MINING TRENDS IN THE NEW WORLD 1500-1810

"God or Gold?" That was the discussion question on an examination that I took many years ago when I started my studies in Latin American history. I do not recall how I answered the question. But the phrase has stuck in my mind ever since. And it has worked its way into much of the history written about the conquest and post-conquest periods, especially the Spanish conquests. From the initial conquests in the Caribbean and certainly after the conquests of Mexico and Peru the search for minerals became more intensive even as the Spanish Crown and its critics argued over religious goals. In the middle of the sixteenth century after major silver discoveries in Mexico and Peru the value of the output of the colonial mines jumped significantly from a few million *pesos* annually (mainly from gold) to several tens of millions. Perhaps "Gold" (mineral output) had not yet trumped "God" (religious conversion) on every level and in every region, but these discoveries altered the economic and financial equation: mining while not the largest sector in terms of value or labor would become the vehicle for acquiring and consolidating wealth. Until the late seventeenth century Spanish America was the New World's principal miner; but then the discovery of gold in Brazil accorded it the ranking gold producer in the New World while Spanish American remained the ranking silver producer. The rise of mining altered fundamentally the course of history in the New World for the natives, the settlers, and the rulers and had no less of an effect on the rest of the world.

Precious metals like gold and silver had little value in a commercial sense. Except for some artistic endeavors they were not fabricated into other products. Today of course they (especially silver) do have a wider applicability within the industrial sector. The history of gold and silver mining is generally associated with coins and currencies. At the time of the conquest gold was the coin of choice. Silver occupied a secondary role in European money systems. Few European coins made their way to the New World where exchange was more "in kind" than "in cash". That would change with the mineral discoveries as the Crown established mints in each viceroyalty Mexico and Peru) and procedures for making coins. Silver was the main mineral discovery, and far more silver was mined than could ever be used in the New World. In the first century of New World

mining as much as 165 tons of gold and 12,000 to 13,000 tons of silver entered the world's precious markets.[1] There is some debate about the size of the world money stock as measured by gold, silver and lesser metals in 1500. The world's money stock was surely in excess of 100,000 tons but probably did not exceed 150,000 tons. The addition of 12,000 to 15,000 tons more in the sixteenth century would have meant anywhere from 10 to 15 percent increase. There is considerable debate about the impact of that 10 to 15 percent – was it inflationary and if so how inflationary – but that debate does not directly bear on the objective of this essay. The increase in the money stock in the first century was no more than a down payment. For the more than 300 years between discovery and independence New World mining would contribute about 100,000 tons to the world's money stock. Over the next 300 years from conquest to independence New World mining may have doubled or tripled the world's money stock.[2] The implications of this were huge for the world economy. There was a negative impact – price inflation for example – but also a positive impact – expanding capital flows. In short the world economy had access to more money to underwrite more investment and to assume more risk. The heavy, constant outflow of bullion from New World mines would make the world richer, but it would also alter money systems almost everywhere, most particularly among the

[1] Much of the gold and silver data used in this analysis were provided to me by Professor John TePaske, Professor Emeritus, Duke University. The current data included additions and revisions to the original dataset assembled by TePaske and Herbert Klein in connection with the larger project to publish all the royal treasury accounts. TePaske new dataset can be accessed through www.historydatadesk.com. Other such data used in this essay belong to older datasets that TePaske and I created independently of each other.

[2] Scores of articles and books have been written on the size of the money stock and especially on the impact of New World mining on the world economies.

	New World Silver Metric Tons	**New World Silver Metric Tons**	**Europe Metal Stock Metric Tons**
Years	**TePaske**	**Barrett**	**Morineau**
1493-1600	10,748	17,000	9,138
1601-1700	27,547	34,000	28,199
1701-1800	40,741	51,000	55,362
1801-1810	8,725		
Totals			
1493-1810	87,760	102,000	92,699
Long Tons	86,374	100,389	91,235

Sources: John TePaske, from published materials plus unpublished materias provided to the author; Ward Barrett, "World Bullion Flows, 1450-1800" in James Tracy, ed., *The Rise of Merchant Empires. Long Distance Trade in Early Modern World, 1350-1750* (Cambridge and New York: Cambridge University Press, 1990,) 224-254; Michel Morineau, *Incroyables gazettes et fabuleux métaux: Les retours des trésors*

New World native societies that had to deal with new financial regimens that accompanied their submission to European rule. Without New World mining it is hard to imagine a Commercial Revolution and then an Industrial Revolution that stand as economic hallmarks in the emergence of modern economic systems. What was once a Eurocentric interpretation of the impact of New World mining has now been broadened into a global perspective. The scope of this essay is narrower than the global economic impact that is currently fashionable to analyze. At the outset of this essay, however, it is important to underscore that of the billions of ounces of gold and silver mined in the New World probably less than 90 percent remained there. In analyzing production trends and cycles we separate the impact that mining had on the New World as well as across the globe from the structure that evolved to produce so much new wealth. This essay is concerned with the performance of the New World mining industries over a long span of more than three centuries with the objective of pinpointing those circumstances and factors that accounted for its longevity as one of the more dynamic, perhaps the most dynamic, sector in the New World colonial economies.

The building of a mining industry in the New World was by any measure a remarkable story. It had to be built from scratch, so to speak, since the indigenous societies had only modest mining operations designed to provide precious minerals for artistic and religious purposes. The early gold mining in the Caribbean and along the littoral of the mainland as well as the later Brazilian strike in Minas Gerais entailed alluvial panning, that is, working the rivers and streams for gold deposits known as pans. Even though gold and silver could appear together in the same underground lode, most of the gold extracted in New World prior to the nineteenth century came from pans. By contrast silver mining began as surface operations but soon evolved into deep lode mining. Europe including the northern Spanish regions of Galicia and Asturias had some experience with underground mining, but few if any of the early Spanish settlers, most of whom came from the southern region of Andalusia, arrived with a background in mining that would equip them for what they encountered in Peru and Mexico. More significant was the fact that rock formations and ore locations were different from what European

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américains d'après les gazettes hollandaises (XVI^{e}-XVIII^{e} siècles) (Cambridge and New York: Cambridge University Press, 1985), 578-579.

miners had experiences. Thus, to exploit the mineral wealth discovered in Potosí and Zacatecas in the second half of the 1540s settlers who became miners had literally to "invent" ways to extract the ore that reached hundreds of feet below the surface and then to process the ore that varied in quality as depths increased. Capital markets to finance such undertakings did not exist, and yet funding mechanisms had to be found to build underground facilities and processing mills. The location of mines in remote and hostile environments posed numerous challenges in mobilizing a work force in such a labor-intensive industry and in creating an infrastructure to move provisions and supplies into the camps and the bullion from the camps to the mints. Finally while mining itself was a private endeavor, it was subject to numerous regulations and dependent upon royal monopolies in the conduct of its affairs. Over time mining became an established business that may have accounted for as much as 15 percent of the gross domestic product of the colonial economies.[3]

The geology of a region determined the formation of mineral deposits. In the long history of volcanic and other geologic disruptions various elements under conditions of extremely high temperatures and pressures fused to create deposits of silver (and occasionally some gold). The configurations of the deposits were different from region to region and from continent to continent. In the some cases the minerals appeared in veins of varying dimensions and grades, and in other cases they appeared in clumps or pockets of ore of equally varying dimensions and grades. The earliest discoveries occurred because the minerals had outcroppings that could be followed underground. Once underground, however, the path of discovery was never straightforward. More often than not luck played a role in finding new deposits that could be profitably exploited. Some miners through experience developed skills in reading the subterranean geology that improved their chances of discovering new deposits. The fact remained, however, that despite promising indicators most explorations ended in disappointment. Big strikes were rare, and vast stretches of the underground in the established mining regions were simply barren.[4]

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[3] This is intended to be a brief description of how lode mining evolved in the New World and not an analysis of the industry and its evolution.

[4] Geological considerations will be expanded upon in the section on "Mercury Supplies" below.

Extracting the ore involved little mechanization and substantial labor. Underground operations consisted of a honeycomb of tunnels on various levels. Ladders constructed of rope or wood connected the levels, and an army of workers often divided by skills or task filled the tunnels. Almost everything was done by hand. Armed with picks and shovels workers cut through the rock and clay to reach the ores, which after being extracted were loaded into sacks strapped on the backs of those who carried the ores up the ladders to the surface. Eventually explosives were introduced as well as primitive hoist and pulley systems. Explosives created their own problems. They could further contaminate the air that was already foul and often uninhabitable. The failure or inability to anticipate how post-explosion repercussions would unfold could collapse walls and ignite fires. Water, often scalding water, was a constant threat, and flooded areas could be so devastated that they were simply abandoned as unrecoverable. In some mines tunnels known as adits were constructed below the areas known to possess the ores for the purpose of draining the water. Although some large mines and perhaps more daring entrepreneurs concocted elaborate hoist and pulley systems with buckets to remove the water, mechanization was barely evident inside the mines even at the end of the colonial period. Labor rather than machines propelled mining operations. Mining remained basically a labor-intensive business.[5]

The processing of ore in contrast to extracting it was less dependent on labor and more on machines. Most ores were purified in furnaces or smelters that were fired by charcoal to temperatures of 700 degrees. At these temperatures ores melted, and the new component known as flux could be further refined to produce gold or silver. Although the term smelting and refining are used interchangeably, they were in fact distinct operations. Smelting heated the ores to create the fluxes, and refining treated the fluxes to produce gold or silver. In addition to smelting, gold since ancient times had been processed with mercury, but silver had not been. Even though smelters could be set up almost anywhere they required high grades of ores (usually more applicable than silver) and inexpensive sources of charcoal. Smelters were widely used in the first half-century of New World mining, but as the grade of silver ores began to drop and cost of firing the furnaces began to rise smelting became too expensive for most of the silver ore being extracted. There

[5] Again my intention is to offer no more than a brief description of mining activities.

clearly was an incentive to find a more economical way to process silver ore. It fell to Bartolomé Medina to take an old technique, combining ores with mercury, along with certain refinements made by German metallurgists and to adapt it to the reduction of New World ores containing silver. These ores, referred to as "low grade" because the silver minerals were less concentrated and harder to separate from the ores themselves, were voluminous but could not be profitably smelted. Amalgamation, as the process was called, where silver molecules attached themselves to mercury molecules became the standard protocol Even at the great late-nineteenth-century Comstock strike in Nevada (USA) gold and silver ores were refined through amalgamation, although many technical improvements in preparing and processing the ores had been and were being introduced. The basic procedure as introduced in the sixteenth century and maintained during the colonial era in Spanish colonial mining consisted of crushing the ores by hand or with a "battery" machine, pulverizing the ores between large stone stamps, placing the ores in a circular, short-walled patio and combining the ores with mercury, salt and one or two other elements to start amalgamation. It took six to nine weeks with frequent stirring for the process to achieve for the completion of the amalgamation. After the residue was washed away, the amalgam was heated to release the silver from the mercury. Once the minerals were separated from the mercury they were shipped to assayers to be tested for purity and shaped into ingots, registered, taxed and marked at the local treasury and finally hauled to the mint to be converted into coins or bars. From the mine to the mint could take months and as long as a year.

Scattered evidence suggests that the cost of extraction was twice that of reduction. In late eighteenth-century Zacatecas extraction costs were between 50 and 60 percent of the final mint value of the silver and reduction from 20 to 25 percent. Miners had other costs to meet as well such as transportation, taxes and mintage. Profits not only depended on how well costs were managed but on how much silver (or gold) could be drawn from a ton of ore. There was probably a limit to how far costs could be restrained if the depths of the mines or the grades of ores did not justify the investments. It is a given that the richer the ores the greater the potential profits. (Even mines with rich ores could become financial disasters.) In the sixteenth and seventeenth centuries mining enterprises were compartmentalized more so than in the eighteenth century. Extracting (or mining) the ore

was separate from refining it. On one level this was logical because mining the ore required a different set of skills from refining it. Over time the two functions were joined into single enterprises, although the independent refiners (*rescatadores* as they were known) never completely disappeared. But some of the most successful of the Spanish silver entrepreneurs made a deliberate effort to create a vertical structure of controlling the ore from the mine through the refinery to the mint. Almost nothing on the finances of small firms has turned up in the archives. Some insight into these operations can be gleaned from treasury accounts and other public documents. Most of what is known about mining and refining operations and finances comes from information concerning large firms. The declaration of silver by miners or refiners or their proxies for tax purposes allows for rankings, and the rankings invariably reveal an oligopolistic character in the major camps. Over the entire colonial period many may have tried to make a living from mining, but only a few made a fortune (and those fortunes were easily lost). Among those who benefited from mining were merchants (mainly international mercantile families) who had the capital to provide the financing for opening and repairing mines, buying mercury and other supplies, paying wages, fees and taxes, and underwriting the construction of refineries and other facilities necessary to support mining. In the ideal economic system merchants and miners would occupy separate positions. The Crown enacted some laws to attain and maintain this separation, that is, merchants were not permitted to own mines, but merchants being richer and savvier than most businessmen could not be restrained or excluded. Since they controlled the flowed of bullion from the colonies into the international markets, they had a strong incentive to be active directly in the mining sector. Many of the most prominent Spanish colonial miners in terms of silver registrations and mining profits began as *aviadores* (financial backers) and became owners of the mines. Not all merchants either as *aviadores* or owners enjoyed financial success. But some of the most successful – Antonio López de Quiroga of Peru in the late seventeenth century and Pedro Romero de Terreros (Count of Regla) of Mexico in the middle eighteenth century to name two – became "millionaires" at a time when that term embraced a handful of people in the Spanish Empire.[6] They and other mining

