a close. The conflict had reduced production on the island, even as it prompted supplemental sugar cultivation elsewhere in the world.[452] Still, the Creole

450. Wender Cohen, 385. For the ever-present fear of late-19th-century conspiracies, see Richard Hofstadter, "The Paranoid Style in American Politics," *Harper's Magazine*, November 1964, and *The Age of Reform: From Bryan to F. D. R., 1st ed.* (New York: Knopf, 1955).
451. *Testimony in Relation to the Sugar Frauds*, 60.
452. Sven Beckert, "Emancipation and Empire: Reconstructing the Worldwide Web of Cotton Production in the Age of the American Civil War," *The American Historical Review* 109, no. 5 (December 1, 2004): 1405–1438.

planters from the eastern provinces who led the revolt made sure to preserve the productive capacity of the estates they conquered, in a conscious attempt to win the rest of the island's elite to their side. During the war Turnure's firm, Moses Taylor, had served as the American representatives of the rebellion. If American refiners disappeared, his firm's status as profitable middleman would be endangered.[453]

In November 1878, the free-trade economist David Wells argued that a uniform tariff would hand the American sugar market to "high price, centrifugal sugars, mainly the product of slave labor in the Spanish West India Islands." Wells was then working as a hired gun for some of the largest firms in the sugar trade. In July 1878 Havemeyer & Elder, Moses Taylor, and others had contracted with him to write a report on sugar duties. His 119 page-report called for the abolition of the Dutch scale and the official adoption of the polariscope, whose use he claimed "would result in the minimum of loss to the revenue."[454] Yet a mere two years earlier he had called the figure of the smuggler "the knight-errant of civilization" joining nations of the world in the natural flow of commerce.[455] To sugar refiners, free trade meant paying lower duties, not opening America to international conspiracies. In an alarming footnote to his report, Wells revealed that it was widely known that in anticipation of a uniform tariff, "a gigantic stock company is contemplated and in process of organization for the erection of an immense refinery in Havana, for the purpose of preparing sugars of the highest possible

453. Perez, *Between Reform and Revolution,* chapter 5, "Reform and revolution in the colony."
454. "The Duties on Sugar," The New York *Times,* 30 November 1878; Moore, 20.
455. Wender Cohen, 393.

grade permissible."[456] Just who might capitalize such an enormous facility, Wells did not say.

Protectionists more friendly to manufacturing labor, like Philadelphia's William Kelley on the Ways ands Means Committee, argued that their policies would protect skilled, white, free American workers from the threat posed by the black enslaved or Chinese indentured laborers of Caribbean islands.[457] This was the "Labor Side of the Great Sugar Question." The author's name was almost certainly a *nom de plume*, and in fact the entire piece was a barely-pseudonymous defense of the Havemeyers and the other German-immigrant refiners of Brooklyn. That was the title given to a pamphlet, published in 1878, by "A Workingman," Robert Howe. It described an imagined dialogue between a Cuban visitor to New York ("a sallow colored gentleman") and a longtime sugar-refinery employee named "Ludwig Kraft."[458] In case the dialogue itself failed to deliver the message, the final pages of the book contained a reprinted editorial from the *New Yorker Staats-Zeitung.*[459]

Specifying the Havemeyers' antagonists, the vocal owners of the firm of Booth & Edgar, in all but name, Kraft dramatically reveals the existence of the conspiracy of

456. David Ames Wells, *The Sugar Industry of the United States, and the Tariff. Report on the Assessment and Collection of Duties on Imported Sugar: On the Results of an Economic and Financial Inquiry into the Relation of the Sugar Industry of the United States in Its Several Departments of Production, Importation, Refining and Distribution of Product, to the Existing Federal Tariff* (New York, 1878).

457. Wender Cohen, 385. For protectionism and the Republican doctrine of the "harmony of interests," see Eric Foner, *Free Soil, Free Labor, Free Men: The Ideology of the Republican Party Before the Civil War* (New York: Oxford University Press, 1970), 20-21. Kelley was in correspondence with Harrison, Havemeyer & Company, a Philadelphia refinery whose proprietors were more often than not opponents of the New York Havemeyers. See Thomas S. Harrison to Kelley, 21 December 1882, and Charles C. Harrison to Kelley, 27 May 1882, William Darrah Kelley Papers, Colection #1921, Pennsylvania Historical Society.

458. Robert Howe, *The Labor Side of the Great Sugar Question* (New York: s.n., 1878).

459. German immigrant identity was bound up in the refineries, which printed management notices in two languages. Havemeyer, *Merchants of Williamsburgh*, 39, esp. footnote.

Cuban planters to destroy the refining industry of the United States by constructing one the island. Their scheme is to claim massive sugar frauds and adulterations by loyal (German-immigrant) refiners in order to "create a public opinion hostile to them, and by the pressure of that opinion force the hand of Congress and the Senate to frame the tariff for which they have all along been plotting."[460] The American importers who are their allies in the scheme were the ones annoyed by the private dock system: "if the refiners had never imported a cargo of sugar direct themselves, but had taken it from the importers, there would never have been a single word about frauds from the importers."[461] The "conspiracy," Kraft claimed, threatened 40,000 jobs in sugar refineries and allied trades. At the book's climax, Kraft stares "steadily into the eyes of the olive man" and warns his visitor not to antagonize a nation that had just fought a war for the privilege of freely engaging in wage work. "You Cubans and your New York agents think Congress is going to pass a law to take the bread out of the mouths of American citizens to enrich your Cuban slaveholders, without even doing any good to the poor wretches you drive on your plantations....Your slave labor is not going to destroy our free labor.'"[462] In the same way that the "slave power" of the Southern states had nearly overwhelmed the North before 1861, now Cuban slaveholders would be stopped from undermining Northerners' hard-fought liberty.[463]

460. Howe, 4. "Corruption itself has the character of conspiracy," Richard Hofstadter wrote of the populists: "they had seen so much bribery and corruption, particularly on the part of the railroads, that they had before them a convincing model of the management of affairs through conspiratorial behavior" (*The Age of Reform*, 71).

461. Howe, 20.

462. Ibid., 25.

463. Eric Foner, *Free Soil, Free Labor, Free Men: The Ideology of the Republican Party before the Civil War* (New York: Oxford University Press, 1970); Hofstadter, *Age of Reform*.

Yet William Booth, of Booth & Edgar, could also use undesirable aspects of the tropics to make his argument in favor of a uniform tariff. In testimony to Ways and Means in 1878, Booth argued that a uniform tariff up to 13 or 16 D.S. would encourage the importation of as valuable sugars as could be imported under that color. Under the present system, he argued, sugar "full of dirt" was being imported at 6¢ per pound, and "that is a dear rate to pay for Cuba," he observed. He too tied Cuba, free labor, and unhealthy impurity. Importing Spain's colony piece by piece, "it would take us a great many years to make Cuba a free Island on that basis."[464]

Fears of being painted as an ally of Cuba were strong enough in the late 1870s that Carlos Rebello, a Cuban sugar technologist, published his own pamphlet only after anglicizing his first name.[465] "Charles Rebello" reprinted a letter written by Miguel de Aldama, a partner in the merchant firm of Aldama & Fuller, to the New York *Sun*. There, the importer explained that Cuba's limited supplies of essential refining resources like coal and bone-black, and the prohibitive cost of imported supplements, would render futile any attempt by the island to compete with American refiners.[466] At the same time, Rebello argued, Americans should not fear the loss of refineries, for even the largest refiner is merely a parasite who "adds nothing to the production of the country. He simply

464. *Testimony in Relation to the Sugar Frauds*, 99.

465. The trick has even fooled some historians. See Cohen, "Smuggling, Globalization, and America's Outward State," 374.

466. Charles [Carlos] Rebello *The Pith of the Sugar Question* (New York: Macgowan and Slipper, 1879).

manipulates an imported article, and for that alone he asks the Government shall sustain him in an odious monopoly."[467]

From threats foreign or domestic, the particular ingenuity of white American labor often needed protection. Garfield marshaled figures about the number of jobs provided by sugar refining to support an argument that neatly connected domestic labor and American ingenuity to overseas markets and empire, all through the quality and qualities of sugar.[468] In the Philippines, Garfield told the House, "there is a class of people who have not enough intelligence and resources to take the first simple step towards clarifying sugar." This was America's opportunity. "In the crudest, rudest, simplest way, by labor the cheapest and least skillful" Filipinos reduced sugar to a "black cheap form." Then refineries in the United States "by our own skill and labor make it into a cheap clean sugar" suitable for consumption.

