CHEMISTRY AS A TOOL FOR HISTORICAL RESEARCH: ESTIMATING THE CONTRABAND OF SILVER FROM POTOSÍ AND ORURO, 1576-1650

Saúl Guerrero, History Department, McGill University, Montreal, QC H3A 2T7, Canada, saul.guerrero@mail.mcgill.ca

Introduction

Historical contraband is a topic that is very difficult to quantify since by its nature it is hidden from production or sales data available in archival records. It is not only a question of the commodity that is the being trafficked as contraband. Even the data on the raw materials required to produce it may be open to question if those materials could also be obtained outside the official channels of distribution. This can leave the historian without a reliable point of reference on which to base calculations. Silver production in the Hispanic New World is a very appropriate case in point. All the historical official silver and mercury production data from the Spanish colonies in the New World are assumed to be an incomplete picture of production levels and practices, due to a combination of contraband and a bureaucracy that was lax, corrupt or both (1). It has been estimated that as much mercury was sold as contraband as was consumed in the Vice-Royalty of Peru (2). In the case of silver the educated guesses of historians have placed the level of contraband anywhere from very low up to twice the official production levels (3). Both sets of official data are thus expected to report values below the real levels of production, reflecting the evasion of tax payments to the Spanish Crown on the true amount of mercury and silver produced in any given year. Contraband of mercury would in fact have a double negative impact on the tax receipts, once on the mercury itself and then on the silver that could have been officially produced from it. This is the reason why contraband mercury was more expensive than the mercury made available through official channels (4).

The workers at the mercury mine of Huancavelica (modern day Peru) are said to have been driven to selling contraband mercury because the Crown was always in arrears in paying for the mercury that was purchased under the Crown monopoly (5). In the case of silver the search for greater profit would have been the only motivation. There were at least four ways to circumvent the payment of royalties on any silver produced (6):

1. By officially declaring less silver than was obtained via amalgamation with mercury supplied by the Crown. This would be best accomplished by negotiating the *correspondencia* value with the local authorities.
2. By underreporting the official silver production with the connivance of the local Crown officials.
3. From the smelting of the richest silver ores using lead, thus avoiding having to purchase official mercury supplies.
4. From amalgamation of silver ores using contraband mercury.

To detect any of these paths is not straightforward. To avoid the first option the Crown established by the end of the sixteenth century that there was a rule of thumb correlation between the average amount of mercury that was lost during amalgamation and the weight of silver extracted. This correlation was called the *correspondencia*, with a range of values that on average corresponded to a weight ratio of mercury consumed to silver extracted of 1.8 ± 0.3 (7). In some jurisdictions fresh mercury would only be supplied to the refiners on the basis of the mercury declared to the Crown as having produced the registered amount of silver (the *consumido*) (8). One way around this control would have been to negotiate with the Crown authorities a higher mercury to silver weight ratio (corresponding to a lower *correspondencia* factor) than actually required by the refiners, which would have supplied them with excess mercury. Indirect evidence for this would be increases in the recorded weight ratio compared to previous average levels.

The last three methods of obtaining contraband silver do not leave any trace in the production records other than the suspicion left by decreases in production that cannot be readily explained through other causes. If the contraband in question is not the household industry variety but is suspected of reaching major levels of output then all four contraband options require an existing plant infrastructure capable of physically processing sufficient silver ore to supply both the official production of silver and the silver to be trafficked as contraband. The silver ore had to be ground in large stamp-mills to the correct mesh size and afterwards treated with mercury and additives in many vats (9). This is the Achilles' heel of any contraband operation based on industrial infrastructure: books can be doctored with care and officials bribed, but stamp mills and amalgamation vats cannot be hidden.

Once capital-intensive production units are built, it is in the interest of the investor to maximize his return on the capital invested by producing at the limit of what his plant would allow. There are historical circumstances that may have imposed an idling of installed silver refining capacity, such as problems with the work force, interruptions of supply of needed raw materials, epidemics, lack of sufficient rainfall to drive the water-mills, changes in ore quality, and others. However, if on a long-term basis a production unit built with private capital is observed to apparently run well below its nominal capacity without defaulting on its financial obligations, and it happens to be producing a commodity that has a high contraband value and market demand, then the difference between registered output and nominal capacity can provide an independent guide to the potential order of magnitude for contraband.