[6] The best biographies are Peter Bakewell, *Silver and Entrepreneurship in Seventeenth-Century Potosí, The Life and Times of Antonio López de Quiroga* (Albuquerque, NM: University of New Mexico Press, 1988)

entrepreneurs (both merchant and non-merchant backgrounds) understood the importance of scale – large operations that could concentrate capital resources to advance operational efficiencies were preferable to many small and even medium-sized operations. Even though hundreds of mine owners could show up in periodic censuses of economic activity by royal authorities, most of the silver registered at the *cajas reales* (branches of the treasury) belonged to a few entrepreneurs. Spanish colonial mining had a heavily oligopolistic character, probably not surprising in a hierarchical society, and at the center of this oligopoly was the colonial merchant. There is a certain but understandable fascination with mining prospectors who scour the landscape for an ever elusive wealth, and while many great strikes in the early modern period began with prospectors, the lode mining that evolved from the initial strikes was a totally different venture that required capital, large labor pools, managerial skill and risk-taking.[7]

One question remains before I turn to the task of analyzing mining trends. Can the data be trusted? All historical numeric datasets must face scrutiny concerning reliability and accuracy. Because Latin American colonial governments were assigned a substantial role in managing the lives of their citizens, scholars have access to large depositories of public records. The numerous taxes, monopolies and regulations under the management of the treasury in sectors like mining resulted in the collection of data that can be assembled and analyzed over several centuries. In the case of mining several taxes and fees were assessed against mineral products, the most important being the *quinto* and the *diezmo*. Indeed nearly all of the silver series that I have created are derived from the tax ledgers. My first encounter with these sources entailed copying from the various ledgers kept by the Zacatecas *caja real* the names of all the miners, refiners, and others who "manifested" or declared silver before *caja* officials from 1700 through 1820. These manifestations were usually first entered into a daily journal and then copied to the master ledger. They contained the name of the owner of the silver, the owner's proxy (usually an *aviador*) who actually made the declaration and paid the tax, the fineness and

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and Edith Couturier, *Silver King, The Remarkable Life of the Count of Regla in Colonial Mexico* (Albuquerque, NM: University of New Mexico Press, 2003).

[7] A new appreciation of the merchant as manager of risk especially in connection with international trade, is emerging in more deeply researched and nuanced treatments such as Matilde Souto Mantecón's *Mar Abierto, La política y el comercio del Consulado de Veracruz en el ocaso del sistema imperial* (Mexico City: El Colegio de México y Instituto Mora, 2001).

weight (in marks) of the silver, based on the royal assay and the taxes and fees to be paid. Once taxes and fees were paid, the bars were stamped. Variations appeared from time to time in how the entries were made, but the were surprisingly consistent over the century. Those who avoided making manifestations either at a local *caja* or (as permitted by law) at another *caja* could have their ores confiscated. In my own studies I have used marks of silver to study production trends in Zacatecas. The most extensive database compiled by John Tepaske, Herbert Klein *et al*. have used the tax rates (which can be determined) to convert the amount of the tax into the value of the silver.[8] The Peruvian miners paid the *quinto* until 1736 when the tax dropped by half. Mexican miners had paid the *diezmo* since the late sixteenth century. These are fairly steep taxes especially the *quinto*, and the temptation to evade the tax must have been great. What one observes in scrutinizing the silver ledgers is that year after year the major producers show up to pay their fees and taxes. Perhaps they held back some silver that might be trade and transferred through some illicit channel for dealing in precious metals. At the same time given the volume of manifestations they seemed to be intent on satisfying the law that they submit their silver for taxation. The list of declarers also included small and marginal producers, who, one might argue, had a financial incentive to avoid these costly tax burdens. One can devise a list of options (some of which can be documented) that miners, merchants, officials and workers could employ to cheat the government, and yet one must also try to associate

[8] The two silver output series for Zacatecas – mine based on marks registered and TePaske and Klein's based on taxes collected – during the eighteenth century do not agree when annual totals are compared. The two series correlate to a high degree, but that is to be expected since the series move generally in the same direction. My annual totals were the sums of all the individual entries in marks rather than *pesos*. When marks are converted to *pesos*, they do not yield the same annual totals that TePaske and Klein computed by multiplying the total taxes collected by a factor that incorporated the *diezmo* and other fees paid at the *caja*. That too is to be expected. The total taxes and fees collected by the *caja* was a figure that was not always accurate – clerks generally keep running totals day by day and month by month that contained addition errors. Mote to the point, however, to apply a rate to the taxes and fees collected in order to arrive at a figure of the total value of the taxed silver would miss any variations in the rates that the *caja* officials used to calculate the taxes and fees. For example in the 1870s and 1880s the most productive mine in Zacatecas, La Quebradilla, owned by the heir of José de la Borda, was first exempt from the *diezmo*, and then paid a rate lower than the *diezmo*. Thus, when the taxes and fees collected for those years were converted to total silver values, the full output of silver in *pesos* converted from taxes from La Quebradilla would be missed. Other such variations occurred determining and applying rates during the eighteenth century in Zacatecas and other camps. Let me note that for trend analysis one could use the taxes themselves without making any conversions. It is useful, though, to have some estimated total of the value of the silver. TePaske and Klein detail how the rates were calculated in the introductions to their publications of the royal ledgers. In another essay on mining in Zacatecas I will take up these issues again. Let me note that in TePaske's latest

some numbers (which are hard to document) with these options. To be sure from time to time a substantial quantity of a camp's unprocessed ore or silver bullion might escape taxation; but could that continue day after day and year after year without the ultimate intervention of the colonial government? Large quantities of ores or ingots were not easy to hide or move. What could be easily hidden and moved was relatively small against the total that was produced and manifested. Some public officials and court critics might testify to evasions, but how big were they relative to the total manifestations and more importantly how often did they happen – once, twice or a hundred times. The last figure would be serious indeed. In the end, even though some writers have proposed 20, 30 or 40 percent of the silver output bypassed the treasury, they do not have much evidence to support such numbers. Perhaps 10 percent (and I regard that as a high number if applied year after year) of the output never showed up in the royal ledgers. Even if there is no agreement about the percentages, there may be a consensus that the figures drawn from silver-tax ledgers represent most of the colonial output. The trends calculated from the existing series would not be significantly altered if somehow the ore unaccounted for reappeared.

Long-Term Trends in Gold and Silver Output

In monetary terms, that is, the nominal value of ore in coin, between Columbus's discovery and Latin American independence, the New World produced more than 4.5 billion *pesos* in gold and silver. It became the world's chief supplier of precious metals. The dominance of silver was clear: it comprised 76 percent of the total compared to gold's 24 percent. On an annual basis the average value of colonial silver production was approximately 11 million *pesos* and of gold 3.5 million *pesos*. By regional rankings Mexico produced 45 percent of the total gold and silver, Peru 33 percent, Brazil 15 percent, New Granada with 5 percent, Chile with 1 percent and the Caribbean, Ecuador and Rio de la Plata with less than 1 percent each. Mexico and Peru were far and away the dominant producers. Mexico's average annual output was over 7 million *pesos* while Peru's was over 5 million *pesos*. Potosí, located in modern-day Bolivia known in the

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revisions he has calculated *peso* values from marks rather than taxes. The bulk of the mining database is derived from taxes.

colonial period as Upper Peru, was the most productive district in the New World with total mineral output of 875 million *pesos* or one fifth of the total. The annual average was over 3 million *pesos*. The next most productive districts, Zacatecas and Guanajuato in Mexico, had totals that were less than half of Potosi's. Those three districts, however, accounted for nearly 40 percent of all the New World minerals.[9]

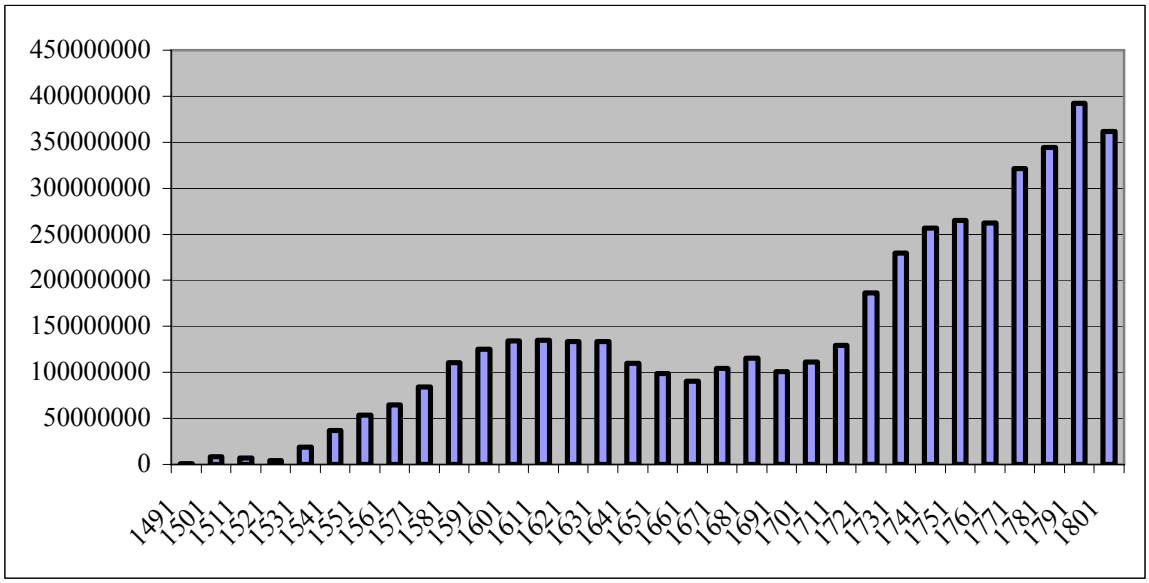
FIGURE 1
Monetary Value of Gold and Silver
(Peso = 272 Maravedís)

Decade	Gold Pesos	Silver Pesos	Total Pesos
1492-1500	700,000	0	700,000
1501-1510	8,200,000	0	8,200,000
1511-1520	7,210,000	0	7,210,000
1521-1530	3,920,000	340,000	4,260,000
1531-1540	11,120,000	7,550,000	18,670,000
1541-1550	8,730,000	28,120,000	36,850,000
1551-1560	10,640,000	42,710,000	53,350,000
1561-1570	8,850,000	56,050,000	64,900,000
1571-1580	13,000,000	71,470,000	84,470,000
1581-1590	10,180,000	100,190,000	110,370,000
1591-1600	11,910,000	113,400,000	125,310,000
1601-1610	12,750,000	121,810,000	134,560,000
1611-1620	10,430,000	124,280,000	134,710,000
1621-1630	9,910,000	123,630,000	133,540,000
1631-1640	5,240,000	128,600,000	133,840,000
1641-1650	6,720,000	102,830,000	109,550,000
1651-1660	6,730,000	92,160,000	98,890,000
1661-1670	4,740,000	85,730,000	90,470,000
1671-1680	4,540,000	100,020,000	104,560,000
1681-1690	5,850,000	109,850,000	115,700,000
1691-1700	8,240,000	92,800,000	101,040,000
1701-1710	33,240,000	78,250,000	111,490,000
1711-1720	37,050,000	92,610,000	129,660,000
1721-1730	74,250,000	112,450,000	186,700,000

[9] Total Gold and Silver Production from TePaske files at www.historydatadesk.www. Original publications of treasury ledgers: John J. TePaske en colaboración con José y Mari Luz Hernández Palomo. *La Real Hacienda de Nueva España, la Real Caja de México, 1576-1816.* México, D.F.: Instituto Nacional de Antropología e Historia, SEP, Departamento de Investigaciones Históricas, Seminario de Historia Económica, 1976, John J. TePaske, Herbert S. Klein, *et al*. *Ingresos y egresos de la Real Hacienda de Nueva España*. México, D.F.: Instituto Nacional de Antropología e Historia, 1986 and John TePaske and Herbert Klein with Kendall Brown, *The Royal Treasury of the Spanish Empire in América*, 3 vols., (Durham, NC: Duke University Press, 1982). One may also consult John TePaske and Herbert Klein, "The Seventeenth-Century Crisis in New Spain: Myth or Reality?" Past & Present, 90 (1981), 116-135 and Richard Garner, "Long-Term Silver Mining Trends in Spanish America: A Comparative Analysis of Peru and Mexico," *American Historical Review*, 93:4 (1988), 889-914.