The reason the Dutch standard was no longer useful as a tariff mechanism, Congressman James Garfield argued as Sherman's ally in Congress, was not merely that it no longer represented the relation between quality and value, but that it was being explicitly and cleverly undermined by foreigners. A uniform tariff would shift refining abroad, to Cuba and elsewhere in the Caribbean, where expertise in sugar production threatened American dominance. The tariff would thus succeed at "bringing in only the sugar that has been advanced by the higher and more intelligent processes of our nearer

467. The *Sun*, 8 October 1878, reprinted in Rebello, *Pith*.
468. James A. Garfield, *Sugar Tariff. Speech of Hon. James A. Garfield, of Ohio, delivered in the House of Representatives, Wednesday, February 26, 1879* (Washington: n.p. 1879), 5-6.

neighbors."[469] Darker skin equated an ingenious product with deception, rather than honest skill. The craftiness of overseas sugar-makers enabled them to subvert the appraisal of American customs officials. This explains the humor in the following exchange in the House, in which he responded to the charge by William Robbins, a Democrat from North Carolina, that government officers were too corruptible to be trusted. Garfield had admitted that if the sampler took sugar from the bottom of a hogshead, "he gets a wet, black, coarse portion." The radical and pro-Cuban annexation Congressman Benjamin Butler of Massachusetts interjected:

> Mr. BUTLER. How much foreign labor is there in the settlings of that sugar? [Laughter.]
> Mr. GARFIELD. There is certainly a good deal of dirt in it. [Laughter.][470]

This was only humorous to Congressmen and others for whom freedom of labor, Cuban independence, and the fear of monopoly were all linked to the qualities of sugar and how that should be measured.[471] The "sugar mite" was a tiny insect found in muscovado, and was, claimed Garfield on the floor of the House, responsible for a malady called

469. Garfield, *Speech*, 12.

470. Ibid., 13.

471. Matthew Jacobson, in *Barbarian Virtues*, argues for a complex relationship between the economic-imperial drive to open new markets, the perceived inferiority of darker-skinned overseas consumers, and racialist concepts of immigrants' abilities. Moon-Ho Jung, in *Coolies and Cane*, shows how while antebellum reports from the West Indies portrayed Chinese coolies as both industrious and inferior, after the Civil War they were recast as "immigrants" to ignore troubling questions of the slave trade for sugar prices. "Neither free nor enslaved labor, coolies signified an ambiguous contradiction that seemed to hold the potential to advance either" (p. 19). Coolies were an anomaly in a racial classification system, and raised all sorts of unhappy questions about dichotomies between white and black, slave and free. Moon-Ho Jung, *Coolies and Cane: Race, Labor, and Sugar in the Age of Emancipation* (Baltimore: Johns Hopkins University Press, 2006); Matthew Frye Jacobson, *Barbarian Virtues: The United States Encounters Foreign Peoples at Home and Abroad, 1876-1917*, 1st ed (New York: Hill and Wang, 2000).

"grocer's itch" that affected retailers of such sugars.[472] Whoever actually wrote "The Labor Side of the Great Sugar Question" claimed that uniform tariff would "give the people sugar teeming with animals and Cuban dirt, and ruin the refiners" in doing so.[473] Repulsive magnifications of insects frequently appeared in advertisements warning buyers to "USE ONLY REFINED SUGARS" (**Figure 4.2**). These mites were said to be "formidably organized," much like their Cuban co-conspirators.[474]

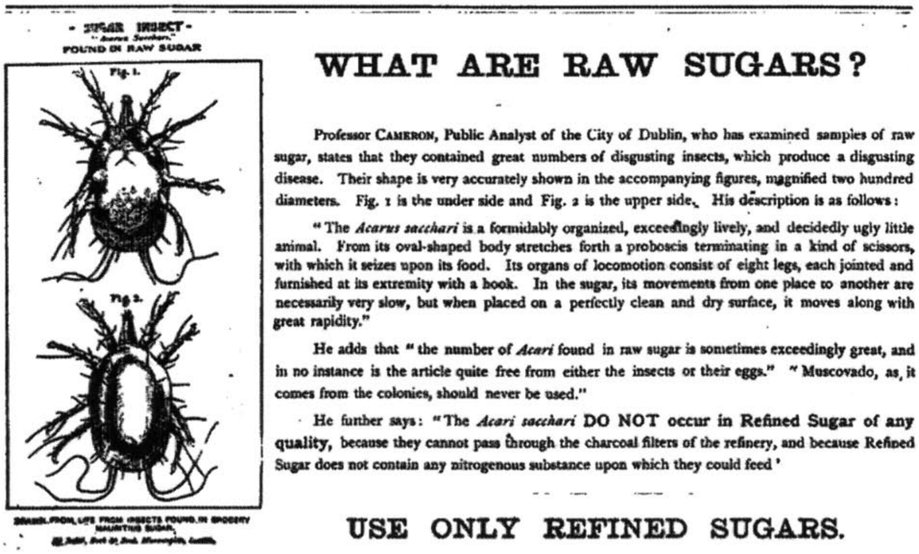


Figure 4.2: Advertisement for refined sugar, warning against the sugar mite. (Willett and Gray's Weekly Statistical Sugar Trade Journal, 1893)

Sugar directly from Caribbean factories was untrustworthy, and Caribbean impurities were a threat to the American worker, medically and economically. These issues could all combine with gruesome results. The New York *Times* of 26 February 1877, in an article on the Chinese government's measures to stem the coolie trade, lamented that labor conditions in Cuba were so miserable that for plantation workers "a

472. Garfield, *Speech*, 6.
473. Howe, 25-26.
474. "What Are Raw Sugars? (Advertisement)," *Willett & Gray's Weekly Statistical Sugar Trade Journal*, January 19, 1893.

favorite way of ending life seems to have been to jump into the sugar caldron" [sic]. The sugar mite and grocer's itch paled in comparison to the horror of sugar adulterated with the corpses of suicidal plantation workers. The newspaper further related tales of the fate of skeletons of Chinese workers. They were routinely exhumed "from the shallow graves in which they were buried, and their mixture with those of horses and oxen for the purpose of refining sugar." In such tragic circumstances, the paper could only applaud the Chinese government's efforts, no matter "whatever effect it may have on the price of sugar."[475] The enslaved bodies of Chinese workers quite literally became impurities counted against the quality of sugar imported to the United States. How purity and impurity would be sampled and assessed in American ports was inextricable from the power of certain refiners over others.

3. The polariscope and the rise of the Sugar Trust

Following his plea in his 1877 annual report to Congress to replace the Dutch standard, in early 1878 Sherman began a campaign to replace the it with the polariscope. In 1843 a commercial polariscope laboratory had opened in Philadelphia, and at about the same time one of that city's refineries began to rely on the instrument.

475. "Suppression of the coolie trade," New York *Times*, 26 Feb 1877, 4.

By the 1870s, New York was full of commercial polariscopic laboratories, on whom sugar brokers relied for their transactions.[476] Within the United States, the instrument's advocates claimed in public and private that it was simple, reliable, and accurate. The polariscope's operation, the Smithsonian physicist Joseph Henry told Sherman in February 1878, "can readily be taught to any intelligent person of ordinary education…by a person thoroughly acquainted with the theory and practice of the instrument." Sherman's allies in Congress, most notably Garfield, argued that the government could therefore safely hand over the collection of sugar duties to polariscope operators. If Henry also felt comfortable that "a layman, a man without special skill, can be taught to use this instrument accurately," Garfield said, "I have not quite the courage to say it is not so."[477] Not all were so sanguine, or confident that just anyone could be taught to use the polariscope and agree with other users. When Garfield suggested that the Treasury Secretary could, in any case of doubt, authorize a full Clerget analysis of a sample's component elements, he was challenged again by North Carolina's Robbins:

> Mr. ROBBINS. One word more. The chemical analysis test is too costly for general use, is it not?
> Mr. GARFIELD. Oh, yes; it would be too cumbrous and costly to be used ordinarily. But it can always be used to verify the polariscope test in any important case.
> Mr. ROBBINS. But who is to know that any correction is needed?
> Mr. GARFIELD. My friend in that question has taken up the conflict of ages. Who shall do anything except the men appointed to carry out the law? Who shall find out any blunder or correct any

476. Charles A. Browne, "A History of the New York Sugar Trade Laboratory," 3. Container 33, Charles Albert Browne Papers, Manuscript Division, Library of Congress, Washington, D.C. (hereafter CAB papers, LOC).

477. Garfield, *Speech*, 14.

> wrong unless you appoint somebody to do it? Congress, I take it, can hardly determine the sweetness or strength of sugar or the amount of glucose in it unless we appoint an agent. The Treasury cannot do it except by its agents.[478]

It was just this utter dependence on agents that made the Columbia chemistry professor Charles Chandler another such skeptic of the polariscope's government use. The differences among the various grades of raw and refined sugars, in terms of the percentage of sucrose they contained, ranged only over a few percentage points. Yet "the ordinary testing of sugars by the polariscope is not accurate within 1%," Chandler wrote to an import firm from Washington, where he was lobbying Congress against the instrument. "Differences of 2 or 3% or even more may occur when different samples are taken from the same lot of sugars and tested by different chemists."[479] Judgments of color, texture, and grain using the Dutch standard were based on what "sugars show to the unaided eye,"[480] and "a great many more men are judges of color than are judges of the test by the polariscope."[481] The new instrument, wrote the ex-agent Brown, would "furnish a vehicle for the safe practice of fraud [at] the option of operators and their instigators." He enumerated some ways polariscope tests might be imperceptibly modified: "The operator adds a few drops more of water than the proper quantity, and the

478. Ibid., 17.

479. Chandler to Ceballos & Co.; New York, 1878 April 18; Box 260, Folder 7, Chandler Papers, RBML.

480. Moore, *Statement Relative to the Artificial Coloring of Imported Sugars*, 4.

481. *Testimony in Relation to the Sugar Frauds*, 44.

grade is lowered; or a few grammes of sugar more than the proper quantity, and the grade is raised."[482]

In fact, the actual work of the polariscope operator was identical to that of assessing sugar with the naked eye. Light entered the polariscope from the far end, then was split, so that one beam passed through the sugar sample while the other did not. This created two differently-colored halves of the eyepiece. By rotating a prism called the analyzer, the operator manipulated the colors; when the two halves of the view in the eyepiece showed the same color, a graded scale on the rotator dial indicated the sucrose content. Thus, the users of the Dutch scale and of the polariscope both had to identify the point at which two colors matched (**Figure 4.3**). Brown complained that "only the most accurate eye and skillful adjustment can exactly determine the perfect color blending, which marks the record of true grade upon the scale."[483]

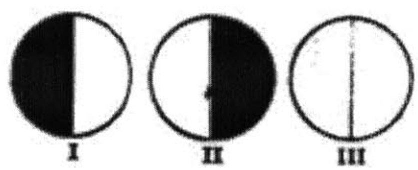


Fig. 61. — Showing divisions of double field of a half-shadow polariscope.
I, analyzer crossed with left half of field;
II, analyzer crossed with right half of field;
III, end point.