Production of Silver in the Vice-Royalty of Peru, 1576-1650

In the first 75 years after the definite introduction of amalgamation of silver ores in the Vice-Royalty of Peru (1572-1574), 93% of all the silver officially accounted for was produced just from the mines and refining centers (*Ingenios*) of Potosí and Oruro (Figure 1) (10). Amalgamation would have been firmly established as the main refining process by 1576 (11). The turn of the century was a watershed in the history of amalgamation in the Vice-royalty of Peru. The period from the mid 1570s to 1585 had seen production of silver rise by nearly nine times after the introduction of the initial amalgamation recipe (Figure 2) (7). A decrease in production after 1585 drove the refiners to search for an improved amalgamation recipe. By 1588 the Viceroy was worried that attempts to find a more efficient use of mercury would endanger the revenues and taxes from the Crown sales of mercury if refiners managed to decrease its consumption. He therefore commissioned a technical audit of all the trials that were being carried out in Potosí to improve the traditional amalgamation recipe, and prohibited any more trials being carried out without official authorization (12). The audit reports that in 1587 the Corzo brothers had obtained positive results by adding finely ground iron metal to the amalgamation mix, the *beneficio del hierro* (13). It also includes among its list of trials the addition of a blue mineral (*copaquiri*, copper sulfate) to the amalgamation recipe (14). However it would only be in the early 1600s that the amalgamation process would incorporate as standard procedure a prior roasting of the ore and the addition of copper *magistral* (copper sulfate from roasted copper pyrites) to the traditional recipe of water, salt and mercury. This was the most efficient amalgamation process that allowed refiners to extract silver from the *negrillos* (silver sulfides) that had displaced the *pacos* (silver chlorides and native silver) as the main type of ore coming out of the mines of Potosí (15). Finally in the late 1610s Barba would propose his new way of refining *pacos* by cooking (*cocimiento*) the amalgamation mix in copper vessels, the *beneficio de cazo* (16). No other period in the history of Potosí would be witness to so many successful innovations applied to the amalgamation process.

By 1650 other mining centers in Peru would contribute larger shares of the total production of the Vice-Royalty. To avoid having to make assumptions on how mercury was distributed to each mining center I have chosen 1650 as the cut-off date for my analysis. For the pur-

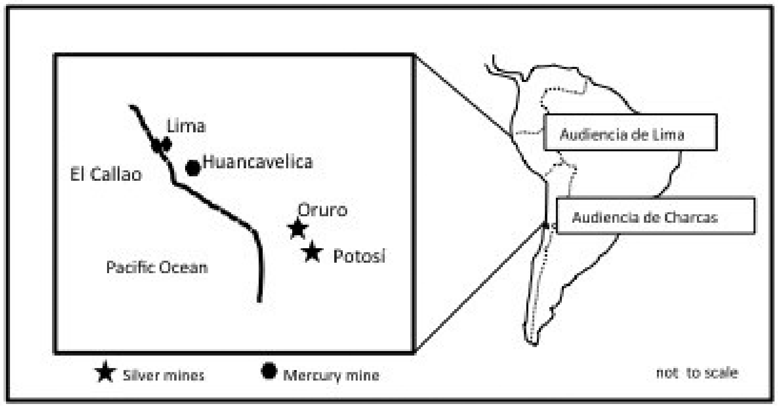
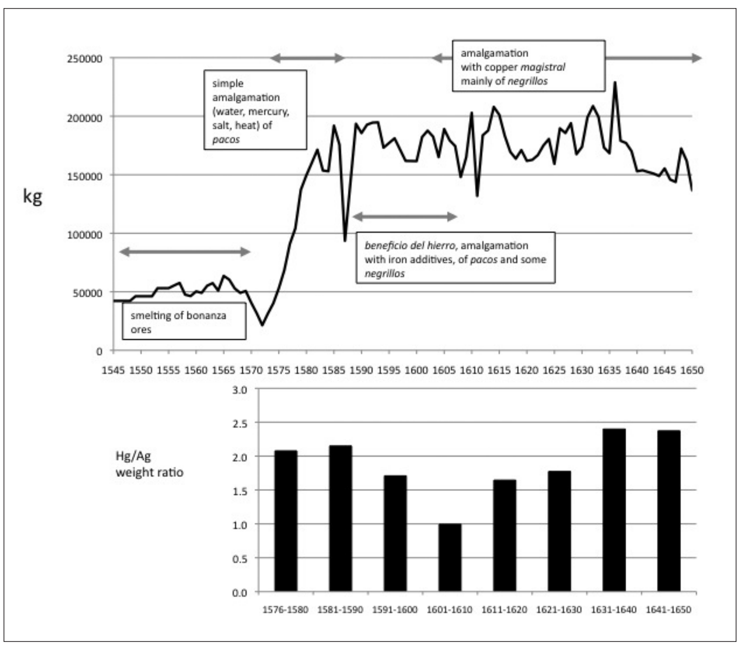