1731-1740	99,120,000	130,650,000	229,770,000
1741-1750	108,730,000	147,940,000	256,670,000
1751-1760	90,410,000	174,580,000	264,990,000
1761-1770	95,410,000	166,720,000	262,130,000
1771-1780	104,650,000	216,550,000	321,200,000
1781-1790	102,270,000	241,880,000	344,150,000
1791-1800	102,590,000	289,940,000	392,530,000
1800-1810	82,060,000	279,460,000	361,520,000
Total	1,099,390,000	3,432,570,000	4,531,960,000

FIGURE 2
Decennial Total of Gold and Silver, Spanish and Portuguese America
(Peso = 272 Maravedís)



When gold and silver production is charted, several important secular trends become immediately apparent. In his own work TePaske has often computed quinquennial and decennial totals in order to overcome gaps in the original sources. These totals have been assembled from the annual accounts of the branch treasuries, and these sources can be damaged, lost, lacking in sufficient specificity or just plan wrong, and one way to overcome these gaps is to compute quinquennial or decennial totals or more specifically averages. Wherever feasible TePaske has estimated annual data in order to fill out a series. Thus, the annual figures within a decade may consist of actual data, estimated data or no data. Quinquennial and decennial totals become a more convenient way to track and discuss trends and changes when the annual data have to be supplemented, although the risk of overstating or understating the totals is high when the

actual decennial figures are few, say for two or three years. Unfortunately how much of a decennial total is based on actual figures and how much is based on estimated figures is not given directly.. Still the decennial totals are useful for general observations about production over time. From TePaske's decennial totals, as illustrated in Figure 2, the pattern comports with recent research on New World mining. Not surprisingly, of course, the total nominal value of gold and silver was distinctly higher at the end of the colonial period than at the beginning. In the first (shortened) decade less than a million *pesos* worth of gold (no silver) from a single region, Caribbean, can be estimated from the available sources, and by the final decade (after 32 decades) the total value of gold and silver, assembled from all the possible sources, exceeded 360 million *pesos*, a final figure that is more than 500 times greater than the initial figure. The final decade was not the highest in output of gold and silver. It was eclipsed by the previous decade when output reached nearly 400 million *pesos*. There is virtually no dispute among scholars that New World mining not only underwent extraordinary growth after discovery but also achieved its pre-eminence in the third century after discovery.

These figures would be impressive even if they represented the whole story. There are many more figures (actual and estimated), and the story as a consequence is far more complicated. Mineral output remained modest during the first 50 years after Columbus's first voyage with a total value of approximately 40 million *pesos*. This added potentially about 225 tons of precious metals to the money stock. Most of the mineral output was gold, but beginning in the 1520s silver made an appearance. The decade of the 1530s was strong as the two metals recorded a nearly fivefold increase. Gold was three times higher than the previous decade, but silver, still only a quarter as large as gold in total value, grew by 22 times. Then in the 1540s a significant change occurred in that gold output actually dropped by about one-third, but silver output, after discoveries at Zacatecas and Potosí increased by nearly fourfold. That would set the course for New World mining until the end of the colonial period. Silver mining overshadowed gold mining, although gold made a strong comeback in the late seventeenth century with large discoveries in Brazil and in the eighteenth century with increased activity in New Granada (northern South America). Gold would never again exceed the value of output from the silver mines. Thus began the silver era in New World mining. By the early

seventeenth century silver output had nearly quadrupled while gold production was only slightly above its high of the 1530s. Almost 90 percent of the production of the two precious metals was the white metal.

A second significant development for the New World mining industry came to the fore in the middle decades of the seventeenth century. Total output leveled off in the first and second quarters and then turned downward in the third quarter, and it remained below its former highs through the first quarter of the eighteenth century. Although the two metals did not move in lock step, they both suffered declines in the range of a third to a half. Gold output declined somewhat more than silver; it reached its nadir in the 1670s at about 4.5 million *pesos*. Silver was more robust. It dropped to its lowest level in 100 years during the 1660s (85.7 million *pesos*), climbed back in the 1670s and 1680s and faltered again between 1690 and 1720. In terms of total output New World mining pierced the 100,000,000-*peso* level in the 1580s and except for two decades (1650s and 1660s) it remained above that level in spite of the aforementioned lurches forward and backward. The middle decades of the seventeenth century have been described in various scholarly works, both from and European and a New World perspective, as a time of economic contraction or depression, in part because of the reduction in the mineral output of the New World. The economic history of the seventeenth century is complicated and controversial, and tracking mineral production through the century will not resolve the more contentious issues. An analysis of how it tracked can be useful in clarifying what issues may be more important to consider.[10]

Prior to the eighteenth century the peak in precious metal output was spread over four decades (1600-1640) when the average decennial figure was about 134 million *pesos*. For the next eight decades output hovered around 100 million *pesos*. From the first decade to the 23rd decade, when the seventeenth-century contraction in mining finally ended, a period of almost 230 years, the New World had pumped 2 billion *pesos* worth of gold and silver into the world economy, equal to about 50,000 tons. More than half was registered in the seventeenth century so that however one may wish to interpret the

[10] A large body of books and articles consider the economic history of the Atlantic World in the seventeenth century. For a recent inquiry see Stanley and Barbara Stein, *Silver, Trade, and War, Spain and American in the Making of Modern Europe* (Baltimore, MD: The Johns Hopkins University Press, 2000), Part 1. There is also an Asian connection that I will explore in another essay.

economic history of the seventeenth century the output of gold and silver was greater in that century than any prior century in human history. And the final century of colonial rule output of New World gold and silver achieved new records. In the first decade of the eighteenth century two observations can be made: first gold production had jumped from several million *pesos* per decade to 33 million *pesos*; and second silver production had fallen off to its lowest level (78 million *pesos*) since 1561-1570. For the first time in 150 years gold constituted more than 20 percent of the total output. Despite its impressive showing gold was still limited to Brazil and a few very small operations in Spanish America. If the mining industry was to launch a new growth cycle it would have to come from silver, not gold. Silver output began to grow in the 1720s and continued to do so until the 1800s.Gold held sway through the first half of the eighteenth century when it topped 100 million *pesos* while silver, rising more slowly, broke through 150 million *pesos* for the first time in the same decade. The combined value of gold and silver reached it highest ever level of 257 million *pesos*, a 367-fold increase since 1500. In the second half of the eighteenth century, as gold plateaued, silver shot up to more than 200 million *pesos* and then came close to 300 million *pesos*. Gold actually maintained a rather respectable ratio with silver, accounting for about a third of total output until the end of the colonial era. The expansionary state of gold and silver mining in the New World may be best understood by underscoring the fact that more than half of the total tonnage of gold and silver produced in the New World between 1500 and 1810 was extracted in the last century of colonial rule.

FIGURE 3
Decennial Percentage Changes in Gold and Silver Output
1541-1500—1801-1810

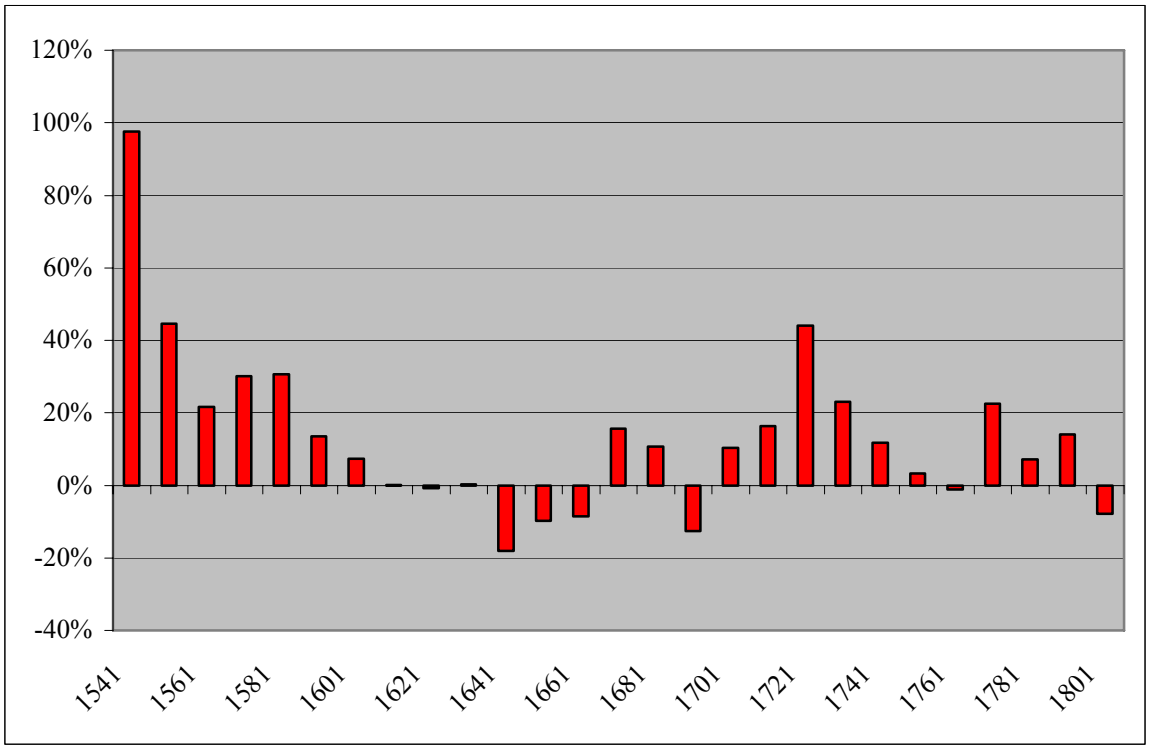


FIGURE 4
Decennial Percentage Changes in Gold and Silver

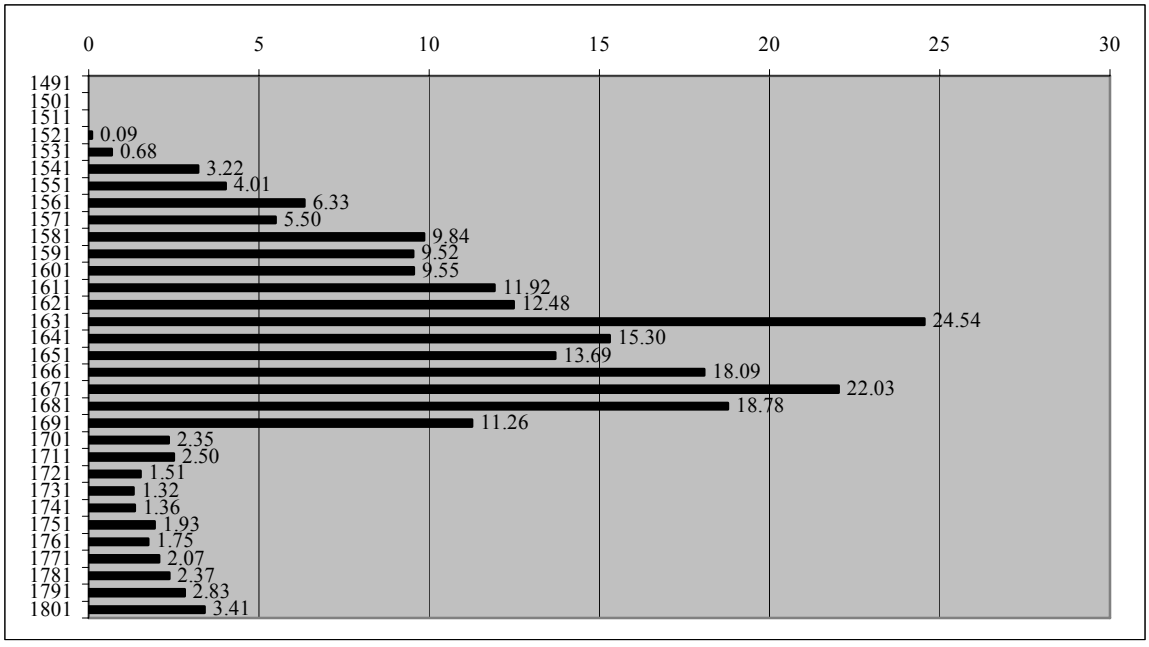
Decade	% Chg
1492-1500	
1501-1510	1071.43%
1511-1520	-12.07%
1521-1530	-40.92%
1531-1540	338.26%
1541-1550	97.54%
1551-1560	44.58%
1561-1570	21.72%
1571-1580	30.15%
1581-1590	30.66%
1591-1600	13.54%
1601-1610	7.38%
1611-1620	0.11%
1621-1630	-0.87%
1631-1640	0.22%
1641-1650	-18.15%
1651-1660	-9.73%

1661-1670	-8.51%
1671-1680	15.57%
1681-1690	10.65%
1691-1700	-12.67%
1701-1710	10.34%
1711-1720	16.30%
1721-1730	43.99%
1731-1740	23.07%
1741-1750	11.71%
1751-1760	3.24%
1761-1770	-1.08%
1771-1780	22.53%
1781-1790	7.15%
1791-1800	14.06%
1800-1810	-7.90%

Decennial percentage changes in gold and silver output reveal another dimension in the secular trend. On Figure 4 I have shown percentage change in output for gold and silver by decade. In the earliest decades the changes were the most extreme – a rise of over 1,000 percent between the first and second decades and a rise of 338 percent between the fourth and fifth decades – because in the beginning the absolute numbers were so small that percentage changes could yield very large numbers. To go from 700,000 *pesos* in the first decade to more than 8 million *pesos* in the second was very large indeed. The data in Figure 4 actually follow the decennial changes from 1541-1550, the decade of the first major silver discoveries, to 1801-1810.[11] The increase of nearly 100 percent in the 1540s shows the impact on mining totals of the near simultaneous silver discoveries in Potosí and Zacatecas. It will represent the largest percentage change between 1540 and 1810. From the decade of the 1540s onward the decennial changes will fluctuate between 45 percent (1551-1560 and 1721-1730) on the up side and 18 percent (1641-1650) on the down side. The majority of the changes fell in a range between +20 and –20 percent. Between 1540 and 1810 there were 27 decades. In 20 (75 percent) of the 27 the output of gold and silver rose if even by just a fraction of a percent. The longest run on the up side was seven decades between 1540 and 1620. The longest down streak was three from 1640 to 1670. On the up side significant gains of 98, 45, 22, 30 and 31 percent were recorded in the first 50 years when the total output ranged from 100 to 150

million *pesos* and other new discoveries followed those at Zacatecas and Potosí. Some significant gains of 45 and 23 (twice) percent were also recorded in the eighteenth century when total production was already established at a higher level and was climbing. (A 22 percent rise in the 1560s added 11 million *pesos* to the pool of precious metals while a similar increase in the 1770s added 60 million *pesos*. Although the pace of decennial increases slowed during the first eight decades – 98 percent in 1540s to less than 1 percent in 1611-1620 – the first negative change of less than 1 percent was recorded in the third decade of the seventh century. The sharpest drop of 18 percent came in the 1640s and after that only five decades had decreases of 1 to 13 percent. It was clearly not smooth sailing for the New World mining sector after the first discoveries, but it was steady sailing across three centuries. More to the point the recovery of mining in the eighteenth century (rehabilitations plus new discoveries) underscored the resilience of an industry after two hundred years and with relatively primitive technologies.