Figure 4.3: View through the eyepiece of a polariscope
(Browne, 1912)

Moreover, the ways the polariscope was used commercially indicated its potential unsuitability for government work. In private exchanges, buyers and sellers each hired

482. Brown, *Sugar Frauds*, 16.
483. Ibid.

their own samplers and chemists, who delivered a certificate of the resulting test. Predictably, negotiations began with buyer and seller quoting widely different values for the same sugar. One refiner might find his own values differed from another's while both disagreed with the seller's chemist. Parties frequently called for resamples and retests, and the sale might even be aborted if no agreement could be hashed out.[484]

The manipulability of polariscope tests was thus accepted as fact among its commercial users, and especially among those who used it regularly. Effectively deploying that manipulability was part of the skill that went into making use of the instrument in transactional settings. "Some will go on color, some on classification, and the seller will have his goods sampled and tested, and will make them test 95 [polarization], and then the buyer will have them sampled and tested and they will test perhaps 92," complained the refiner Lawson Fuller, "and then both parties knowing how much they are cheating each other, will come to a square understanding and strike a balance just [as] though they had not sampled or tested the goods at all."[485] To Searles, Fuller, and other polariscope opponents, this proved that chemists were not to be trusted with the administration of customs. For while an importer might challenge a high assessment by a customs chemist, there would be no adversarial challenge to a value that was too low. The apparent accuracy of polariscope tests was inseparable from their commercial, negotiated context.

484. *Memorial Presented to the Committee of Ways and Means on the Sugar Tariff, Advocating a Uniform Rate of Duty up to No. 13 Dutch Standard, with Arguments in Favor of Same by John E. Searles, Jr., and Edward P. Eastwick, January, 1880* (Washington: T. McGill & Co., 1880), 16.

485. *Testimony in Relation to the Sugar Frauds,* 44.

In fact, the polariscope's opponents, which included most of the smaller refiners and importers, argued that it was supported by the large refiners precisely because of, and not despite, the fact that it would make customs manipulation easier to commit and harder to detect. "I think Havemeyer is trying to persuade the Government to use the Polariscope in connection with the duty & we are against him & don't think it wise as it will leave such an open door for fraud," wrote the refiner William Booth to his friend Chandler.[486] If Havemeyer and his fellow large refiners were capable of bribing samplers on their docks, nothing would seem to stop them from equally colluding with polariscope operators, whose work would be even more difficult if not impossible to hold to account.

In the context of civil service reform, it was impossible to disentangle questions about the unreliability of the polariscope as an instrument from claims about the unreliability and incompetence of customs employees. The claimed goal of civil service reform was to depoliticize the Custom House by routinizing the appointment procedure and eliminating the practice of "assessment," in which the beneficiaries of patronage were canvassed for donations to the political party through which they had landed their posts. But trustworthiness and expertise were not separable qualities, and neither were political means of appointment and perceived reliability distinct. Hence, Sherman placed great emphasis on matters of trust when instructing Collector Arthur precisely which of his Custom House employees to release following the commissioners' reports. At the highest levels, Sherman wrote, Arthur was to pick "the more efficient and trustworthy,"

486. William Booth to Chandler, 1878 January 16, Chandler Papers, Box 260, Folder 7, RBML.

while for lower-ranking officers, he should "employ only those who are competent for the special work assigned them, whose industry, integrity, and good habits give guarantees for faithful services, honestly rendered."[487] Arthur testified that in his opinion many of the men overseeing "the delicate duties of the appraiser's office, requiring the special qualities of an expert, were better fitted to hoe and plow."[488] The concern of the polariscope's opponents was that if its operators were on the payroll of one of the large refiners, no one would ever be able to tell. One refiner put it best. "Men are generally honest," he said, but "some men's sight through the polariscope would be very defective if a fifty or a hundred dollar bill got into one end of the instrument."[489]

In February 1878, as Congress considered revisions to the tariff, a large group of New York's importers and smaller refiners met and appointed a committee to propose an alternative system for the assessment of sugar, electing as their spokesman Lawrence Turnure, fresh from his work on the Jay Commission.[490] To circumvent the problem of sampling they endorsed a "uniform" tariff of a single rate below 13 D.S., similar to what Sherman had proposed the previous year. Such a tariff, one refiner testified, would specifically exclude "the class of sugars which trouble the Appraisers." The idea was to

487. Sherman, *Forty Years*, 676.
488. Ibid., 678.
489. *Testimony in Relation to the Sugar Frauds*, 44.
490. "The sugar tariff. Large meeting of sugar men." The New York *Times*, 8 February 1878. Lawrence Turnure seems to have been frequently confused with his brother David, also a sugar importer. "Death of David M. Turnure," New York *Times*, 23 February 1889; "Lawrence Turnure Dead," New York *Times*, 2 May 1899. For example, in 1878 "David M. Turnure" was listed as testifying before the Ways & Means subcommittee, but whoever was sworn in testified to having worked for Moses Taylor for 25 years, which Lawrence but not David Turnure did.

discourage the importation of anything but the most valuable sugars that were possible below that number, while rendering darker coloration pointless.[491]

Proponents of the uniform tariff viewed opponents conspiratorially. Two large public meetings on the question in New York City in 1879 and 1880 ended in fisticuffs. The 1879 meeting was held at Chickering Hall in Union Square to propose "a revision of the tariff as will provide for the honest collection of duties on sugars, and also to protest against adulterations." Invitations were distributed to those, like Columbia's Chandler, whose attendance would bolster its credibility.[492] The meeting was large enough that President Hayes and several cabinet members sent telegrams regretting their absence, "all roundly applauded by the uniform tariff men." Statements against the polariscope were at the top of the agenda, so pro-polariscope forces had attempted to pack the hall. A squad of "rough-looking" Havemeyer employees from Williamsburg, across the river, attempted to enter and "capture" the meeting, but they were blocked by an augmented police guard arranged at the last minute. Henry Havemeyer himself appeared at the door, dismissed his men, and then made an entrance himself. When Lawson Fuller accused him from the dais of having "on the proceeds of fraud and adulteration, built up eight new refineries," Havemeyer and David Wells stood up and declared their eagerness to settle the matter with their fists. "The callers of the meeting had prepared a series of resolutions," the Times reported, but given the gathering's tense atmosphere "did not deem it advisable to even read them."[493]

491. *Testimony in Relation to the Sugar Frauds*, 98.
492. Invitation in Chandler Papers, Box 260, Chandler Papers, RBML.
493. "The Sugar Men's Quarrel," The New York *Times*, 7 January 1879.

By April 1880, when a second meeting was called, the government's policy on the sugar question had become decidedly less popular. The meeting produced resolutions expressing "public opinion against the unjust private dock and tariff systems." Decrying the existence of a "sugar ring" comparable to the Tammany Hall machine, a speaker complained that "it was strange indeed that the Custom-house of this great port could not be run on business principles, like our Post Office, instead of being run as an electioneering bureau." Sherman was pilloried for not releasing the many affidavits about fraudulent importing practices that it was rumored he had collected over the last 15 months. According to the speakers at the meeting this was because he wanted the sugar refiners as backers for the Republican presidential campaign in 1880, in which he would be a candidate. He had, speakers alleged, promised a uniform tariff one morning, submitted testimony to the Ways and Means Committee that afternoon in favor of the polariscope, privately recommitted to the uniform tariff in the evening, and then been spotted playing polo with Theodore Havemeyer in Newport the next day.[494]

In spite of such opposition Sherman pressed ahead with plans for the polariscope. He circulated an order in 1879 asserting his administrative authority to implement the device. The existing statutory language, he claimed, implied that the Dutch scale was intended as "essentially a measure of saccharine strength and not of color as an abstract physical attribute of matter."[495] Several importers sued the Federal government, claiming

494. "The Sugar Tariff Ring," The New York *Times*, 14 April 1880. The constituencies for reform of appointments were the urban merchants and professionals who wanted "the business of government done on business principles," as President Hayes himself put it. Quoted in Skowronek, 51.