***Figure 1**. The Vice-Royalty of Peru in the sixteenth and seventeenth centuries.*

poses of the exercise all the mercury registered as produced at Huancavelica or imported into Peru from Europe during these years is considered consumed at Potosí and Oruro. No correction will be made for any supplies to New Spain from Huancavelica during this period (17). Since there is a delay between production of mercury and consumption at the Ingenio this introduces a distortion in short term correlations of data. Bakewell when faced with a similar problem staggered the data sets he compared by one year (18). Since the effects of back-ups of mercury within the whole official distribution system are not necessarily dissipated within one year, as shall be seen for the case of the decade 1601 to 1610, I prefer to simply acknowledge this degree of uncertainty in the method I employ.



Sources: Silver production from Ref. 10, 188-191; mercury to silver weight ratios from Table 1.

***Figure 2.** Annual production of silver (official) from Potosí and Oruro and mercury to silver weight ratio.*

In the case of the official data on silver production, the primary sources used by historians are not actual production outputs measured in units of weight, but the amount of tax collected at each of the regional Treasuries (*Caja Real*). Refiners brought the refined silver to the *Caja Real* of Potosí or Oruro, where officials would calculate the tax to be paid. Over a fifth of the silver was retained in order to pay for the royal taxes, the *quinto* or fifth plus an additional tax, the *derecho de Cobos*. The amount of silver that must have been produced is calculated based on the tax records (19). On the other hand, according to Whitaker, sales of official mercury were used to estimate the amount of tax on the deemed silver produced via amalgamation: "[the Crown] protected itself against tax evasion on the part of the latter [silver miners] by computing the *quinto* ... not on the basis of the silver which the miners reported they had produced, but on the basis of the amount of mercury which the records of the mercury administration showed they had bought" (20). Though Whitaker does not mention how the officials arrived at the deemed production level of silver it must have been on the basis of the *correspondencia* factor. This calculation of an estimated production using the *correspondencia* factor avoided the problem of silver refiners bringing less silver to the *Caja Real* than they had refined, and then requesting again the same amount of mercury as the last batch. It is possible that both methods were applied concurrently or that practices differed according to each locality.

The other caveat regarding the official data on silver production in Potosí is that in at least one period it is shown to be completely divorced from events on the ground. In 1626 one of the dams built to create water reservoirs above the city gave way with devastating consequences. When the dam broke the resulting flood is reported as having destroyed 126 out of 132 *Ingenios*, 76 of which were claimed to be beyond repair (21). In spite of this, silver production (in marks) derived from the tax records shows an increase from 570,171 in 1626 to 594,682 in

1627, reaching a peak of 646,543 in 1628, and then dropping to 536,473 in 1629 (22). Even taking into account possible delays in the register of production data the loss of over half the *Ingenios* should have been reflected in the official production data, unless the extent of the damage was misrepresented in the primary sources.

In spite of all these elements of uncertainty and change, the calculation of the mercury to silver weight ratio using the official figures of mercury and silver production for Potosí and Oruro provides a remarkably consistent picture for the period in question. The average value of this ratio in Table 1 for the period 1576 to 1650 is 1.9 ± 0.37. The use of the mercury to silver weight ratio as an analytical tool for the study of the historical production of silver is not new (see below) but what is novel is the proposition that it is a factor determined by the stoichiometry of the chemical reduction of silver chlorides by mercury, and not an empirical number. The range of values of this ratio in Table 1 correspond, with one sole exception, to what is expected from an amalgamation reaction based on the reduction of silver chlorides with mercury (7). The conclusion is valid whether the production data of silver and mercury are derived from actual physical quantities or if the official silver production was calculated from the official mercury supplied to the refiners.

Table 1. Mercury and silver official production data, in metric tons, 1576-1650

period	silver[a]			mercury[b]	weight ratio Hg/Ag
	Potosi	Oruro	Potosi + Oruro		
1576-1580	550	0	550	1143	2.1
1581-1590	1622	0	1622	3486	2.1
1591-1600	1770	0	1770	3025	1.7
1601-1610	1708	68	1776	1766	1.0
1611-1620	1373	389	1762	2898	1.6
1621-1630	1308	447	1755	3111	1.8
1631-1640	1340	517	1857	4453	2.4
1641-1650	1152	370	1522	3611	2.4

Sources:

a) Ref. 10, Tables 4.5 and 4.7, 188, 191.

b) Ref. 2, 264 and Appendix V, 453-54; Ref. 17, Tables 1 to 4, 1959-1965.