FIGURE 5
Ratio Between Silver and Gold Output



[11] To ignore the data from the decades prior to 1540 results in a more manageable figure for the rest of the colonial era. It is easier to illustrate the small changes that took place in some decades with a narrower scale than is necessary when the earliest years were included.

It is well known that New World mining was mainly a silver story. Gold was important (still the preferred currency the West, less so in the East), but relative to silver it was a minor player in the New World. In the first few decades gold mining clearly dominated. For each unit of gold only a fraction of a unit of silver was produced. Once major silver deposits were located, the ratios changed markedly. Beginning in 1541-1550 for each unit of gold produced more than three units of silver were produced, and a century later (1631-1640) for each unit of gold there were 25 units of silver. The ratio fluctuated between 11 and 25 over the next six decades until 17101-1710 when it fell to the lowest level since 1531-1540: 1 unit of gold to 2(+) units of silver. It remained in a range of 1 to 3. The explanation for the shift in the eighteenth century was specifically related to the emergence of large-scale gold mining in Brazil and more generally to the expansion of gold mining in Spanish America, particularly in New Granada. Part of the growth in Spanish American gold mining was relation to the exploitation of silver-bearing ores with higher gold content. Several other precious minerals such as diamonds (in Brazil) and base metals like copper and zinc could be added to the pot to give an even broader accounting of metal mining in the New World, but that will have to be the topic for another scholar.

Trends in Colonies and Regions

Having considered New World mining trends in the broadest measure possible, I will turn now to a more discreet analysis of mining trends within colonies and regions. In Spanish America as the mining industry took root the crown established mining districts that often had their own *cajas reales* or branches of the royal treasury. Briefly, as noted earlier, the *cajas reales* managed the crown's rather complicated relations with the mining sector from the collection of taxes and fees to the operation of various state monopolies (monopolies, salt, powder) that served the mining industry. As explained earlier production series can be created from the *caja* tax accounts, and both TePaske and Klein have created such series. Certain problems have to be overcome. Those concerned with the reliability – are the accounts accurate and complete? – may never be resolved to everyone's satisfaction. One problem that is persistent is whether taxes collected in a calendar year cover only metals manifested in that year or include balances carried over

from the previous year. In other words if a *caja* bookkeeper added whatever tax receipts remained (not remitted to the central treasury) in Year 1 to the tax receipts collected in Year 2 the total for Year 2 would be inflated, and if that continued year after year the subsequent totals would be significantly distorted. This problem can be addressed if the tax receipts are copied from the tax ledger for each year rather than the general ledger where all the figures for all the *ramos* or functions were consolidated. Associated with this problem is the question of the origin of the manifested or taxed ore. It was possible for owners of metals to pay their taxes in cajas outside of the areas where the ores were mined. This may have been mainly a problem associated with the central treasuries located in the viceregal capitals. Because large merchant houses were usually headquartered in the viceregal capital and had numerous dealings with the viceregal officials, they may have preferred to pay mining taxes on metals they owned or their clients owned at the Caja Matrix (central office) rather than at the *caja* where the ore originated. This would raise the total value of ore identified with the central treasury and reduce the branch's total value. Colonial totals would be less directly affected than *caja* totals. In the case of the Caja Matrix in Mexico City the value of the silver computed from the tax receipts recorded in the central treasury's ledgers seemed at times to be far higher than what the mines in the Mexico City region could have produced. A second matter involving the Caja Matrix may be more serious. The *cajas reales* remitted funds on an irregular basis to the viceregal Caja Matrix. How strict were the bookkeeping controls for consolidating silver-tax remissions from all the *cajas* with the silver-tax collections at the Caja Matrix. Did the tax-receipt figures that showed up in the accounts of the Caja Matrix contain only taxes collected on manifestations of silver at the central treasury or did they also contain remitted tax receipts from the *cajas* to the Caja Matrix? This would represent a form of double-counting since the receipts had already appeared in the *caja* accounts and then again in the Caja Matrix account. The task of converting silver-tax receipts to silver-bullion values is not so simple as it would seem. The ways in which the accounts were kept or summed or transferred have a bearing on the reliability of the figures that will enter the dataset. Certainly TePaske and Klein are aware of these pitfalls, and in the silver series that they have created they have tried to seek out and correct for incomplete totals, double-counting and other problems. In my own experience

working through *caja* accounts page by page and year by year is preferable to relying on account totals, but by the same token because the former is extraordinarily time consuming the reliance on totals given certain constraints may be reasonable and useful.

A gold and silver database by region has been assembled recently as a part of John TePaske's continuing work on the royal accounts. He has divided the New World into nine regions: Caribbean, Mexico, Central America, New Granada, Ecuador, Peru, Chile, Río de la Plata and Brazil. Six of the nine – Mexico, Central America, New Granada, Ecuador, Peru and Chile – had almost continuous mining operations discovery to independence while the remaining three had limited operations. Mining in the Caribbean ended for the most part by the middle of the sixteenth century, and in Brazil it did not begin at any significant level until the late seventeenth century. Figures from Río de la Plata mining appear at the same time as the establishment of the new viceroyalty of Río de la Plata. Under the new arrangement Potosí, long the dominant camp in South America, came under the jurisdiction of the Buenos Aires, the new viceregal capital, and as such Potosí silver tax revenues should have appeared in the royal treasury of Buenos Aires. That does not appear to have happened because the figures reported for Río de la Plata were far below what is known to be the output of Potosí after 1771. Four of the regions – Caribbean (gold), Central America (silver), Ecuador (gold) and Brazil (gold) – only reported production of one metal, gold or silver. The remaining regions reported production of both metal, although one metal predominated.[12]

FIGURE 6
Gold and Silver Decennial Totals by Region
(Millions of Pesos of 272 Maravedís)

Decade	Caribbean	Mexico	Central America	Peru	New Granada	Ecuador	Chile	Rio de la Plata	Brazil	TOTAL
1492-1500	0.70									0.70
1501-1510	8.20									8.20
1511-1520	7.21									7.21
1521-1530	2.40	1.82	0.04							4.26
1531-1540	1.55	4.67	0.06	10.61	1.61	0.17				18.67
1541-1550	0.90	11.38	0.09	20.44	1.48	0.56	2.00			36.85
1551-1560	0.03	18.71	0.09	25.91	3.97	1.64	3.00			53.35
1561-1570		34.42	0.09	21.89	5.39	2.08	1.03			64.90
1571-1580		39.27	0.30	32.15	5.65	3.96	3.14			84.47

[12] TePaske's regional data at www.historydatadesk.com.

1581-1590		34.16	0.85	65.44	4.77	4.15	1.00			110.37
1591-1600		42.67	0.68	70.31	8.90	2.25	0.50			125.31
1601-1610		50.39	0.64	72.21	9.88	1.34	0.10			134.56
1611-1620		52.98	0.55	72.62	7.91	0.60	0.05			134.71
1621-1630		50.75	0.30	74.53	6.67	1.28	0.01			133.54
1631-1640		46.39	0.21	84.17	2.65	0.41	0.01			133.84
1641-1650		34.55	0.30	69.33	5.29	0.08				109.55
1651-1660		37.27	0.34	55.76	5.39	0.13				98.89
1661-1670		36.21	0.26	50.77	3.08	0.15				90.47
1671-1680		53.39	0.17	47.95	2.92	0.13				104.56
1681-1690		59.88	0.17	51.31	4.21	0.13				115.70
1691-1700		51.52	0.26	42.92	3.29	0.22	0.04		2.79	101.04
1701-1710		51.21	0.34	28.48	3.36	0.19	0.01		27.90	111.49
1711-1720		66.30	0.51	27.66	4.83	0.22	0.12		30.02	129.66
1721-1730		83.04	0.68	30.54	5.58	0.09	0.16		66.61	186.70
1731-1740		95.63	1.76	36.53	6.59	0.06	0.27		88.93	229.77
1741-1750		107.07	1.73	44.04	9.57	0.03	0.46		93.77	256.67
1751-1760		123.85	2.08	53.55	11.49	1.30	0.71		72.01	264.99
1761-1770		113.67	1.73	58.40	13.25	1.08	4.41		69.59	262.13
1771-1780		154.06	1.51	72.33	14.90	1.17	6.44		70.79	321.20
1781-1790		176.16	1.71	76.35	18.53	2.66	7.57	0.22	60.95	344.15
1791-1800		209.28	1.95	97.57	22.48	3.27	9.97	0.44	47.57	392.53
1800-1810		217.33	1.42	76.79	23.38	0.62	8.50	8.01	25.47	361.52
Total	20.99	2058.03	20.82	1470.56	217.02	29.97	49.50	8.67	656.40	4531.96
Mean	3.00	70.97	0.72	52.52	7.75	1.07	2.25	2.89	54.70	141.62
Median	1.55	51.21	0.34	52.43	5.49	0.58	0.61	0.44	63.78	113.60

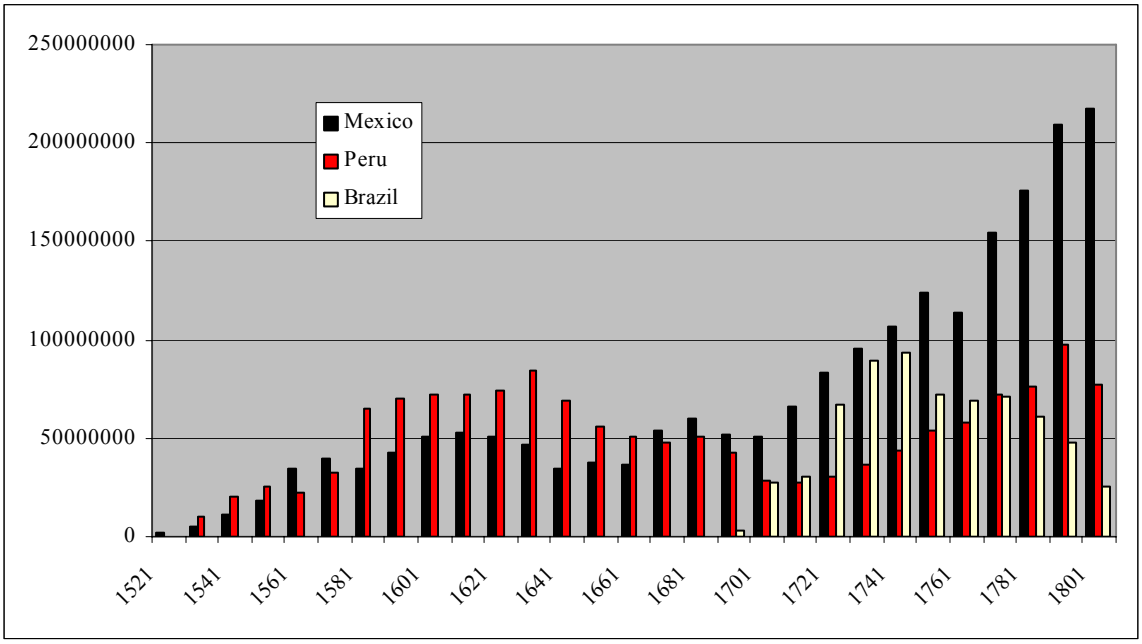
FIGURE 7
Percent of Decennial Total by Region