495. Moore, 7.

that they had been overcharged on a cargo as a result. The case worked its way to the Supreme Court, which in 1881 ruled in favor of the plaintiff: if the department was to use the polariscope, then Congress had to authorize the specific use of that instrument. As a result the Treasury was forced to refund two million dollars in sugar duties, and telegraph custom houses that the "apparent color" was to be the basis of future levies.[496] Only in 1882 did Congress eventually mandate the polariscope's use, as a result of Sherman's own legislative maneuvering. Having lost his campaign for the Republican nomination to his polariscopic ally Garfield, he had resumed his seat in the Senate in 1881. From there, he watched Chester Arthur—whom he had eventually dismissed as Collector—ascend to the White House after now-President Garfield was fatally shot at a Washington railway terminal.[497]

Polariscope opponents continued to lodge allegations of fraud just as Henry Havemeyer continued his consolidation of the refining industry along the East Coast. Several attempts to form price cartels among refiners in the early 1880s failed, especially when the Havemeyer refinery burned to the ground in January 1882.[498] It would be set ablaze again in June 1887, allegedly in retaliation for a recently crushed strike. But by then Havemeyer had consolidated the East Coast's refiners into the Sugar Trust, which controlled 84 percent of the refining capacity east of the continental divide. What had finally given his firm the power to compel others into cooperating was that his new

496. Warner, "How Sweet It Is," 158-159.

497. "Five hours spent in talk, the Senate objecting to the polariscope test for sugar," The New York *Times*, 26 July 1882.

498. Eichner, 62-64; Ayala, *American Sugar Kingdom*, 256 n. 28; "A Million-Dollar Fire: Havemeyer's Refinery a Huge Mass of Ruins," The New York *Times*, 12 June 1887.

refinery was the largest and most efficient in the world. It could melt three million pounds of sugar a day, twice as much as the nearest competitor. Its refining costs were 0.44¢ per pound of product, but the price margin between raw and refined sugar had fallen to just over 0.7¢ by 1885. Havemeyer's firm may in fact have been the only one in the country to earn a profit that year. In 1888, the year after he formed the Trust, the margin jumped to 1.258¢.[499]

Perhaps nothing testified to the way that the mercurial character of sugar itself could interact with such ferocious competition among refiners better than the elaborate hoax that made fools of many of New York's most expert sugar men between 1885 and 1889. A German émigré calling himself Henry C. Friend, claiming to be an electrician and chemist, approached refiners in his home country, in England, and finally in America. He wanted investors for his new "electric" process, which could refine sugar for only eighty cents a ton—about seven percent of the cost by normal methods—and do so to an unfathomable degree of purity. In New York, he naturally first offered partnership to the Havemeyers, who were so impressed by the quality of his samples that they offered him $2 million for his "secret." His unwillingness to detail his procedure led them to refuse to fund his project, but others, among them the refiner Lawson Fuller and the sugar-newsletter publisher Wallace Willett, helped Friend form a company in early 1885, with offices on lower Manhattan's William Street.[500]

499. Ayala, *American Sugar Kingdom*, 33.
500. "The Electric Sugar Swindle," *Harper's Weekly*, March 30, 1889, 247.

A waterfront location had become part of the necessary trappings of a convincing modern refinery, so for its main facility, the Electric Sugar Refining Company refurbished a flour mill in Red Hook. Friend persuaded his investors to advance him hundreds of thousands of dollars with which to purchase machinery of his own design. By dispersing orders for parts, he ensured that no engineering firm saw the entirety of his equipment and thus, he said, kept his process secret. The pieces of machinery arrived in oddly shaped containers that were taken directly to a secure space within the refinery. There Friend, alone, conducted "his marvellous work." At the company's celebrated and publicized trials, witnesses "saw raw sugar hoisted up to the secret rooms, and saw the beautiful crystals that they could not buy in the market tumbling down...and they were content." This was no P. T. Barnum-esque artful deception. Spectators were not attracted to Electric Sugar by the sense of excitement that came from trying to determine whether they were really being fooled, and if so to decipher the trick. Friend's investors wanted to believe.[501]

With a private process, however, Friend needed public allies. In late June 1885, therefore, the company approached Columbia's Chandler to test a sample of raw sugar for a "demonstration." Chandler's analysis made him skeptical: the proportions of "cane sugar by polarization," of glucose, water, and ash, the four components he expected to find in unrefined sugar, added up to 100.46%. When a representative of the firm attempted to convince him his analysis was wrong, he wrote that "I do not care to be

501. Ibid. For Barnum, see Neil Harris, *Humbug: The Art of P.T. Barnum* (Little, Brown & Company: Boston, 1973), and James W. Cook, *The Arts of Deception: Playing with Fraud in the Age of Barnum* (Cambridge, Mass.: Harvard University Press, 2001).

connected in any way with your sugar enterprise even to the extent of certifying the composition of the raw sugar." Chandler was convinced that the firm merely wanted his test of their raw sugar "as a sort of an endorsement" of their business, and told his office to refuse to hand over any of his analyses, and to refuse any payment in return.[502]

Chandler's skepticism was borne out, though not for a few years. The scheme began to unravel after Friend died ("at least it is supposed he died," *Harper's* pointed out), and his widow took over the company. Eventually, she promised to reveal the secret method on New Year's Day 1889, but fled to Michigan instead. Her lawyers asked whether creditors would accept, as the "secret," a way to turn already-refined sugar into that of the "coveted quality." They would not, the building was raided, and the conspirators were arrested. The creditors found the building crammed with the raw sugar their money had bought for Friend to refine with his electric process. The secret space was nearly devoid of machinery: the strange boxes had been filled not with novel parts but with already-refined sugar. The company, the New York *Times* wrote, was "as utterly collapsed as any corporation can be, its assets...still only to be guessed at." Yet even after the discovery, speculators in Liverpool nonetheless remained optimistic that "confidence in the company will be restored."[503] The allure of electric sugar remained.

The Electric Sugar Refining swindle quickly became widely known throughout the sugar world. It was cited in March 1890 by George Stade, a Berlin sugar engineer and

502. Chandler analysis, 26 June 1885, Chandler's note to his office, 7 July 1885, and Electric Sugar Refining Company to Chandler, 9 July 1885, all in Chandler Papers, Box 260, Folder 10, RBML.
503. "The Big Sugar Swindle: Trying to Find Mrs. Friend and her Relatives. Mr. Cotterill's Reports from Michigan—How the Managers Made Money by Speculating," The New York *Times*, 8 January 1899.

frequent contributor to *The Sugar Cane*, as a tale that had already inspired excessive caution in those among the business's participants who sought a magical escape from its fierce combat. "In many cases the planter-manufacturer has been exceedingly cautious in adopting the troublesome innovations" that really did represent productive investments, Stade wrote, because of such deceptions: "he had already too often been bitterly disappointed and deceived by advertising firms, and compelled to pay dearly for his experiments."[504] *Harper's* wrote that the Electric deception "had its foundation in the keen competition among sugar refiners." Yet if Friend's secret was not a cheap electric refining process, it was nonetheless still secret. Even if he began with refined product, he truly seemed to have "produced at times sugar that is unlike and superior to any other sugar known in the market," and no one else knew how.[505]

It was in this combative environment of the mid-1880s, and this uncertainty over the value of sugar, that Boston refiners complained that the New York Custom House was charging a lesser duty than its Boston counterpart. Identical samples of sugar, they alleged, were declared as much as three percent less pure by the New York chemist than by the chemist in Boston. In October of 1886, a journalist for the Boston *Herald* named T. Aubrey Byrne began to look into their claims, and shortly thereafter he was commissioned by President Cleveland's Treasury secretary as a special investigative agent.[506]

504. George Stade, "On the Working of a Cane-Sugar Central Factory and Distillery," *The Sugar Cane*, March 1890, 131.

505 "Electric Sugar Swindle," *Harper's Magazine*, 30 March 1889, 247.

506. "Byrne Again in Office," Boston *Daily Globe*, 13 September 1893. The idiosyncrasy of Byrne's background if anything typified the irregular nature of the Treasury's agents. He had been born in 1850 to

The Boston merchants claimed that this discrimination was sufficient to render them uncompetitive. Conditions were so uncompetitive that sugar cargoes were being diverted to New York, and then reloaded onto ships to be sent up the coast to Boston refiners, in order to save $150,000 in duties each year. Relatively small amounts of money could affect trade substantially, as Byrne pointed out at the beginning of his final report. "Inasmuch as 1/16 cent per pound is considered a margin of profit in handling and refining sugar, the net cost of that commodity, including customs duties, must be very carefully considered for one degree by polariscope for duty is nearly equivalent in value to 1/16 cent per pound."[507] The Boston importers wanted Dr. J. T. Leary, the chemist in their city's custom house, fired, and "a more liberal man substituted" who would round down fractions as they claimed New York's chemist did.[508]

The Custom House sugar laboratory in New York had been headed, since Sherman's 1879 order to institute the polariscope, by a chemist named Edward Sherer. With his brother John, he had run a polariscopic laboratory at 122 Front Street in Manhattan from the early 1870s. They became the most prominent private chemists in the city, and before the Custom House had acquired its own polariscope it had sent Sherer Brothers samples of sugar that needed testing.[509]

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missionary parents posted in Kingston, Jamaica. After returning to the United States at 14, he had ranched in Colorado and then worked as a general freelancer for Boston papers before he had heard grumblings among the city's refiners.