The only exception to the above is the decrease of the weight ratio to unity in the decade from 1601 to 1610. This reflects the increasing impact of the implementation of the *beneficio del hierro* from the late 1580s to the early 1600s before it was phased out by amalgamation using copper *magistral* (23). The iron in the *beneficio del hierro* competes with mercury for the reduction of silver chloride to form elemental silver and calomel, so that consumption of mercury would decrease for the same amount of silver refined. This is the explanation to the observation by a refiner in the sixteenth century that "with the new iron process ... even though not much silver was extracted, no mercury was lost" (24). That the *beneficio del hierro* played a major role in the amalgamation of silver ores in Potosí up to the early 1600s is indicated by the 1603 report that 4,000 *quintales* (184 tons) of iron were used to refine silver that year, though no breakdown exists to quantify its overall share of the refining process (25).

The impact on mercury demand would be felt from the 1590s to the early 1600s, tracking the rise and fall of the *beneficio del hierro*. Lohmann Villena has documented the accumulation of 17,000 *quintales* (782 tons) of unused mercury by 1604 in the inventory of Huancavelica. The Crown had committed to purchase amounts of mercury based on historical levels (pre-1587) when no *beneficio del hierro* existed. Lohmann Villena also argues that the Crown preferred to purchase as much as possible from the Huancavelica miners so as to avoid contraband sales of mercury. Faced with a glut of mercury the Spanish authorities imposed strict limits of production in 1604 (only 859 *quintales* were produced in that year, down from previous levels over 5,000 *quintales*) and the decrease in production levels lasted until the end of the decade (26). The system had backed up because now less mercury was consumed for equivalent amounts of silver production. It would seem that the Viceroy Don Fernando de Torres y Portugal had been correct in fearing a sharp decrease in the Crown sales of mercury due to new improvements in the amalgamation recipe. The ability of copper *magistral* to efficiently convert the silver sulfides of the *negrillos* into silver chlorides would eliminate the use of the *beneficio del hierro*.

Does the profile of the mercury to silver weight ratio throughout this period provide any guide as to the presence or extent of contraband, once the effect of the change in amalgamation recipe has been accounted for? The ratio stays within the average historical range of 1.8 ± 0.3 except from 1631 to 1650 when it reaches 2.4, indicating that much more mercury was being used than previously. This would imply either a lower efficiency in the physical recycling of mercury or that mercury was also being used to produce contraband silver.

Can the weight ratios in Table 1 provide any indications as to the contraband of silver obtained by smelting after the introduction of amalgamation? By themselves the ratios can only indicate if enough silver produced by smelting was declared to the Crown so as to decrease the weight ratio beyond the average deviation observed in the historical *correspondencia* values. Thus the value of unity explained by the *Beneficio del Hierro* could also be explained by a surge in smelting of official silver that would account for a significant decrease in the use of mercury. As to contraband silver, it would only be inferred if independent evidence showed that smelting produced large quantities of silver in any given period but the mercury to silver weight ratio did not decrease significantly below 1.5.

One independent source to estimate an order of magnitude of total silver produced by smelting is a study carried out by Abbott and Wolfe of lead deposits in core samples taken from the sediments of a lake in the vicinity of Potosí. The concentration of lead per gram of sediment is correlated to different periods in time, from the year 600 to the present. The plot shows a prominent peak with a concentration of just under 300 μg/g around 1550, the period when Spanish miners were producing silver using only smelting. After amalgamation was introduced the concentration of lead begins to decrease, but it is quite an asymmetrical peak, since between ca. 1600 and 1650 a shoulder persists around a concentration level of approximately 225 μg/g (27). The authors of the study recognize that the high overall levels of lead deposits in the lake are the result of lead smelting to refine silver. The concentration of lead can be taken to be directly proportional to the amount of silver that was being extracted by smelting in the period 1550s to 1650, if the loss of volatilized lead per unit of silver refined by smelting remained relatively constant. In the period 1550 to 1572 an average of at least 50 tons per year were produced by smelting of silver ores with lead (28). A rough estimate would place the level of smelting from about 1600 to about 1650 at around 35 tons of silver by smelting, proportional to the average 25% decrease observed in the concentration of lead in the lake sediments, all other factors remaining equal. This level of smelting is too low to decrease substantially the Hg/Ag weight ratio beyond its expected average historical range, so it cannot be assigned unambiguously as having been destined either for contraband or registered as official production. However it can be ruled out as having been the major factor responsible for the decrease in weight ratio to unity in the decade 1601-1610.