Decade	Caribbean	Mexico	Central America	Peru	New Granada	Ecuador	Chile	Rio de la Plata	Brazil	TOTAL
1492-1500	100.00%									100.00%
1501-1510	100.00%									100.00%
1511-1520	100.00%									100.00%
1521-1530	56.34%	42.72%	0.94%							100.00%
1531-1540	8.30%	25.01%	0.32%	56.83%	8.62%	0.91%				100.00%
1541-1550	2.44%	30.88%	0.24%	55.47%	4.02%	1.52%	5.43%			100.00%
1551-1560	0.06%	35.07%	0.17%	48.57%	7.44%	3.07%	5.62%			100.00%
1561-1570		53.04%	0.14%	33.73%	8.31%	3.20%	1.59%			100.00%
1571-1580		46.49%	0.36%	38.06%	6.69%	4.69%	3.72%			100.00%
1581-1590		30.95%	0.77%	59.29%	4.32%	3.76%	0.91%			100.00%
1591-1600		34.05%	0.54%	56.11%	7.10%	1.80%	0.40%			100.00%
1601-1610		37.45%	0.48%	53.66%	7.34%	1.00%	0.07%			100.00%
1611-1620		39.33%	0.41%	53.91%	5.87%	0.45%	0.04%			100.00%
1621-1630		38.00%	0.22%	55.81%	4.99%	0.96%	0.01%			100.00%
1631-1640		34.66%	0.16%	62.89%	1.98%	0.31%	0.01%			100.00%
1641-1650		31.54%	0.27%	63.29%	4.83%	0.07%				100.00%
1651-1660		37.69%	0.34%	56.39%	5.45%	0.13%				100.00%
1661-1670		40.02%	0.29%	56.12%	3.40%	0.17%				100.00%

1671-1680		51.06%	0.16%	45.86%	2.79%	0.12%				100.00%
1681-1690		51.75%	0.15%	44.35%	3.64%	0.11%				100.00%
1691-1700		50.99%	0.26%	42.48%	3.26%	0.22%	0.04%		2.76%	100.00%
1701-1710		45.93%	0.30%	25.54%	3.01%	0.17%	0.01%		25.02%	100.00%
1711-1720		51.13%	0.39%	21.33%	3.73%	0.17%	0.09%		23.15%	100.00%
1721-1730		44.48%	0.36%	16.36%	2.99%	0.05%	0.09%		35.68%	100.00%
1731-1740		41.62%	0.77%	15.90%	2.87%	0.03%	0.12%		38.70%	100.00%
1741-1750		41.72%	0.67%	17.16%	3.73%	0.01%	0.18%		36.53%	100.00%
1751-1760		46.74%	0.78%	20.21%	4.34%	0.49%	0.27%		27.17%	100.00%
1761-1770		43.36%	0.66%	22.28%	5.05%	0.41%	1.68%		26.55%	100.00%
1771-1780		47.96%	0.47%	22.52%	4.64%	0.36%	2.00%		22.04%	100.00%
1781-1790		51.19%	0.50%	22.19%	5.38%	0.77%	2.20%	0.06%	17.71%	100.00%
1791-1800		53.32%	0.50%	24.86%	5.73%	0.83%	2.54%	0.11%	12.12%	100.00%
1800-1810		60.12%	0.39%	21.24%	6.47%	0.17%	2.35%	2.22%	7.05%	100.00%
Total %	0.46%	45.41%	0.46%	32.45%	4.79%	0.66%	1.09%	0.19%	14.48%	100.00%

Mexico and Peru, not surprisingly, dominate the regional statistics. Of the more than 4.5 billion *pesos* in total gold and silver 2.1 billion *pesos* or 45 percent was registered in Mexico and 1.5 billion *pesos* or 33 percent was registered in Peru. Third on the list was Brazil, which reported 656 million *pesos* entirely in gold for 15 percent of New World totals. The remaining six regions contributed slightly less than 350 million *pesos* or 7 to 8 percent of the total. Of this last group New Granada was far ahead of its peers with 5 percent of the total. Caribbean, Central America, Ecuador and Río de la Plata had less than 1 percent while Chile had slightly more than 1 percent.

FIGURE 8
Decennial Totals Peru, Mexico, Brazil
(Peso=272 Maravedís)



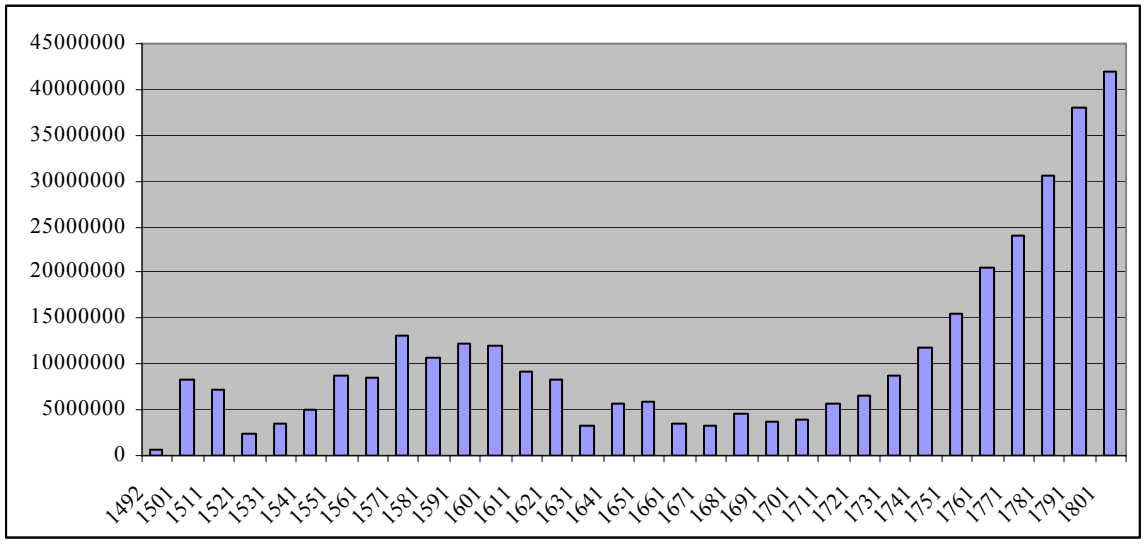
The decennial statistics on flows of gold and silver during nearly three centuries reveal a changing relationship among the principal mining regions – Peru, Mexico and Brazil. Let me note for purposes of clarity that in governmental terms the Viceroyalty of Mexico included the regions described above as Caribbean and Central America and the Viceroyalty of Peru included all of South America but Brazil. The mining statistics, compiled by TePaske, however, stripped out the peripheral regions so that Peruvian mining statistics were from the central Andes, mainly the modern-day nations of Peru and Bolivia, and Mexican mining statistics were from central and northern modern-day Mexico. Had gold and silver flows of the excluded regions been added to the totals of the viceroyalties to which they belonged they would have boosted Peru's output more than Mexico's. It would not have altered the basic patterns that can be observed in the foregoing charts. In the first two centuries (180 years) metal production was centered in Potosí and Zacatecas and in the vicinity of those two camps. Peruvian output climbed steadily from the decade of 1541-1550 through the decade of 1631-1640 (except for a brief downtown of 16 percent during 1561-1570). At its peak in 1631-1640 it accounted

for almost 85 million *pesos* or 65 percent of the total gold and silver. The contraction began in 1641-1650 and continued through 1711-1720 (with the exception of a 7 percent rise in 1681-1690). A turn-around in Peruvian mining began in 1721-1730 and continued through 1791-1800 in part due to a recovery at Potosí and in part to new ventures undertaken in Pasco and other northern Peruvian mining camps. The contraction in Peru was severe and long. Output fell to levels not seen since the middle of the previous century. At the depth of its depression n 1711-1720, two-thirds less gold and silver was being produced than at its peak in 1631-1640. In the eighteenth-century recovery Peru retraced the path that it had followed in the first expansion, and in the decade of 1791-1800 it actually reached a new high of 98 million *pesos*. Although output fell in the first decade of the nineteenth century, it was still comparable to the production levels of the first quarter of the seventeenth century. Indicative of the changes that had occurred in New World mining since Peru's triumph in the first century of mining, when its share of the total reached 50 to 65 percent, was a recovery in which Peru's share was slightly more than 20 percent. Still important Peru was no longer the center of New World mining.

Even though Mexico's colonial mining history followed a similar path to Peru's history, it also stands in contrast to Peru's. Its gold and silver output also rose in the first 100 years but less spectacularly than Peru's. Mexico's downturn began earlier in the decade of 1621-1630 but overall was less severe and less durable. By 1641-1650 Mexican mining having dropped by a third had reached the bottom of the trough, and in the next decade production turned up slightly. Although the upswing during the next five decades was bumpy, gold and silver production as measured in *pesos* had returned to the level of the previous high in 1611-1620. This laid the foundation for what would become a century in which each decade scored a higher number than the decade before except in 1761-1770 when production declined by 8 percent. At the end of the eighteenth century Mexico produced almost five times more than it had at the beginning of the eighteenth or seventeenth century. Whereas Mexico had lagged behind Peru in the first half of the colonial period, it turned the tables on the second half. The decade in which Mexico surpassed Peru was 1671-1680 as Mexico produced slightly ore than 50 million *pesos* in gold and silver and Peru slightly less than that.

The new player in the mix during the second half of the colonial period was Brazil. The Portuguese colony reported no metal production before 1701-1710. Its mining history began as Peru was sliding deeper into depression and Mexico was laying the groundwork for its late colonial boom. In the second decade Brazilian production, exclusively gold, moved ahead of Peru's gold and silver output, and Brazil remained ahead of Peru until 1781-1790, after which its mineral production fell off sharply. For three decades, 1721-1750, Brazil's mineral output came within striking distance of Mexico's mineral output, and the two colonies combined to account for more than 75 percent of the New World's total output. As so often happened with new discoveries output shot up more than 900 percent from the first to the second decade, although the actual figures - 3 million to 28 million *pesos* – were modest. In the third decade it rose another 8 percent, and then it shot up again by 122 percent in the fourth decade. That was followed by a moderate increase of 33 percent in 1731-1740 and only a slight increase of 5 percent in 1741-1750. The string of contractions began in 1751-1760 and was only broken once with a slight upturn in 1871-1780. By 1800 the level of output was not greater than it had been a century before.

FIGURE 9
Decennial Totals 6 Minor Regions
(Peso = 272 Maravedís)

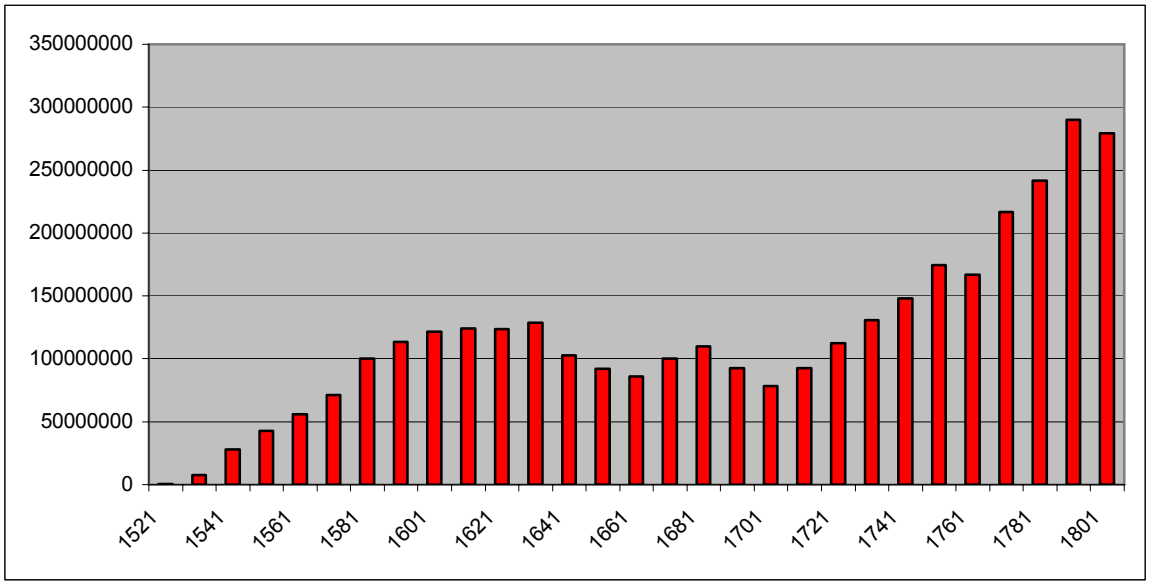


The remaining group of six regions with mineral production established a secular pattern similar to but also notably divergent from what we have just seen for the three major regions. Output peaked at 13 million *pesos* in the fourth quarter of the sixteenth century, earlier than in Peru and Mexico, although it remained high through the early seventeenth century. The remainder of the seventeenth century was more depressed than expansive, but after bottoming in the first decade of the eighteenth century output turned sharply upward through 1801-1810 when output exceeded 40 million *pesos*. Five of the six – Caribbean, Central America, Ecuador, Chile and Río de la Plata - accounted for a third of the total. The other two-thirds belonged to New Granada, which was by far the most important of the minor regions. Its principal mineral was gold, and until the middle of the eighteenth century its decennial totals never exceeded 10 million *pesos*. Beginning with the decade 1751-1760, however, it regularly reported between 10 and 25 million *pesos* in mineral (gold) production. It boosted production at the time that Peru and Mexico were moving toward new records and Brazil was peaking before it began a late colonial slide.