507. "Letter from the Secretary of the Treasury, Transmitting, in Response to Senate Resolution of January 8, 1889, Information Relative to the Sugar Frauds," Senate Executive Document 77, 50th Congress, 1st session, (20 January 1889), 2-3.

508. Ibid., 4-5.

509. Browne, "History," 2 CAB papers, LOC.

Byrne's investigation and subsequent reports to the Treasury and to Congress exhaustively documented all sorts of malfeasance on the part of both brothers, supported by hundreds of dense pages of statements from weighers, samplers, examiners, laboratory assistants, brokers, refiners, and other custom-house officials. The Sherers would finish their duties at the government laboratory and then head downtown to their private one, working all night for the same importers and refiners whose cargoes they were meant to be evaluating for the Treasury. Witnesses also testified to the persistence of a ring of customs chemists and Treasury agents in New York that conspired to lower sugar duties by hundreds of thousands or even millions of dollars by manipulating samples and especially by shaving fractions or whole degrees off polariscope readings. Among them was Ira Ayer, a longtime Treasury special agent who had been responsible for drafting much of the sugar tariff legislation since 1880.[510] The ringleaders, however, seemed to be not the Sherers but the broker for Havemeyer's refinery, James Burt, who moved with ease among the appraiser's stores, the refinery docks in Brooklyn, the Sherer firm's laboratories, and Havemeyer's offices around the corner at 120 Wall Street. It even emerged that Edward Sherer was an honorary consul for the Ottoman Empire. It seemed strange to many that a Federal official should also represent a foreign power. Odder still was the fact that Byrne found himself unable to ascertain whether the consul's office was in the waiting room of the Sherer Brothers laboratory, or the laboratory in the waiting

510. Ibid., 5; Senate Executive Document 77 (1889), 50. See also Ayer's obituary in the San Francisco *Call*, Volume 93, Number 66, 4 February 1903.

room of the consulate.[511] This bizarre revelation seemed to capture the ambiguity of space that characterized the sugar trade.

Yet Byrne was no more immune to criticism than any other officer of the Treasury. The New York *Times* dismissed the Byrne report as perhaps calling for further inquiry, but not "in any sense...the result of a thorough investigation." The paper acknowledged that "in the public service this kind of work has sometimes to be done, and the Treasury Department keeps in its employment a considerable number of special agents, presumably skilled, trained, and trustworthy," but only in order to emphasize that "Mr. Byrne was not one of these."[512] Conversely, Charles H. Ham, who had left his post as Appraiser of the Port of Chicago to become an editorialist for that city's *Tribune* in 1885, defended Byrne and attacked instead former Special Agent Hinds, who had come to James Burt's defense. Hinds had been a member of one of Sherman's 1877 commissions investigating the customs houses, but was now a lobbyist (the word Ham used was "agent") of the Woolen Goods Association, which was tangling with Byrne on one of his subsequent investigations. From Chicago, Ham detected a miasma of corruption in Manhattan. "There is something in the atmosphere of New York," he wrote, "which transforms a special agent watchdog of the Treasury into a watchdog of the commercial interests of this city."[513]

Nonetheless, the Sherers resigned under pressure in 1888, only to be reinstated in September 1889 when reports surfaced that the New York Custom House's polariscope

511. Senate Executive Document 77 (1889), 45.
512. "The Byrne Report," The New York *Times*, 8 February 1889.
513. "Eyes Closed to Fraud," Chicago Tribune, 8 February 1889.,

had somehow been tampered with.[514] They were fired again in 1890, and the circumstances of their last sacking testify better than anything else to the impossibility of determining whether polariscope operators were acting improperly. In December 1889, a mere three months after the Sherers were reinstated, enough doubts had been raised about Byrne's report that three special agents, led by O. Z. Spaulding, were asked to either corroborate or condemn his findings. Spaulding's report, received in June of 1890, rendered a harsh verdict on Byrne himself. Having spoken to those in the Boston sugar business who had complained of the lower New York tests, the agents found that nearly all "denied any conversation with him [Byrne]" or else "accused him of a perversion of their language." Moreover they claimed to have always "complained of Dr. Leary's rigid tests at Boston, not of Dr. Sherer's liberal tests at New York."[515] They concluded there was no Burt sugar ring "or any other sugar ring" in existence, at any level of kinship, friendship, or political appointments.

The trouble was that the discrepancy between the New York tests and the Boston tests refused to disappear, and Spaulding chose to turn his attention to the polariscopes themselves. In particular, much of his report was occupied with puzzling out the fate of a quartz plate mounted in a brass tube. Quartz, like sucrose in solution, rotates the polarization of light; thus a slice of quartz crystal of established rotatory power could be used to calibrate polariscopes. In 1885, on Treasury orders to rectify their laboratories'

514. "Sugar frauds alleged. Somebody has been tampering with Dr. Leary's polariscope," The New York *Times*, 26 February 1889; Warner, 161.

515. "Letter from the Secretary of the Treasury, transmitting in response to a Senate resolution, July 14, 1890, a report of special agents who were instructed to investigate the manner in which sugars are classified," United States Senate Executive Document 190, 51st Congress, 1st session (18 July 1890), 5.

differences, Sherer had met with Leary, but "neither was willing to accept the other standard to the discredit of his own." So Sherer had purchased, and sent to Leary, a quartz plate, on the side of whose mounting tube was inscribed "99 ½," indicating the value that a properly configured polariscope should indicate when the plate was inserted.[516] But this seemingly straightforward bit of notation proved just the opposite.

Sherer told the agents that "the fraction is a decimal," and that the plate's value was therefore 99 plus "between one-tenth and two-tenths." Leary, by contrast, had declared the value to be 99.5 "both from its marking and from his reading" in his polariscope, calibrated with other tubes. Spaulding sent the plate to the National Academy of Sciences, which reported its value as 99.12, though it was not clear whether this represented the consensus of the three Academy members who evaluated it or the average of their independent values. It then traveled to Cambridge, where an MIT professor measured it at 99.42. Finally the exasperated agents dispatched the plate to its maker, the German instrument firm of Schmidt & Haensch, who, after several months, unsurprisingly replied that their engraved value was correct. The only trouble was that the firm read it as "99.12." "Several other eminent professors came near it or had exactly the same," the firm wrote. "Only one gentleman who is in the sugar trade found it one-tenth less," they added, "but then these gentlemen find always a little lower than others."[517] The supposed standards used to calibrate the instrument were demonstrating themselves to be anything but.

516. For material collectives of standardization see O'Connell, "Metrology."
517. Senate Executive Document 190 (1890), 5-6.

Yet even the dissensus about the plate's value could not explain the pervasive discrepancy between the ports. As the Boston *Daily Globe* wrote, "the controversy reverted to the main question, the honesty of the chemists at Boston and New York."[518] After an elaborate series of over 250 blind tests of sugar samples exchanged among the Boston, Philadelphia, and New York customs houses, it became clear that the Manhattan laboratory consistently tested sugars as containing over half a percent less sucrose, on average, than the others. "New York tests are on a plane below that of all the other ports," wrote the agents, "and these planes never intersect."[519] The same was concluded by the Agriculture Department's chief chemist, Harvey Wiley, after testing samples from the three customs houses. Overwork was no excuse: the fact that New York handled a hundred samples a day would not, Wiley argued, by itself produce systematic errors in one direction or another. The "rapid work" at a customs laboratory should not, he thought, mean that "the instruments used should not read practically the same numbers with the same solution, why the flasks should not be accurately calibrated, the tubes of proper length, and the operations of weighing, dissolving, and reading made with a fair degree of accuracy." Wiley visited each city's laboratory, but even such personal inspection could not trace the source of the variation. Slightly over half of it he attributed to "the tendency of the New York assayers to read too low, combined with a tendency to fill the flasks too full," yet that still left 0.2 percent difference. [520]

518. "Crafty Plot," Boston *Daily Globe*, 1889 Feb 25.
519. Senate Executive Document 190 (1890), 7.
520. Ibid., 8-9.

To Spaulding, Sherer offered a startling explanation: different people read polariscopes in different ways. This was just what critics of the polariscope had always claimed, and what its advocates had insisted could be eliminated through training. "He believes that the Boston chemists are high readers," noted the agents of Sherer, but they were not convinced by his practice of "giv[ing] the doubt to the importer" and rounding down his decimals. "A doubt at best is an unsafe standard," they cautioned. Yet without any evidence implicating Sherer in any illicit practice or against his "personal integrity" all they could do was recommend that the New York laboratory's tests "be 'toned up' by an average of nearly .5 of a degree."[521] They deemed such an adjustment sufficient as a compensation for Sherer's tendency to measure low, since they could not point to any way in which he was being dishonest in his use of the instrument.[522]

The fact that they could not find an explanation for Sherer's persistently low readings was not enough for the Secretary of the Treasury. In late June 1890, Sherer was again dismissed from the government laboratory.[523] Thus by the middle that year the Custom House in New York was in desperate need of good publicity. In July, a few days after Sherer's firing, a reporter for the *Times* was invited to accompany visiting customs appraisers from across the country on a tour of its sugar procedures.[524] They began at the dock, where the reporter described in exquisite detail the samplers' behavior, down to the positions of his fingers:

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521. Ibid., 10.