Infrastructure Limitations on Silver Refining in the *Ingenios*

The bottleneck to the production of silver by amalgamation, whether official or contraband, was the maximum rate at which the mineral could be processed through the stamp-mills and the amalgamation vats in the context of an industrial batch process. In the discussion that follows I will limit my attention to Potosí towards the end of the sixteenth century because of the availability of infrastructure data for that time and place. In 1585 Luis Capoche, a Spaniard who owned *Ingenios* in Potosí, published a list of the *Ingenios* existing at the time, with their location, the number of heads and stamps used for crushing the ore, and their source of power (water or horse). Thanks to the data published by Bakewell on the processing capacity of these types of mills it is therefore possible to arrive at an estimate of the physical limit to the amount of ore that could be ground in these *Ingenios* in an average year during this period (29). Table 2 provides a summary of the calculated milling capacity for Potosí around 1585, and an annual total estimated at 3.4 million *quintales* based on a 200 day operating period in a year (30). Capoche mentions a much lower annual capacity of 1 million *quintales* of ore, of which according to his estimate only 600,000 *quintales* were actually processed. If his estimate was correct it would require the silver content of the ore to be around 10 pesos per *quintal* to produce the official quantity of silver reported on average for the decade of the 1580s. This is contrary to the information given throughout Capoche's work on the silver content of the ores in this period (31).

A separate document with detailed information on Potosi, dated 1603, coincides with the estimates given in Table 2. The anonymous report states that 2.7 million *quintales* of ore were brought down from the mountain to be processed in one year. It also provides the information that there were 128 stamp heads in operation, each capable of processing 150 *quintales* of ore per day, so that in 200 days (the assumption used in Table 2) a total of 3.8 million *quintales* would have been processed. Finally, according to the same primary source 4,262 *quintales* of silver were refined from the 2.7 million *quintales* of ore, which indicates a silver content in the ore of 2.7 pesos per *quintal* (0.16% by weight of silver) (32). The information in this document is more consistent with what is expected of the silver content of these ores from the majority of Capoche's work. Since the output calculated in Table 2 is based on a separate 1576 document used by Bakewell to calculate the ore processing capacity of the stamps, the data from 1603 provides strong independent support

Table 2. Estimated installed milling capacity in Potosí, 1585.

Ingenios	Type	total stamps	*quintales* ore per day per stamp	total *quintales* ore per day	sub-total *quintales* ore for 200 days	total *quintales* of milled ore for 200 days
75	Water	823	19.75	16,250	3,251,000	
31	Horse	231	3.02	698	140,000	
						3,390,000

Sources: Ref. 19 (Capoche), 118-122; Ref. 11.

to these results (33).

Silver production would depend not only on milling capacity but also on the number of available amalgamation vats, called *cajones*, with a capacity each of 50 *quintales* of amalgamation mix. Cold amalgamation could require up to 25 days, but use of a heated *cajón* could reduce this to 6 days (34). Table 3 indicates how many *cajones* would be needed to handle the maximum milling capacity of the *Ingenios*. An anonymous report from Potosí dated 1603 mentions the existence of 60 thousand *cajones*, greater than the requirements estimated in Table 3 (35). Based on this report the physical bottleneck in production would have been the installed milling capacity and not the number of available *cajones*.

Table 3. *Cajones* required to process milled ores

total amalgamation batches (per year)	65,020	in water mills
	2,790	in horse mills
At 25 days per batch	15	batches per *cajón* per year
At 6 days per batch	60	batches per *cajón* per year
total *cajones* at 25 d	4,520	
total *cajones* at 6 d	1,130	

Each batch in a *cajón* corresponds to 50 *quintales*

How much of this plant capacity could have been destined for producing contraband silver? As Table 4 shows, it depends on the silver content of the ore being processed. Capoche provides information on a variety of ores of the period, and I have chosen to calculate the values in Table 4 from the lowest range of 2 pesos per quintal (0.12 % by weight of silver) to 8 pesos per quintal (0.49%) (36). The level of potential contraband depended on how much capacity is freed as the silver content of the ores increases. At the high end of the scale, if ores were being processed that had an average silver content of 8 pesos per *quintal*, only 25% of the installed capacity was required to produce the levels of silver reported in the official data, and the remaining 75% could be used to produce contraband silver. Even at a silver content of 4 pesos per *quintal* half the plant could be dedicated to refining contraband silver. This means that the estimated ranges reported in the historiography of 1 to 1 or 2 to 1 contraband to official silver production (Ref. 3) could in principle be accommodated by the existing plant capacity in 1585. Only with the ores poorest in silver (2 pesos per quintal) could it be said that the installed capacity was in line with official production data.