Silver Production Trends

Although the New World added more than 2,500 tons of gold to the world's supply, with about 60 percent from Brazil, it made a far greater contribution in silver. Converted to metric tons the New World mines produced about 100,000 tons, or 40 times the quantity of gold. Some of the gold was produced in Spanish America, but all of the silver came from the Spanish colonies. Peru carried the torch until the middle of the seventeenth century when it passed to Mexico. By the end of the colonial era, despite the richness of Potosí, Mexico would produce more silver than Peru. Mexico's advantage lay with higher grades of ore, several profitable camps and lower costs of production. Potosí became a financial albatross, and that that affected how mining projects were conceived and executed in the viceroyalty. Moreover the Crown exercised a much heavier hand in Peru than in Mexico, and that too affected the mining culture. Even so Potosí would remain Peru's largest producer, and by the end of the colonial period it would account for 5 percent of all colonial production and 25 percent of Peruvian production.

FIGURE 10
Decennial Silver Output
(Peso=272 Maravedís)



Silver was discussed earlier in the broad context of the total mineral output, but when viewed separately from the total the silver series has some special features that need to be explained. The foregoing chart plots decennial silver production. Beginning with the first discoveries in 1521-1530 output rose steadily until 1631-1640 when it totaled about 129 million *pesos*. By the decade of 1661-1670 output had fallen back to a total of 86 million *pesos*, a decrease of 33 percent. Output turned up for two decades (1671-1690), and then it turned down for the next two decades (1691-1710). On this second descent output in 1701-1719 fell below the low of 1661-1670 to 78 million *pesos*. Output had not been this low since 1571-1580. A turn-around began in 1710-1720, and for the next five decades output moved steadily higher until 1761-1770. In the decade of 1751-1760 output reached 175 million *pesos*. In the previous half-century decennial output had grown by 36 percent. The reversal in the next decade, 1761-1770, was modest. Output declined to 168 million *pesos* or about 5 percent. In the next decade production rose by more than 25 percent to 215 million *pesos*, and the upsurge continued for two more decades until 1791-1800 when it reached its all-time high of 290 million *pesos*. In the final decade, 1801-1810, output retreated to 280 million *pesos*, which was a 3 percent loss from the previous decade but was still the second highest production in the colonial period. What happened after hostilities began is more speculation than fact. Certainly

production fell, and perhaps significantly so. The actual figures may never be known, but some scattered references suggest that it may have dropped to 100 million or lower for the decade.

FIGURE 11
Annual Silver Production, 1559-1810
(Peso=272 Maravedís)

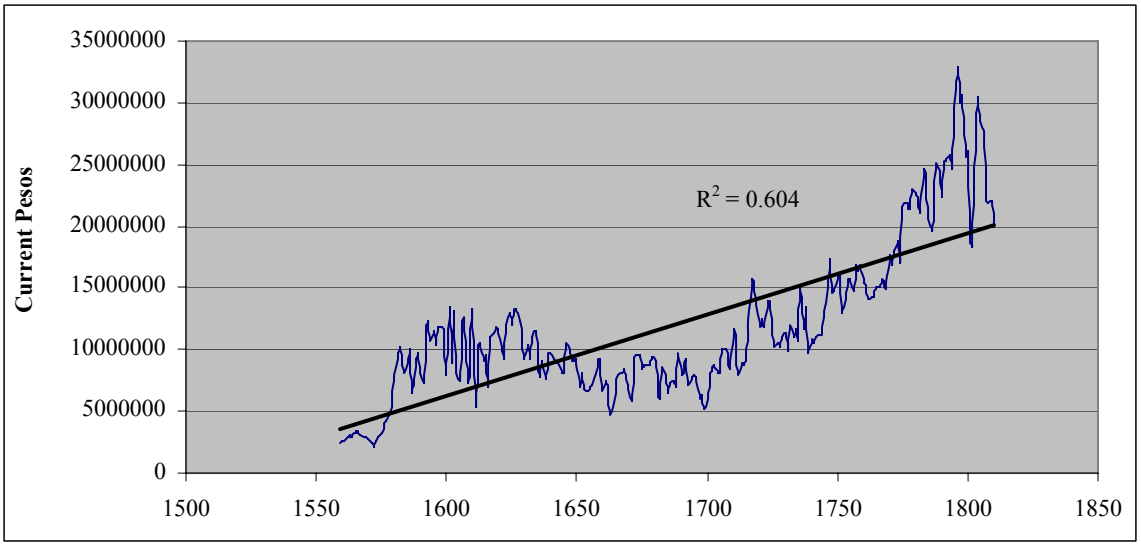
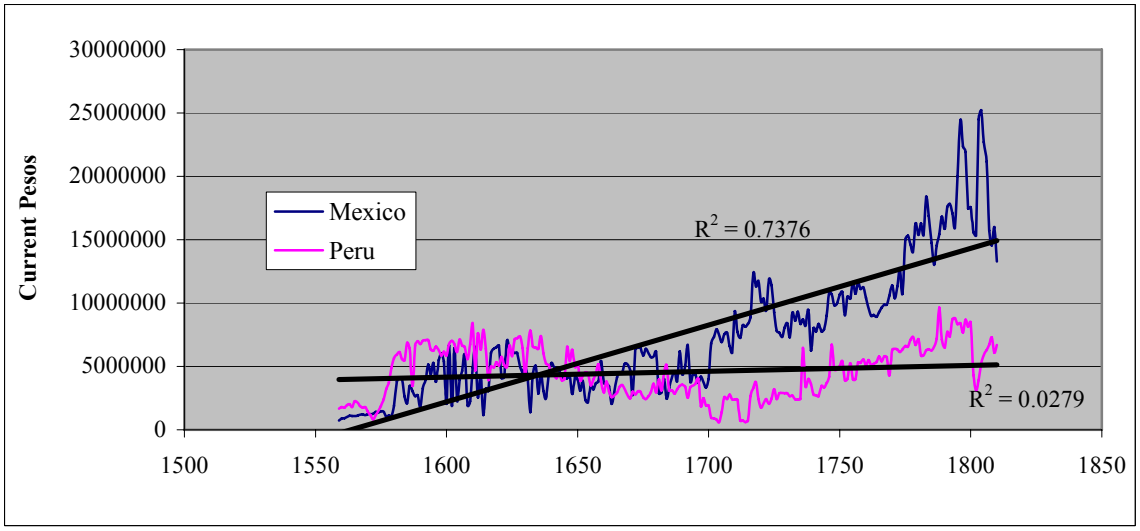


FIGURE 12
Annual Silver Production, Mexico and Peru, 1559-1810
(Peso=272 Maravedís)



In an earlier analysis of colonial silver-mining trends based upon the creation of an annualized dataset from TePaske and Klein's original publications of the treasury accounts with some corrections based upon other silver series.[13] This annualized series covers a somewhat shorter period from 1559 to 1810 than TePaske's decennial series from 1491 to 1810. Eventually my older annualized series will be updated to include data prior to 1560. In the annualized series I have computed growth rates for the colonial series and for each of viceregal series. For the colonial series the rate is about 0.6 percent year. At that rate the output should at least double in slightly more than 100 years so that in the final year (1810) output should be around 21 million *pesos*, and in fact it came in at about 20 million *pesos*. The R^2 value explains how many data points fall within the calculated trend line, and a 60-percent figure is moderately positive but not strongly so. That a trend existed can also be confirmed simply by looking at the chart. One can observe that output rose over time, but one can also observe that the trend was somewhat volatile with periods of declining output or unchanging output. With a computed trend line the variations from year to year and the changes in direction become a part of the calculation, and the results may suggest that the variability limits the strength of the trend line. Trend lines are often used to project beyond the final year of data to see what might occur in the future, and a R^2 of .60 would suggest caution in accepting whatever projected figures might emerge from the regression calculations. Projecting into the future is not the purpose of this study, but still declaring that a trend existed in the silver data over 250 years requires that attention be paid to the degree to which the trend line captures the data points. Colonial silver mining did grow over the long term, but as seen in the statistical tests and the plotted data the growth was not without interruption.

A temporary solution to how fast the mining economy expanded from 1500 to 1810 is possible. If one assumes an estimated initial number (say 800,000 *pesos* worth of gold and silver) and then calculates a geometric growth rate from 1500 to 1810, the rate of growth from 800,000 *pesos* to 20,000,000 *pesos* worth of gold and silver would be about 1 per cent per year. At an annual rate of 1 percent meant that output doubled in less than three-quarters of century (about every 72 years) after 1500 (as opposed to a doubling

[13] Garner, "Long-Term Silver Mining Trends in Spanish America," *American Historical Review*, 93:4 (1988), 889-914 and for a list of sources see footnote 1.

that took more than a century at the slower rate from 1560 to 1810). Certainly the higher rate for more than 300 years resulted in part from the rapid rise in gold and silver output in the initial decades of the sixteenth century. By the sixth decade output had already reached 3 million *pesos* worth of gold and silver, nearly three times greater than output in the first decade. Over the next 250 years output rose seven or eight times from the figure of the sixth decade of the sixteenth century and during the 310 years it rose 24 times from the figure of the first decade of the sixteenth century. Those early decades of the sixteenth century can exert a strong influence on any computation of the long-term growth rates.[14]

Growth rates were affected by the long slide in output in Peru during the second half of the seventeenth century and the first quarter of the eighteenth century. When the two viceroyalties are separated, Mexico had a growth rate of about 1 percent per year after 1560 and Peru had no growth at all over the very long colonial period. For the total colonial output after 1560 the R^2 suggested that the computed trend captured about 60 percent (moderately strong result) of the annual observations. Mexico's R^2 was even stronger at about 73 percent. Peru's R^2, on the other hand, was near zero, and this indicated that the data were so scattered that they had no trend. In cases like this a simple observation of the plots may be the best guide. Over nearly three centuries total silver output as measured in *pesos* moved gradually higher, although this trend was more the consequence of more positive mining circumstances in Mexico than in Peru.[15]

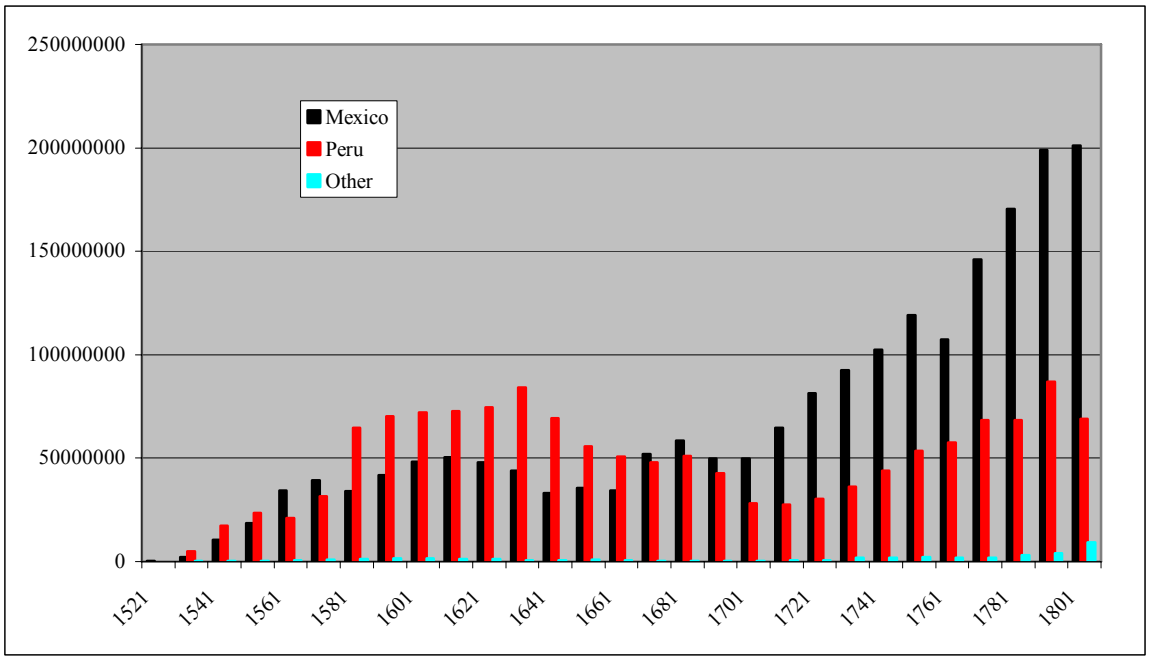
FIGURE 13
Decennial Silver Output in Pesos with Percent Change by Regions
(Peso=272 Maravedís)

Decade	CN AM	%	MEXI	%	PERU	%	NW GR	%	CHIL	%	RDLP	%	TOTAL
1521	40000	11.76%	300000	88.24%									340000
1531	60000	0.79%	2240000	29.67%	5100000	67.55%	150000	1.99%					7550000
1541	90000	0.32%	10570000	37.59%	17330000	61.63%	130000	0.46%					28120000
1551	90000	0.21%	18630000	43.62%	23630000	55.33%	360000	0.84%					42710000
1561	90000	0.16%	34340000	61.27%	21130000	37.70%	490000	0.87%					56050000
1571	300000	0.42%	39220000	54.88%	31440000	43.99%	510000	0.71%					71470000
1581	850000	0.85%	34110000	34.05%	64800000	64.68%	430000	0.43%					100190000
1591	680000	0.60%	41710000	36.78%	70200000	61.90%	810000	0.71%					113400000

[14] The formulas for these calculations are fairly standard:
[15] Garner, "Long-Term Silver Mining Trends in Spanish America," *American Historical Review*, 93:4 (1988), 889-914. Even though TePaske's revised dataset has different figures, the differences would not greatly affect the computed secular trends. I have compared the earlier dataset against the later one and the resulting growth rates and R^2 values were nearly the same.