522. For attempts to quantify individual differences in the practice of positional astronomy, known as the "personal equation," see Simon Schaffer, "Astronomers Mark Time: Discipline and the Personal Equation," *Science in Context* 2 (1988): 115-145.

523. "Will not test sugar any more," Brooklyn *Daily Eagle*, 27 June 1890.

524. "Appraisers get to work," The New York *Times*, 25 July 1890.

> The tester...has a circular handle, and when it is pushed into a hogshead or other package of sugar and given a turn and withdrawn it takes a core of sugar out...The sampler sticks his thumb into the groove at the upper end of the tester and draws the tester through his clasped hand...

If the transparent goal of the trip to the docks was to inspire confidence in the rectitude and rigor of the sampling process, the visit to the laboratory was meant to emphasize that both polariscope and polariscopists could make reliable and consistent measurements. The results did not go exactly as planned. The correspondent was invited to look through the eyepiece, but to him the two halves of the view "looked enough alike in color to seem to the unpracticed eye just alike," so he struggled to make his measurement. When he gave the polariscope over to the supervising chemist for confirmation, the chemist replied that the reporter was wrong by two tenths of a degree. But the second chemist in the room disagreed with the first, by three tenths.[525]

Most of all, the customs service wanted to advertise the secure procedures they had built into the architecture of the laboratory itself. The confidence of Spaulding and his colleagues that no sugar ring existed rested on the fact that the chemist "could not discriminate in favor of particular persons unless he knew whose sugars he was testing," and they felt that no conspiracy of the required magnitude to inform the chemists could long remain invisible. The *Times* reporter agreed: "to complete the safeguards for a purely scientific test, the chemists and polariscope readers are not permitted to know

525. "No sand in this sugar: how Uncle Sam tests the imported article. The functions of the polariscope and the nicety to which it determines the grade of sugar." The New York *Times*, 27 July 1890.

anything whatever about the ownership of the sugar to be graded, its place of production, the steamer by which it was brought to port or the date of its arrival." The only thing the polariscope operator knew was a serial number assigned by a clerk in a separate room. The reporter lauded the physical isolation of the laboratory, which was connected to the clerks' room only by the dumbwaiter used to deliver samples. "To reach the laboratory from the classification or examiner's room, [I] had to descend two flights of stairs, pass through the anteroom to the series of laboratories...through a small hall and then up two other flights of stairs."[526]

Yet this highly choreographed anonymity could not protect the Treasury. For one thing, as the Boston *Globe* had written, "the numerous samplers and examiners who handle the sugar before it reaches the chemist may be able to doctor it so that the polariscopic test would not record the true standard." These were the "infamous practices which made it so easy to organize the Sugar Trust."[527] Yet the reason to discriminate among sugar samples from different cargoes or bound for different refiners had vanished. There was only one refiner of sugar, one ultimate buyer, not just in New York but up and down the East Coast. The beneficiary of a low polariscope reading would always be the Sugar Trust.

The formation of the Trust might also have explained the sudden disappearance of Byrne's Boston witnesses. Whereas it had, in the mid-1880s, been in the interests of New England refiners to complain about Sherer's liberality in New York, it was now decidedly

526. Ibid.

527. "New York's Sugar Ring," Boston *Daily Globe*, 30 March 1888.

in their collective profit-sharing interest to complain of Leary's stinginess in Boston, and to deny that they had ever told Byrne what he reported they had told him. It was with an unwitting pun that Spaulding concluded his report on the government's laboratory. "Its employés," he wrote, "are as faithful to their trusts as are the employés of private parties, or the employés of the great corporations."[528] The somewhat paradoxical message of the demonstration to the reporter was that the polariscope users were both the most important men in the New York sugar trade and also the ones most subject to suspicion. The constant inability to determine just what a polariscope chemist was doing—even when the observer was a sugar chemist himself—was exactly the problem of unaccountability to which Brown, Chandler, and other critics of the polariscope had pointed ten years earlier.

4. Spaces of value

In the summer of 1907, a weigher for the American Sugar Refining Company, since 1891 the legal vehicle for the Sugar Trust, approached the Treasury Department to confess that for the previous ten years he had "been in the habit of using methods for lessening the apparent weight of drafts of sugar" at the Brooklyn docks of Havemeyer's refinery. This had been done "with the knowledge, and indeed by the direction, of the Company's dock superintendent," who had been the boss of its wharves for two decades.

528. Senate Executive Document 190 (1890), 10.

One morning that November, Federal agents raided the docks and interrupted the company's weighers. They found spring-loaded mechanisms, one in each of the docks' seventeen scale-houses, which the company weigher could activate with his left hand out of sight of the government weigher in the room, and which would lower the reading on the scale by between twenty and fifty pounds on a thousand-pound sack of sugar (**Figure 4.4**).[529]

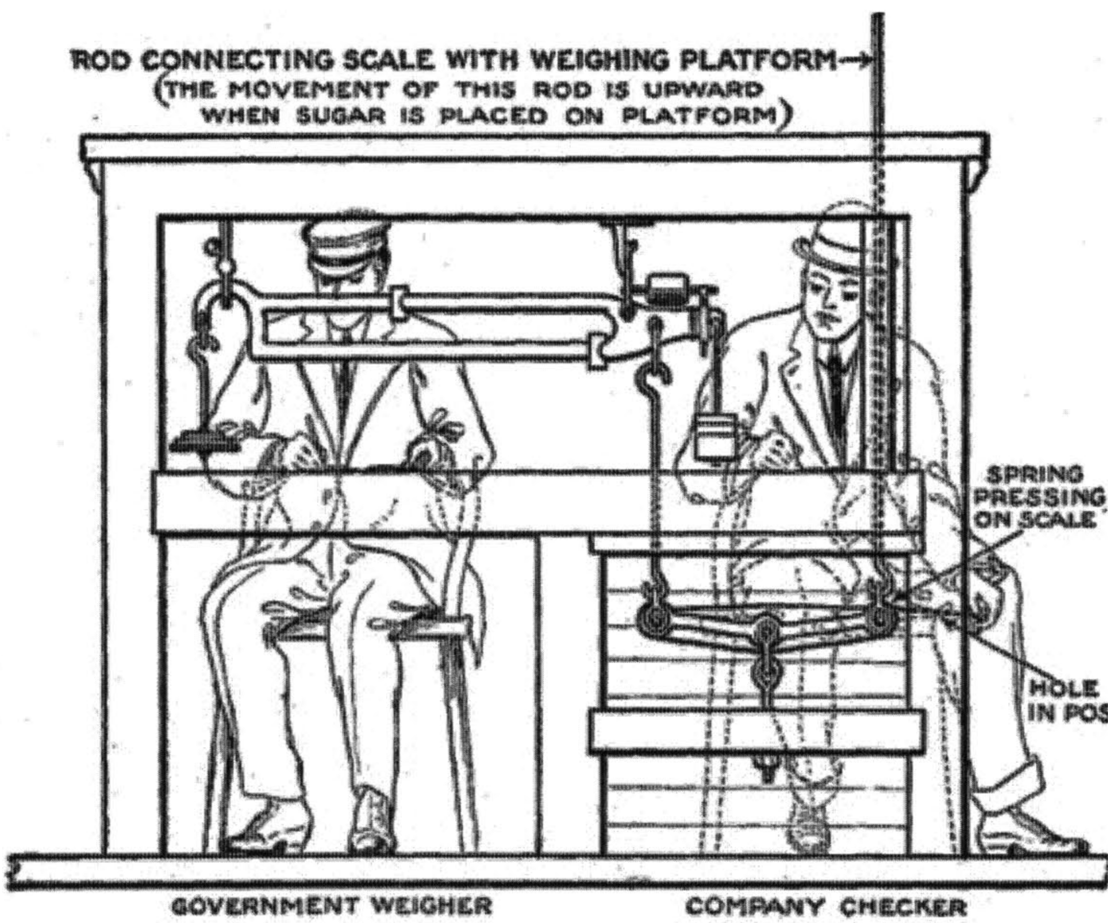

Figure 4.4: Mechanism for reducing the apparent weight of a cargo of sugar (*The Outlook*, May 1, 1909, accessed via unz.org)

529. Harold J. Howland, "The Men Higher Up," *The Outlook*, August 6, 1910, 31. See also Harold J. Howland, "The Case of the Seventeen Holes," *The Outlook*, May 1, 1909.