As the silver content of the ore and the total processing capacity of the *Ingenios* decreased over time (the number of *Ingenios* is reported as dropping from a high of 132 to a low of 34 in 1692 (37)), official silver production figures would have come closer to the nominal capacity of the installed infrastructure required to process ore and extract silver.

Comparison to Other Estimates of Contraband in Potosí

Bakewell discussed at length the possible impact of contraband in Potosí both on production trends and on the mercury to silver weight ratio. He concluded that the impact on the former might lead to more pronounced decreases but that it would be difficult to arrive at any solid conclusion based just on the shape of the production curve over time. His analysis of the significance of the mercury to silver weight ratio is hampered by the fact he did not recognize that the ratio was not an empirical factor but that it has a chemical underpinning which defines the possible interpretations to its low or high values. In an amalgamation process other than the *beneficio del hierro* or the *beneficio de cazo*, the consumption of mercury by a silver ore is not determined by whether it is rich or poor in total silver content, but whether it is rich or poor in native silver (7). He concludes that based on the empirical values of the ratio as derived from the official registered data there is no evidence of any major amount of contraband taking place, since these values

Table 4. Installed silver production capacity circa 1585.

total *quintales* of milled ore for 200 days	silver in ore (pesos per *quintal*)[a]	potential silver production (pesos)	potential silver production (marks) at 8 pesos to 1 mark	average official yearly silver production 1581 to 1590 (marks)[b]
3,390,400	2	6,780,800	847,600	760,771
	4	13,561,600	1,695,200	
	8	27,123,200	3,390,400	

Sources:
a) Ref. 19 (Capoche), 78-79.
b) Ref. 3 (Bakewell), 92.

correspond very well to the lower *correspondencia* value of 150 marks to the quintal quoted in the technical audit of 1588. He considers that smelting was not important after the 1580s. He dismisses any possibility of major quantities of contraband mercury being available to produce silver (38).

The weight of his argument against any significant production of contraband silver relies on the fact that a very good correlation is observed between the *correspondencia* factor and the historical mercury to silver weight ratios for the period 1593-1686. The fact this correlation exists only means that the empirically derived *correspondencia* factor corresponds, as it should, to the factor predicted by the chemistry of the most widely used amalgamation process during the period. It does not mean that no contraband was possible during this period.

Noejovich more recently carried out an analysis of the magnitude of contraband in Potosí based also on the mercury to silver weight ratio. He detects a peaking in the level of mercury consumption around 1640-1650 where the mercury to silver weight ratio increases beyond the previous historical levels. He concludes that this would indicate an increase in the contraband production of silver during this period (39). He repeats the assumption in the historiography that a value of unity of the weight ratio represents the chemical losses and the rest the physical loss, but he does not provide any chemical background to sustain this assumption, which in any case is incorrect as a generalization. My own analysis coincides with his appreciation that the values of the ratio towards the 1640s and 1650s indicate a higher consumption of mercury, most probably due to mercury being diverted to producing contraband silver under the guise of a higher *correspondencia* factor.

Conclusions

I have tested two approaches to detect and quantify contraband of silver during the period 1576-1650 coming out of the two main silver production centers of this period in the Vice-Royalty of Peru, Potosí and Oruro. I have first analyzed the variations of the mercury to silver weight ratio on the basis it is a factor determined by the stoichiometry of the reduction of silver chloride to elemental silver and the production of calomel from mercury, together with the extent of physical losses of mercury during amalgamation. Since it does not depend on absolute production levels it is not influenced by factors that affect production and that could be confused with contraband (40). Its limitation is that to calculate the ratio requires information from the official records. If these were altered according to the expected correlation (*correspondencia*) between mercury consumption and silver extraction then its utility to detect contraband becomes more limited. The range of mercury to silver weight ratios from 1576 to 1650 only indicate a higher than average use of mercury from 1630 to 1650, which could be due to increased contraband activity. The ratio does not register any lower values than expected except in the decade 1601 to 1610, where the effect of the *Beneficio del Hierro* created a glut of mercury in the distribution system.

The second approach involves the estimation of the nominal production capacity for a refining center, and therefore has the advantage that it does not rely on any set of production data, either of mercury or of silver. This freedom from possible biases introduced in the official tax record makes it a very valuable method if the information on the infrastructure is available. The richer the ore, the wider is the gap between the potential refining output and the official silver production data for the Potosí refining infrastructure of 1585. The existing plant capacity could refine up to twice more silver than appears in the official production data, if sufficient contraband mercury was available. A similar exercise carried out on the nominal capacity of the physical infrastructure that existed in Huancavelica for the production of mercury during this period is required to complete the picture.