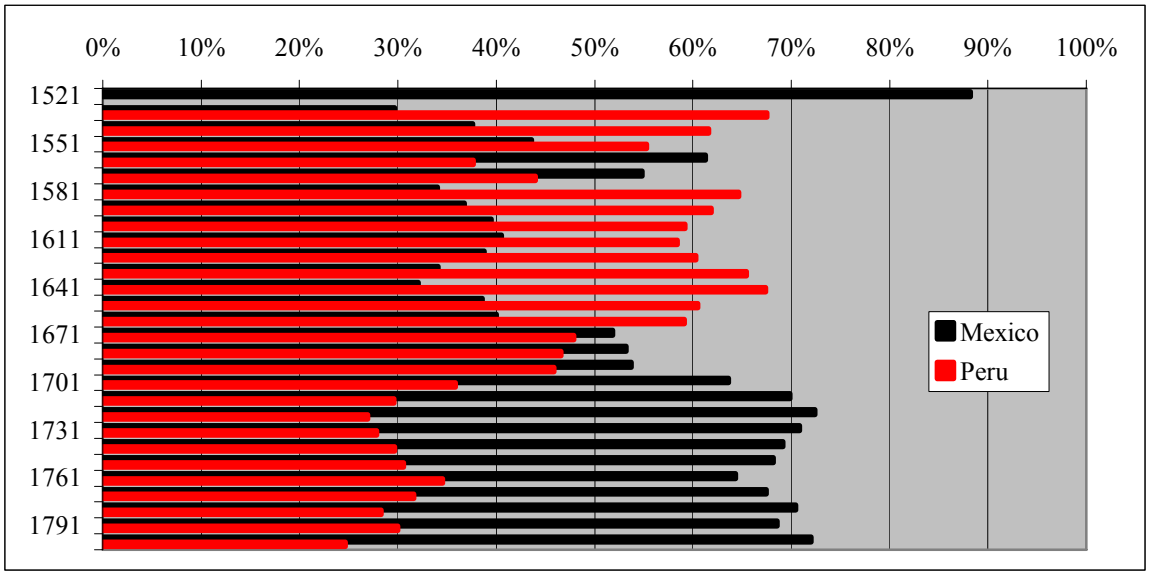
1601	640000	0.53%	48120000	39.50%	72150000	59.23%	900000	0.74%					121810000
1611	550000	0.44%	50390000	40.55%	72620000	58.43%	720000	0.58%					124280000
1621	300000	0.24%	47900000	38.74%	74530000	60.28%	900000	0.73%					123630000
1631	210000	0.16%	43860000	34.11%	84170000	65.45%	360000	0.28%					128600000
1641	300000	0.29%	32990000	32.08%	69330000	67.42%	210000	0.20%					102830000
1651	340000	0.37%	35530000	38.55%	55760000	60.50%	530000	0.58%					92160000
1661	260000	0.30%	34320000	40.03%	50720000	59.16%	430000	0.50%					85730000
1671	170000	0.17%	51870000	51.86%	47900000	47.89%	80000	0.08%					100020000
1681	170000	0.15%	58480000	53.24%	51140000	46.55%	60000	0.05%					109850000
1691	260000	0.28%	49880000	53.75%	42560000	45.86%	100000	0.11%					92800000
1701	340000	0.43%	49790000	63.63%	28070000	35.87%	50000	0.06%					78250000
1711	510000	0.55%	64690000	69.85%	27410000	29.60%		0.00%					92610000
1721	680000	0.60%	81400000	72.39%	30320000	26.96%	50000	0.04%					112450000
1731	1760000	1.35%	92530000	70.82%	36350000	27.82%	10000	0.01%					130650000
1741	1730000	1.17%	102300000	69.15%	43880000	29.66%	30000	0.02%					147940000
1751	2080000	1.19%	119030000	68.18%	53430000	30.60%	40000	0.02%					174580000
1761	1730000	1.04%	107280000	64.35%	57570000	34.53%	30000	0.02%	110000	0.07%			166720000
1771	1430000	0.66%	146080000	67.46%	68500000	31.63%	80000	0.04%	460000	0.21%			216550000
1781	1490000	0.62%	170360000	70.43%	68520000	28.33%	30000	0.01%	1430000	0.59%	50000	0.02%	241880000
1791	1820000	0.63%	198870000	68.59%	86960000	29.99%	100000	0.03%	2160000	0.74%	30000	0.01%	289940000
1801	1370000	0.49%	201210000	72.00%	68870000	24.64%	50000	0.02%	1650000	0.59%	6310000	2.26%	279460000
Total	20340000	0.59%	1968000000	57.33%	1424390000	41.50%	7640000	0.22%	5810000	0.17%	6390000	0.19%	3432570000
Average	701379		67862069		50871071		282963		1162000		2130000		118364483
StDv	654254		54156680		21842235		289201		852273		3620000		70424046
CofV	93.28%		79.80%		42.94%		102.20%		73.35%		169.95%		59.50%

FIGURE 14
Decennial Silver Output by Regions
(Peso=272 Maravedís)



Not surprisingly, as discovered with total output of gold and silver, regional circumstances can make a difference. Using TePaske's classification I have arranged the silver data into three categories: Mexico, Peru and other. Figures 13 and 14 show output (measured in *pesos*) for each category as well as the percentage of the total between decades 1521-1530 and 1801-1810. On Figure 14 Other barely shows up at all. Mexico and Peru, as defined by TePaske, were the only players. Silver production in all the others regions combined only reached about 40.2 million *pesos* or 1.2 percent of the total. In contrast Mexico reported 1.97 billion *pesos* or 57.3 percent and Peru reported 1.42 billion *pesos* or 41.5 percent. In the other category only Central America had at least one half of 1 percent of the total. The other regions all came in at less than that percentage.

FIGURE 15
Decennial Proportion of Silver, Mexico and Peru



Since I am interested in analyzing "total" production but not necessarily production by minor regional players, I have organized the silver database into two large regions bound by the traditional viceregal boundaries of Mexico (north of the Isthmus) and of Peru (south of the Isthmus except for Brazil). Some royal accounts escaped the original TePaske and Klein survey and have not yet made their way into the database, but since the major camps in both Mexico and Peru have been included, the omissions will not make much difference in the overall trends. When the Mexican and Peruvian decennial series are charted, the results will be immediately recognizable. Once the major discoveries got underway in the middle of the of the sixteenth century (that is, ignoring the modest registrations before 1550) Peru led the way until the middle of the seventeenth century after which Mexico took the lead. The changeover came in the decade of 1671-1680 as Peru's slump continued and Mexico's expansion accelerated. In the two decades after 1550 the lead shifted back and forth between Peru and Mexico, but beginning in 1571-1580 Peru took the lead and held it for a century. In that period Peru recorded about 61 percent of all the silver and Mexico 38 percent. In the final century and a half, with Mexico in the lead, the gap was even greater: 67 percent versus 32 percent.

The seventeenth-century segment of the silver curve has long attracted scholarly attention. One can readily observe that production sprinted ahead in the sixteenth century,

languished in the seventeenth century, and sprinted ahead again in the eighteenth century. The silver curve was flat for more than half of the seventeenth century, and that lack of growth could not help but affect the overall growth rate. The sixteenth-century surge, which lasted until the end of the first quarter of the seventeenth century, had a rate of growth greater than 2 percent per year (R^2=.90 when corrected for autocorrelation), while the eighteenth-century resurgence rose at a more moderate rate of slightly more than 1 percent per annum (R^2=.91 when corrected for autocorrelation). The first would denote a doubling about every 30-35 years and the second a doubling about every 70 years. In between the end of the first quarter of the seventeenth century and the end of the seventeenth century the rate of growth may have been negative by a few tenths of 1 percent, but the R^2 values do not inspire much confidence that any trend can be established. Recall that the computed growth rate for total silver output between 1559 and 1810 was 0.6 percent per year.[16] What happened in the seventeenth century was the rise in output slowed and flattened in both Peru and Mexico during the first quarter and then turned downward in the second quarter. At this point it is better to examine the total curve in light of what happened to the respective viceregal curves. But when the series is broken out by its respective viceroyalties of Mexico and Peru, the seventeenth-century contraction assumes a somewhat different face. Peru suffered a more severe contraction than Mexico. While Mexican production appeared to be highly volatile in the late sixteenth and early seventeenth centuries (in part because of missing annual data) it stabilized in the middle of the seventeenth century and began an upswing that more or less continued until the end of the colonial era. In Peru after a spectacular sixteenth century output began to slow, and when it turned downward it became relentless. It did not turn up again until the second quarter of the eighteenth century, and in the meantime Mexico assumed the lead and was never seriously challenged again during the remainder of the colonial period. To be sure, Mexican silver mining experienced a falling off or slowing down in the rate of growth in the middle decades of the seventeenth century but

[16] These calculations and others are spelled out in greater detail in Garner, "Long-Term Silver Mining Trends in Spanish America," *American Historical Review*, 93:4 (1988), 900-901.

nothing comparable to the near collapse of the Peruvian industry in the seventeenth century.[17]

The colonial curve offers a reasonable overview of mining operations in Spanish America, but the Mexican and Peruvian curves, the two main components of the colonial curve, provides a different perspective on those operations. Discoveries in Mexico and Peru occurred about the same time, around 1550, in Zacatecas and Potosí, respectively. Both would remain active camps until the end of colonial rule, but Potosí with almost literally a "mountain" of silver would far outshine Zacatecas. No other camp in the New World achieved the status (financial or literary) of Potosí, even though from the middle of the seventeenth century to the end of the colonial period Potosí struggled to re-establish its dominance. And since Potosí accounted for most of Peru's silver registrations, Peru's production curve would heavily reflect Potosí's performance. Peru had other important camps - Oruro in the seventeenth century and Pasco in the eighteenth

[17] The most compelling case on the seventeenth-century depression appeared in Woodrow Borah small volume, New Spain's *Century Depression* (Berkeley & Los Angeles, CA: University of California Press, 1951, Ibero-Ameriana Monographic Series, 35). Peter Bakewell in *Silver Mining Society in Colonial Mexico: Zacatecas 1546-1700* (Cambridge: University of Cambridge Press, 1971), 222-226, was critical of Borah's interpretation on the basis of a comparison of the data on demographic and economic trends in Zacatecas and elsewhere in New Spain. Bakewell also argued that Borah's attempt to compare sixteenth-century New Spain with seventeenth-century New Spain suffered because the comparison had to take into account the emergence of a more capitalistic system in the seventeenth century. No doubt the economic system inherited by the Spaniards had to change as Spanish rule and policy became the dominant forces. But the question remains: as the system underwent change did the colonial economy experience a severe contraction that might qualify as a depression? Part of the debate involves duration. A century-long depression in all of New Spain seems unlikely and untenable. Zacatecas and colonial mining continued to expand well into the second quarter of the seventeenth century. Such a fact would render any –all-encompassing economic stagnation somewhat moot. But the debate about depression in New Spain is tied to a debate about depression in Western Europe during the seventeenth century. Thus enters another part of the colonial equation: trans-Atlantic trade. Huguette and Pierre Chaunu in their eight volume *Seville et L'Atlantic (1504-1650,* (Paris: SEVPEN, 1955-1959), 8(2): 1557-1560 proposed that a shrinking market for Spanish goods in New Spain after 1620 was attributable to an economic downturn in New Spain along the lines suggested by Borah. If Borah's demographic and economic evidence are less than convincing, the Chaunus' hypothesis must be accordingly suspect. It is entirely possible that the Mexican economy in the seventeenth century was not as crippled by the structural changes as Borah may have concluded or by the European events as other have concluded. When examining the "numbers" relative to the output of silver the mining expansion of the first hundred years slowed in both Mexico and Peru but only briefly reversed in mid-seventeenth-century Mexico compared to Peru's sharply downward spiral. (Borah actually hinted in the final footnote (134) of *New Spain's Century of Depression* that the story on mining was incomplete, and as more research were undertaken a different picture may emerge.) Since the publication of Borah, the Chaunus and Bakewell, many other articles and monographs have taken up the depression debate directly or indirectly. In some ways the published research of the last quarter century has made the issue of a depression or not less important or relevant. The idea of a century of depression was an overreach, the linkage between the New World and Western Europe was too deterministic and the economic picture of the New World was in need of more discreet analysis.