Human mechanisms were equally crude. One of the Federal agents testified later that Oliver Spitzer, the refinery superintendent, took him aside and asked him to name the price of his silence. A witness called by the government in the subsequent trial swore that he had seen customs officials simply walk up to the Havemeyer company cashier for their monthly envelopes of cash. A secret set of the company's books revealed that those weighers assigned to the spring-loaded scales were given a fifty percent bonus on their salary.[530] Over the next few months Federal auditors compared the company accounts with declared weights and shipping invoices. On almost all types of sugar cargoes, the company paid buyers for several tons more sugar than it reported to the government. The exceptions were cargoes delivered in hogsheads: because every hogshead was branded with its weight as it left the scales, the difference between the official and commercial weights would have been too obvious to ignore. From 1901 to 1907 the American Sugar Refining Company had "paid for seventy-five million pounds of sugar on which it paid no duty."[531] No one higher than Spitzer was prosecuted, though a memo to President Taft argued that "this company, down to minute details, was virtually run by one man"—Henry Havemeyer himself.[532]

At precisely the same moment—November 1907—Havemeyer was attempting to remove the lingering effects of a competitive marketplace from the city's commercial laboratories. In 1905 Harvey Wiley had suggested to John Arbuckle, the coffee and sugar magnate whose firm colluded with Havemeyer's Trust, that since a third laboratory

530. Eichner, 291-297.
531. Howland, "Seventeen Holes," 25-38.
532. Quoted in Eichner, 293 n. 8.

almost always mediated between buyer and seller, they might just as well establish a permanent referee. As with the formation of the Trust itself, Havemeyer's endorsement was the only one that mattered. A longtime Havemeyer advisor was named one of the two trustees, while a representative of the largest merchant firm named the other, and Wiley picked his own assistant, Charles Browne, to lead the laboratory.[533] More than anything, this new laboratory was designed to ameliorate the image of the sugar business as a fraudulent one. Once it opened, only the chemists and trustees would be allowed inside.[534] Even the name was chosen carefully. The trustees rejected "United States Sugar Trade Laboratory" because it seemed to imply an official relation to the government, but "American Sugar Trade Laboratory" sounded too much like the name of Havemeyer's company.[535]Once it opened for business in December 1907, in advance of the Cuban grinding season, only the chemists would be allowed inside.

The way the laboratory's procedures were designed and described institutionalized the fact that the buyer's chemist would come in low and the seller's chemist would come in high. Within the laboratory every sample was to be tested twice, once by each assistant chemist. The average of the two values was considered the value of the Laboratory and compared to those that emerged from the chemists hired by buyer and seller. All the firms in the city had signed contracts stating that the value of a transaction was to be the average of the Trade Laboratory figure and that of whichever chemist, buyer or seller, was nearer to it. If the Trade Laboratory was "exactly midway"

533. Browne, "History," 8, CAB papers, LOC.
534. Ibid., 22.
535. Ibid., 18.

then the average of all three was taken—which is to say that the Trade Laboratory's value won out. During the first month of the laboratory's operation the average variation between buyer and seller chemists fell from half a degree to about one third.[536] This was not a solution to the problem of not knowing how to use an instrument, but rather to the problem that some people knew how to use it all too well.

For this same reason, the new United States Bureau of Standards had been investing large resources on the design of a new polariscope since its founding in 1900, trying to combine features of several polariscopes on the market into a single device. In late 1907 they had their instrument, one which, they claimed, avoided the need for frequent recalibration under bad light or with dark sugars, and which could even be used by those suffering from colorblindness. No longer could polariscopic chemists claim a monopoly on its use. The Treasury adopted the new polariscope immediately, even though each instrument cost an extravagant $800. But no instrument could itself guarantee the elimination of "inconsistencies" among custom houses. Each of the four largest custom houses, in Philadelphia and New Orleans as well as in New York and Boston, were required to send samples of sugar to the others every day of the week so that their instruments' calibrations could be aligned. Samples had to be sent to the Bureau in Washington, too. By the middle of the next decade the director of the Bureau felt comfortable stating that gaps in sugar valuations at the principal custom houses "have been reduced to as low as 0.2 per cent; a concordance which is quite satisfactory."[537] It

536. Ibid., 23-24.
537. Warner, "How Sweet it Is," 162, 165.

took such complete surveillance to combat the power of a sugar refiner looking over the shoulder of a chemist in the custom house or of a sampler on the docks. Even then, the government remained uncomfortable. In a request for the services of an undercover agent in 1909, the U. S. attorney for the Southern District wrote to the attorney general that even the government's own weighers on the Havemeyer docks "are still more afraid of the Sugar Company's influence than they are of our prosecution."[538]

As this chapter has shown, the collection of tariff revenue depended on control of the spaces, labor, and expertise of the sugar trade. In the 1870s, investigations into the customs houses deprecated the credibility of its sugar experts. They also revealed the ways that the government's control over those spaces and those people was being challenged by refiners and importers, who sought to exploit them for their own competitive advantage in the internecine struggles of the sugar trade. Advocates of the polariscope, therefore, presented it as a technological fix to the problems of complex sugars and of untrustworthy employees. The polariscope's opponents countered that the instrument and its attendant practices, far from preventing corruption, would instead make it even more difficult for the Treasury to tell what its employees were actually doing. Already, they claimed, the largest refiners were taking advantage of the privacy of their docks to influence the activity of samplers, thereby enhancing their power. The obscure operation of the polariscope would only make such influence easier to obtain, while making it harder to distinguish proper practices from corrupt ones.

538. Quoted in Eichner, 295 n. 13.

In reducing the value of sugar's complex substance to a single quantity, Congress and the Treasury hoped to exert distant control over its valuation. In fact, however, they found themselves over and over again at the mercy of their supposed agents. This was because these agents were responsible not merely for assessing the value of sugar, but rather, in a far more active sense, for assigning it. In studying the history of commodities, we must pay attention both to the ways that experts like samplers and appraisers valued natural materials, and to the grounds on which their judgments were so often contested.

Conclusion:

Expertise and commodity capitalism

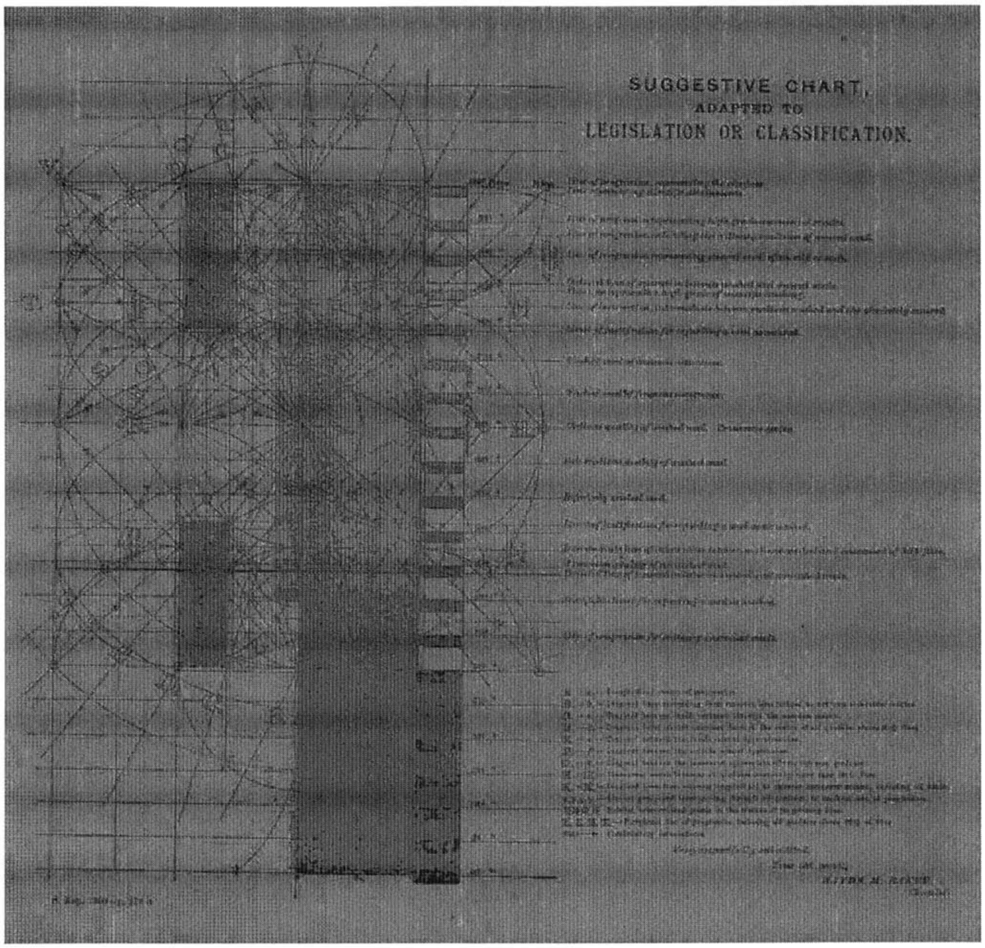

Figure 5.1: Dr. Haydn Mozart Baker's "Suggestive Chart" for the valuation of wool (1887)

Sugar was not the only commodity whose means of valuation was in question in Gilded Age New York. In fact, the most impressive visual representation produced by nineteenth-century science may not be a diagram of heavenly motions, the geology of the British Isles, or the periodicity of elements, but rather this "Suggestive Chart, Adapted to

Legislation or Classification" of wool. It was submitted, in 1886, to the Appraiser in New York, Lewis McMullen, and thence to a commission of the United States Senate, which was again investigating the possibility that imported goods were being systematically undervalued. Its designer was Dr. Haydn M. (for Mozart) Baker, who oversaw the assessment of textiles and dyes in the U.S. customs laboratory in New York, which McMullen supervised. Through "microscopical examinations" Baker's job was to identify the particular kinds of hairs and threads, and their proportions in mixed fabrics, for the purpose of levying their legislated duty.[539] In his Senate submission Baker explained that the purpose of the chart was to eliminate all uncertainty in the assessment of wool tariffs, which accounted for a substantial portion of the Federal government's revenue, though not so substantial as sugar's. Different rates were assessed on wool classified as washed, unwashed, or scoured, the three categories allowed under then-current US law. These three terms plainly referred to the processes that had been applied to the wool before it arrived in the custom house, but after it left the sheep. Yet in the search for the human activity embedded in the commodity Baker and other customs officers were hampered by their lack of information. "In the absence of a history of the events connected with a parcel of wool," Baker explained, "the determination of its 'status' in either [sic] one of these classifications can only be deduced from its condition." The activity had to be found in the goods themselves.[540]

Thus Baker constructed his chart to establish "the theoretic line of separation"

539. "A Big Laboratory: Where the Government Chemists Do Their Work," Atchison (Kansas) *Daily Globe*, December 22, 1887, 2.