The implications of such potential contraband reach beyond the sphere of economic history. Already the official record of mercury production points to average yearly losses of nearly 500 tons of mercury as calomel and as elemental mercury in the Hispanic New World for over 250 continuous years. How much more was actually lost as a consequence of the production of contraband amalgamated silver remains to be established.

Acknowledgment

I would like to thank Dr. David A. Johnson for his very helpful comments after reviewing a draft of my thesis chapter from which I extracted the section on amalgamation recipes and ore quality that appears in this paper.

References and Notes

1. K. J. Andrien, "Corruption, Inefficiency, and Imperial Decline in the Seventeenth-Century Viceroyalty of Peru," *The Americas,* **1984**, *41*, 1-20.
2. G. Lohmann Villena, *Las Minas de Huancavelica*, Escuela de Estudios Hispanoamericanos, Sevilla, 1949, 388.
3. An estimate of one third official production to two thirds contraband silver towards the end of the colonial period is quoted from *El Mercurio Peruano* of 1793 in P. Bakewell, "Registered Silver Production in the Potosí District, 1550-1735," *Jahrbuch für Geschichte Lateinamerikas,* **1975**, *12*, 67-103 (see p. 80); contraband as half of total silver output in Peru, see footnote 27 in D. O. Flynn and A. Giraldez, "Cycles of Silver: Global Economic Unity through the Mid-Eighteenth Century," *Journal of World History*, **2002**, *13*, 391-427 (see p. 404); for silver contraband estimates in the trade between the Vice-Royalty of Peru and New Spain, with official exports around 50 to 80% of real total silver exported in this route, see D. O. Flynn and A. Giraldez, "Arbitrage, China and World Trade in the Early Modern Period," *Journal of the Economic and Social History of the Orient*, **1995**, *38*, 429-448 (see p. 435).
4. Ref. 2, 439.
5. Ref. 2, 354.
6. For other schemes applicable to the contraband of silver see P. Bakewell, *Silver Mining and Society in Colonial Mexico. Zacatecas 1546-1700*, Cambridge University Press, Cambridge, 1971, 182-183.
7. S. Guerrero, "Chemistry as a Tool for Historical Research: Identifying Paths of Historical Mercury Pollution in the Hispanic New World," *Bull. Hist. Chem.*, **2012**, *37*, 61-70.
8. Ref. 6, 175.
9. Some of the best visual depictions of the concatenated operations involved in the industrial-scale refining of silver ores in Potosí can be found in the engravings that accompany the work by B. Arzáns de Orsúa y Vela, *Historia De La Villa Imperial De Potosí*, L. Hanke, and G. Mendoza L. (Eds), Brown University Press, Providence, 1965.
10. J. Tepaske and K. W. Brown, *A New World of Gold and Silver*, Brill, Leiden, 2010, 188-191.
11. By 1576 there were already 108 mills in operation in the Potosí area, as quoted in P. J. Bakewell, "Technological Change in Potosi: The Silver Boom of the 1570's," in P. J. Bakewell, Ed., *Mines of Silver and Gold in the Americas*. Variorum, Aldershot, 1997, 86.
12. M. Jiménez de la Espada, *Relaciones Geográficas de las Indias - Peru*, Vol. II, J. U. Martínez Carreras (Ed.), Biblioteca de Autores Españoles, Tomo 184, Editorial Atlas, Madrid, 1965. Instructions of the Vice-Roy Don Fernando de Torres y Portugal to Juan Ortiz de Zárate as quoted on p. 121.
13. Official reports on the Corzo amalgamation recipe, dated 1588, as quoted in Ref. 12, 124-125.
14. Ref. 12, 122-126.
15. Juan de Ibarra, "Suma de lo que el licenciado J de Ybarra como procurador general de la Villa de Potosí pide," 14 August 1617, Madrid, British Library; letter written by Don Pedro de Cordoba Messia to the Viceroy of Peru, 1 Novermber 1602, as quoted in Ref. 12, 132.
16. A. A. Barba, *Arte De Los Metales*. Editorial Labor, Barcelona, 1977.
17. Up to 99% of the mercury of Huancavelica was destined for mines in colonial Peru according to P. Chaunu, *Seville et l'Atlantique (1504-1650) La Conjoncture, Tome VIII*, SEVPEN, Paris, 1959, 1970.
18. Ref. 3 (Bakewell), 82.
19. L. Capoche, *Relación General de la Villa Imperial de Potosí*, Biblioteca de Autores Españoles, Tomo 122, Ediciones Atlas, Madrid, 1959, 178; Ref. 3 (Bakewell), 74-80; Ref. 6, 181-186. Bakewell indicates that the records for Zacatecas in New Spain up to the 1700s contain information as well on the marks of silver produced.
20. A. P. Whitaker, *The Huancavelica Mercury Mine*, Harvard University Press, Cambridge, 1941, 6-7.
21. W. E. Rudolph, "The Lakes of Potosí," *Geographical Review*, **1936**, *26*, 529-554; see 537.
22. Ref. 3 (Bakewell), 94.
23. The same conclusion is reached, albeit without any calculation of mercury to silver weight ratios or a chemical explanation to sustain it, in Ref. 2, 133.
24. "*La invención del hierro ... no se les sacaba mucha plata, [pero] no se perdía azogue*" in an anonymous document titled "Descripción de la Villa y Minas de Potosí. Año de 1603," as reproduced in M. Jiménez de la Espada, *Relaciones Geográficas de las Indias - Peru*, Vol. I, J.U. Martínez Carreras (Ed.), Biblioteca de Autores

Españoles, Tomo 183, Editorial Atlas, Madrid, 1965, 375. All translations by the author. For a discussion of the chemistry see Ref. 7.

25. "Thanks to the discovery this year 603 [*sic*] of amalgamation using lime, it has been posible to use less iron, since previously no less than 4 thousand *quintales* of iron were consumed every year." ("*Con la ocasión que este año 603 ha habido en el descubrimiento del beneficio de la cal, es ocasión de que no se gaste tanto hierro como solía, pues no había año que no se gastasen 4 mill quintales de hierro*." Anonymous, Ref. 24, 383.)
26. Ref. 2, 156, 178, 453.
27. M. B. Abbott and A. P. Wolfe, "Intensive pre-Incan Metallurgy Recorded by Lake Sediments from the Bolivian Andes," *Science*, **2003**, *301*, 1893-1895; see 1894. All years in the text are to be understood as being Common Era.
28. Ref. 10, 188.
29. Ref. 19 (Capoche), 118-122; other data from Ref. 11, 86-89.
30. Taking into account sixteenth century technology, water restrictions and a remote site such as Potosí, a plant operating factor of 55% may be a realistic level with potential to increase output subject to economic incentive and available ore and mercury.
31. Ref. 19 (Capoche), 164.
32. Anonymous, Ref. 24, 379, 383.
33. Ref. 11, 86-89.
34. Ref. 19 (Capoche), 123.
35. Anonymous, Ref. 24, 384.
36. Ref. 19 (Capoche), 78-79.
37. J. A. Cole, *The Potosí Mita:1573-1700: Compulsory Indian Labor in the Andes*, Stanford University Press, Stanford, 1985, 47. Even though a decrease in number could be compensated by an increased capacity of the remaining ones, the sharp drop reported is expected to have decreased the overall processing capacity for silver ores at the end of the seventeenth century.
38. Ref. 3 (Bakewell), 80-86.
39. H. O. Noejovich, "El consume de azogue: ¿Indicador de la corrupción del sistema colonial en el Virreinato del Perú? (Siglos XVI-XVII)," *Fronteras de la Historia*, **2002**, 7, 77-98.
40. Copper *magistral* would make the recipe more efficient, since copper sulfide is converted into silver chloride, and thus more silver is extracted from the ore, but it would not change the underlying weight ratio of mercury to silver that is determined by the stoichiometry of the reduction by mercury of silver chloride to elemental silver and calomel. It can be argued that ores difficult to treat, for example the *negrillos*, increase the possibility that more mercury will be lost mechanically. The range of historical *correspondencia* values corresponds to a range of physical losses of 0.05 to 0.1% per amalgamation cycle. See Ref. 7.

About the Author

Saúl Guerrero received his degree in Chemistry at the Universidad Simon Bolivar (Venezuela) in 1975 and a Ph.D. in Polymer Physics from Bristol University (UK) in 1980. After a career of teaching and research in the area of polymers and then as an international marketing manager for a major oil company, he obtained an M.A. in Global History at the University of Warwick (UK) in 2009 and is at present a Ph.D. candidate in the History Department of McGill University thanks to the award of a Peter Cundill Fellowship.

2012 HIST Election Results

Congratulations to the winners of 2012 HIST division elections.

- Chair-Elect (Term 2013-2014): Gary Patterson
- Secretary/Treasurer (Term 2013-2014): Vera Mainz
- Councilor (Term 2014-2016): Roger Egolf
- Alternate Councilor (Term 2014-2016): Joe Jeffers

As 2012 comes to an end, E. Thomas Strom ends his term as HIST Chair, replacing Janan Hayes in the Past Chair seat on the Executive Committee. Ned Heindel succeeds Strom as Chair, and Patterson succeeds Heindel as Chair-Elect.