540. United State Senate Report no. 1990, 49th Congress, 2nd Session (March 3, 1887), 232-234.

between each category, on either side of which was a "zone of doubt" beyond which he considered the government could no longer plausibly maintain "its liberality and its dignity." He repeatedly expressed dismay at the need for human judgment, especially so because of the process by which unhappy merchants might challenge customs decisions. The cycle of protest and appeal merely transferred the site of judgment from one person to another, each likely to experience "conditions entirely at variance with those which surrounded or were accessible to the original referee." In place of that fallibility, Baker's chart would scientifically represent the "obligations which co-exist with the natural relations connected with the subject-matter under contemplation." In other words, it would show how the economic value of wool derived from its organic properties.[541] Karl Marx would have been surprised. "So far," he wrote in 1867, "no chemist has ever discovered exchange-value either in a pearl or a diamond."[542]

Baker's wool chart is an extreme example, but the crucial instrument of commodification was, always, a system of grading. As scholars from Marx to Cronon have shown, commodification of all kinds depends on systems for turning a "first nature"

541. Senate Report No. 1990 (1887), 234. "When the inquiry is pushed to its utmost extreme," Baker wrote, "the investigator will discover that 'chemically pure fiber' constituted absolutely clean wool, therefore determinations of the percentages of fiber are the incontestable or uncontrovertable [sic] methods of distinguishing the appropriate classifications."

542. Karl Marx and Friedrich Engels, *The Marx-Engels Reader*, ed. Robert C. Tucker, 2nd ed. (New York: Norton, 1978), 328. Speaking of gold and silver as materials suitable for coinage, Marx wrote, "An adequate form of manifestation of value, a fit embodiment of abstract, undifferentiated, and therefore equal human labour, that material alone can be whose every sample exhibits the same uniform qualities." (*Capital*, Vol. 1, Chapter 2, https://www.marxists.org/archive/marx/works/1867-c1/ch02.htm) Marx notes Locke's observation that "a Law cannot give to [paper] Bills that intrinsick Value, which the universal Consent of Mankind has annexed to Silver and Gold." But Locke's point is the "universal consent" that accords those metals "intrinsick value," and specifically not the existence of "uniform qualities" themselves. John Locke, *Some Considerations of the Consequences of the Lowering of Interest, and Raising the Value of Money. In a Letter to a Member of Parliament* (London: Awnsham & John Churchill, 1692).

of plants, animals, minerals, and human beings—enslaved through much of the nineteenth century, then legally free—into a "second nature" that traffics in market abstractions.[543] Such systems took many forms. Grain was sorted into No. 1 or No. 2 White Winter, trees were sawn into boards, cattle slaughtered into sirloins and porterhouse, wisps of cotton baled with others equivalently rated as Inferior or Middling or Fine.[544] In each case, the question confronting states or economic institutions, like Chicago's Board of Trade, was, as William Cronon put it, "how to impose artificial boundaries on the world of 'natural'" substances.[545] Nineteenth-century systems of commodification became exceptionally proficient at writing these "necessary fictions."[546]

The nineteenth and twentieth centuries gave birth to new commodities—whether frozen mutton, artificial indigo, or a canned substance called "extract of meat" (extracted by feeding carcasses through secondhand sugar mills[547]), at the same time as it reimagined old ones like wool in the terms of modern scientific knowledge. These processes required not just the deployment of heavy machinery, but also for distant individuals to achieve a working consensus on what the valuable properties of those pieces of nature should be, and how they should be measured. That consensus, however,

543. For human frailties, discredits, and failures as commodified objects, see Scott Sandage, *Born Losers: A History of Failure in America* (Cambridge, Mass.: Harvard University Press, 2005), chapter 5, "The Big Red Book of Third-Rate Men."

544. Cronon, *Nature's Metropolis*, 118; Johnson, *River of Dark Dreams*, 249.

545. Cronon, 133-4.

546. "To understand wheat or corn in the vocabulary of bulls, bears, corners, grades, and futures," Cronon wrote, "meant seeing grain as a commodity, not as a living organism planted and harvested by farmers as a crop for people to mill into flour, bake into bread, and eat" (p. 146). The constant tension between fiction and reality, Jonathan Levy has argued, left Americans of this period deeply uneasy. Jonathan Ira Levy, "Contemplating Delivery: Futures Trading and the Problem of Commodity Exchange in the United States, 1875-1905," *American Historical Review* 111 no. 2 (2006): 307-335.

547. Brock, *Justus von Liebig*, chapter 8, "Liebig on Toast: The Chemistry of Food," 215-249; Rebecca J. H. Woods, "Breed, Culture, and Economy: The New Zealand Frozen Meat Trade, 1880-1914," *Agricultural History Review* 60, no. 2 (2012): 288–308.

was not achieved by fiat nor by the victory of rationality, but rather by the conquest of certain ways of thinking by others more closely tied to political power. In sugar, the uncertainty engendered by the supposedly impartial polariscope, an uncertainty manipulable by those who knew how, proved consequential for the shape of American refining and, eventually, the Atlantic economy as a whole.

One of the accomplishments of historians of commodity capitalism has been to expose how such "fictions" frequently had consequences in the "real" world. A syndicate might corner the April market for a grade of wheat, or a fall in the price of cotton might destroy banks in London that had leveraged themselves on securitized American slaves.[548] Yet though they emphasize the artifice of grades or qualities, historians have rarely questioned contemporaries' claims that the boundaries between them could, eventually, be found and policed. When writing of "fraud," "adulteration," or "honest grading," we must beware whose metrology we inhabit. Patrolling such borders is never merely a matter of finding sufficiently upstanding policemen, nor is it enough for historians merely to note that qualities used to value commodities, such as plumpness or fuzziness, are inherently "subjective."[549] As science studies has long shown, there is no "objective" way to subdivide and measure nature, no method of producing experimental facts that is not social and does not rely on other, equally-socially-produced facts.

The employment of sucrose as the metric of value for sugar was shaped by political

548. Edward E. Baptist, "Toxic Debt, Liar Loans, Collateralized and Securitized Human Beings, and the Panic of 1837," in *Capitalism Takes Command: The Social Transformation of Nineteenth-Century America*, ed. Michael Zakim and Gary John Kornblith (Chicago ; London: The University of Chicago Press, 2012), 69–92.

549. Cronon, 118.

and economic power. The foregoing dissertation has exemplified how such power does not stop at the door to the laboratory, and that accuracy and precision are claims as social as any other. Instead, the metrology of sugar was the means by which centralistas tried to extend their power into the landscape of Caribbean sugar islands, and refiners tried to control the sugar trade across the northeastern United States. Under regimes of "chemical control," factory chemists promised their masters that polariscopes could guarantee purity and quality, freeing them from the tyranny of artisan knowledge, which they denigrated and discredited yet tried desperately to capture. The polariscope gave hope to revenue officials that they could circumvent frauds in the collection of sugar tariff, yet it equally gave mischievous merchants further opportunities to plunder the Treasury.

By writing histories of commodification that emphasize how systems transform nature into goods, historians neglect the pivotal role of intermediaries who made empires of commodities seem possible. Thus, even as their narratives help decompose the process of commodification, they nonetheless ensure that structures and institutions of commodification appear stable and automatic. From Isaac Newton at the Royal Mint to Henry Havemeyer in his Williamsburg refinery, this was just what those who attempted to exploit such systems wanted. There is more than a metaphorical connection between contemporaries' claims for the power of the polariscope and historians' treatment of the social machinery of commodification, which depends on expert labor precisely in order to seem as though it functions on its own.

But there is never a point at which harvests or herds sublimate into interchangeable commodities, because commodification is not a transformation that can be mechanized or automated. Rather, it is a continuous and continual process, in which privileged valuers must constantly reaffirm that idiosyncratic natural specimens are fundamentally the same. The fact that modern systems for creating and transporting commodities seem to operate so smoothly is not a cause, but a consequence, of economic, social, and ultimately political choices about how to value nature. The efficiency of those systems does not indicate that human judgment has been either automated or obviated. Instead, it should invite us to look ever more closely for how such consensus was won.

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