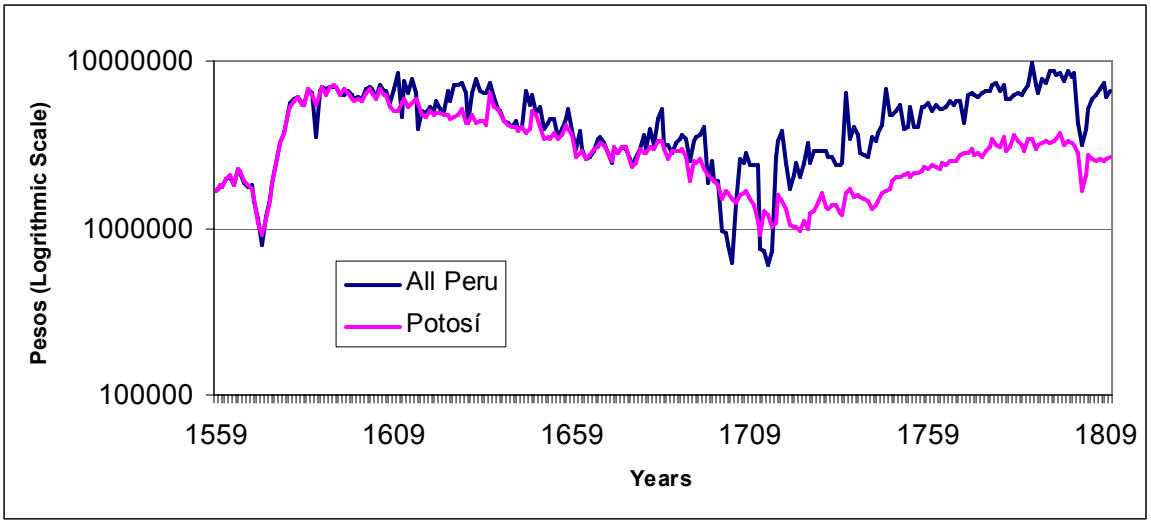
century - but none of them ever seriously challenged Potosí even in Potosí twilight. In Mexico, by contrast, several other camps - in particular, Guanajuato – supplanted Zacatecas as the biggest producer. Peru's mining history was closely bound up in a single camp, but Mexico's was dispersed among several large camps.

Production in Peru

Silver mining in Peru took off between 1550 and 1600. By the end of the century annual production topped 7 million *pesos*. That meant that two-thirds to three-fourth of all registered colonial silver came from Peru. In the first third of the seventeenth century annual output bounced around between 6 and 8 million *pesos* before the seventeenth-century contraction set in. From the 1650s to the 1720s production declined irregularly but relentlessly until total annual registrations fell below 1 million *pesos*. Peru's share of total colonial production dropped precipitously to under 10 percent. Eighteenth-century Peru experienced a recovery as production rose to a level of 8 to 10 million *pesos* per year by 1800, and its share reached a quarter to a third of the total. In the end despite a bifurcated colonial mining history Peru accounted for 38.5 percent of the total registrations from 1550 to 1810. Viceroyalty of Peru was split in 1777 into Peru, which was basically the geography that corresponded to Lower Peru and is today modern Peru, and Río de la Plata, which corresponded to Upper Peru or modern-day Bolivia plus the land between Upper Peru and Buenos Aires. After the reorganization silver from Upper Peruvian camps, although registered and taxed in the local *cajas* was more likely to be shipped to Buenos Aires than to Lima.

FIGURE 16

Potosí and All Peru Colonial Production



Peru's silver-mining fortunes were inextricably linked to Potosí, at least until the second half of the eighteenth century. If Potosí mining skyrocketed or skidded, so too did the viceregal silver curve. Even mining across the Empire was affected. From time to time other camps blossomed - Oruro accounted for periodic up-ticks in the middle of the seventeenth century and Pasco in the late eighteenth century - but none of them replaced an even diminished Potosí. To demonstrate further the importance of Potosí to Andean silver mining I have prepared a chart (logarithmic scale) of output for all of Peru and for only Potosí's mining district.[18] Figure 16 illustrates that Potosí was the principal driver of

[18] All of the annual series for Potosí and other Peruvian mining districts are drawn from the treasury records. I created several series for my own purposes – to compare trends within Peruvian camps and between Peru and Mexico – based on the published treasury accounts of TePaske and Klein *The Royal Treasury of the Spanish Empire in América*, 3 vols., (Durham, NC: Duke University Press, 1982). I converted the taxes collected on silver to total *peso* value by a factor of 5 up to 1736 and then by a factor of 10 to the end of the colonial period. Also since the accounts did not always follow a calendar fiscal year I disaggregated the total for whatever fiscal year was used and then tried to re-aggregate the monthly figures into a calendar fiscal year. Both of these conversions were less than precise, but I employed them because reasonably estimated annual figures would suffice for trend analysis. For Potosí from 1549 through 1735 Peter Bakewell had assembled a set of annual figures in marks rather than *pesos* from the *libros reales communes del cargo y data* and other treasury *libros* in Seville and Potosí with much more precision than I had used to create my dataset. His technique is explained in "Registered Silver Production in Potosí District, 1550-1735," *Jahrbuch für Geschitchte von Staat, Wirtschaft und Gesellschaft Lateinamerikas*, 12 (1975), 69-78. While he had to consult other sources for some missing years, most of dataset was drawn from the *libros*. It does not appear that disaggregating and then re-aggregating to achieve a calendar-year total was necessary. The dataset that one will find in the above article (93-97) will show the year, the tax rate, the total tax (in *pesos de ensayados* of 450 *maravedís*) total production in marks (the tax is multiplied by several different converters) and the archival source. TePaske's revised gold and silver dataset contains

Peruvian silver production in the sixteenth century, and only at the beginning of the seventeenth century did the All-Peru curve begin to separate from the Potosí curve. In the seventeenth century the Potosí and All-Peru curve track closely but not identically as other camps came into production. Most prominent among the other camps was Oruro, also in Upper Peru A newly established *caja real* in Oruro reported nearly 1 million *pesos* worth of silver in 1609 and the figure was to climb to 3.5 million *pesos* in 1632 before falling back to less than a million *pesos* per year by mid-century. The separation into All-Peru and Potosí curves during the first half of the seventeenth century was due in large measure to the discovery and exploitation of Oruro ores. In spite of the Oruro contribution the All-Peru curve like the Potosí curve plateaued in the first quarter of the seventeenth century and then turned downward, a course that continued into the first quarter of the eighteenth century. From time to time as other camps came into production in Lower or Upper Peru the All-Peru curve would reverse course and move higher, but the reversals were short-lived. At the beginning of the eighteenth century Peruvian mining was in total disarray. Production had fallen to levels not experienced since the 1550s when Potosí was the sole silver producer. The addition of new camps during the seventeenth century could not compensate for the relentless downward spiral of output at Potosí. The turn-around came in the first quarter of the eighteenth century. The All Peru curve began to diverge sharply from the Potosí's curve. To be sure the recovery at Potosí helped to fuel the upswing in All-Peru production, but the separate in the two curves indicates that other camps were having an impact of the All-Peru curve. During the late colonial period more than a dozen *cajas reales* in Upper and Lower Peru registered silver from mining camps under their jurisdiction In addition to the recovery at Potosí Oruro made a partial comeback, although it fell notably short of its mid-seventeenth-century highs, and Pasco (Lower Peru), whose *caja real* registered its first silver in 1670 in the amount of several thousand *pesos*, was producing nearly three-quarters as much as Potosí in the last quarter of the eighteenth century. By the end of the eighteenth century Potosí's output still accounted for between a third to a half of the total Peruvian registrations, and

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annual data for all the Peruvian camps in total *pesos* and in total kilograms, and I have compared his series with mine (based on the earlier TePaske and Klein publication). It is worth noting that for trend analysis one can use the tax figures without making any conversions. They will indicate how a *caja* series moves

its contribution to Peru's late colonial resurgence cannot be denied. The shapes of the logarithmic curves for both Peru and Potosí in the eighteenth century look similar except that some of the peaks and dips in the Peru curve do not match up with the Potosí curve. Other Peruvian camps were having an impact on the overall curve, and yet Potosí remained South America's most productive (although not necessarily its most efficient) silver-mining camp.

It is not all that useful to calculate growth rates for total Peruvian production. It peaked in the first half of the seventeenth century, lost 90 percent of its value by the early eighteenth century, and then peaked again in the last half of the eighteenth century. Thus, production was only fractionally higher at the end of the colonial period than at the beginning. What can be measured are discrete components: a rise of 3.7 percent per year (R^2=69 percent) in the sixteenth century (50 years), a decline of 1.5 percent per year (R^2=64 percent) in the seventeenth century (100 years), and a rise of 1.2 percent per year (R^2=65 percent) in the eighteenth century (110 years).[19] Although other timelines could be used, trends by centuries serve the purpose of illustrating how the Peruvian silver industry and its major camp performed over a period of more than 250 years. The importance of silver mining outside of Potosí came more strongly into focus in the eighteenth century. Upper Peru (Potosí, Oruro, Charcas, etc.) rose at a rate of 0.7 percent per year (R^2=38 percent), but Lower Peru (Pasco, Puno, Lima, etc) rose at a rate of 2.4 percent per year (R^2=69 percent), nearly three times that of Upper Peru. Expansion in Lower Peru imparted a more broadly robust character to the Andean silver curve even though on average during the eighteenth century Upper Peru still produced about twice as much silver as Lower Peru.

What accounts for the sagging fortunes of the Andean silver empire? Peter Bakewell and others have pinpointed several special problems. The upswing in the last quarter of the sixteenth century resulted not only from extracting more ore at Potosí but also from processing ores already extracted but discarded, often called tailings. This was

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over time. All of the annual series for all of the Peruvian camps can be downloaded from www.historydatadesk.com.

[19] It is important to note that the growth rates are calculated from regression equations that compute the mean and then fit a line to the data points. When the line is expressed in logarithmic terms, a rate of change can be derived from it. Thus the data for the first and last years are not directly relevant to the computation of a growth rate.

made possible because Spanish miners switched from smelting or cooking ore to separate the silver from other minerals to crushing the ore, adding mercury and allowing time for the mercury to amalgamate with the silver. Amalgamation is often discussed in terms of refining low-grade ores, but in fact amalgamation could be efficiently applied to an array of silver-bearing ores. Smelting worked for a narrow range of ores, but amalgamating worked for a much wider range, some of which could be rich in silver.[20] Generally in the initial decades discarded ores, often around the mines' openings, were classified as "poor" because they could not be smelted economically. The fact that these ores were already on the surface and only awaited a more efficient processing system meant that when amalgamation arrived a backlog of ores on hand helped to explain why production could be pushed up so rapidly in the second half of the sixteenth century. This situation of unprocessed ors may have also helped to obscure the facts about costs. Over the long haul Andean silver mining may have been more expensive per unit of silver than Mexican mining. Andean ores tended to fall on the lower end of the quality scale, that is, a unit of ore yielded less silver than Mexican ores. Andean miners had an advantage over Mexican miners because they could draw on mercury deposits from a large mine at Huancavelica (Lower Peru) and were not dependent on imports from Spain as were the Mexican miners. But even that may have become a disadvantage. Spanish mercury was of a higher quality than Peruvian mercury, and therefore more mercury had to be incorporated to refine Andean ore than was true on average with Mexican ore. The quality of both the ore and the mercury had an financial impact in that they probably raised per-unit costs: less silver per unit of ore and more mercury to refine that unit. To be perfectly honest comparative data on costs and yields are less than complete, and the view that Peruvian mining had a higher cost structure than Mexican mining is based as much on inference as evidence. The inferences are based on comments from royal inquiries and from calculations of mercury inputs and silver outputs, and they appear to carry some weight. The higher cost structure (despite numerous protests) did not seem persuasive until the eighteenth century by which time Andean silver production had nearly fallen off the charts. In the eighteenth century the crown introduced the *diezmo*

[20] At the great bonanza on the Comstock Lode (Nevada) in the western United States some ores could be very rich, usually in combination with gold, and they were all refined with mercury. It helped that

(tenth) to replace the *quinto* (fifth) (more than 100 years after it had been introduced in Mexico) and also dropped the price of mercury by half. Perhaps dazzled by Potosí's early wealth that was in part derived from the processing of extracted but discarded ores, the Crown continued to impose heavier financial burdens on Peru than Mexico because it was thought to be richer in ores. It was easy to be blinded or confused because even as its star dimmed Potosí remained the largest and most productive camp in Spanish America if not the world. It was almost as if whatever its difficulties it could absorb the punishment. On the other side the Crown did not believe that it could afford to lose the revenues that the higher payment provided. Besides from the Crown's perspective Potosí also some subsidies that were not widely extended to other camps, not even in the Andes.

One of those long-time subsidies was the *mita*, the forced-labor system that the Crown permitted at Potosí. In this case the *mita* acted like a subsidy, and yet for miners and investors it further distorted the task of determining the true mining costs. *Mita* remained in effect until the end of the colonial era despite many efforts to dismantle it. As time passed, though, Potosí's labor force was made up mainly of non-*mita* workers. Even as output was falling, so too was the indigenous population from which *mita* workers were recruited. To get permanent workers and certainly skilled workers operators had to pay wages that supply and demand mandated. These so-called "free" wages (there is a question as to how free the workers were in these negotiations) came closer to representing the actual labor costs than any forced-labor regime. M*itayos* were paid wages but usually below the "free" wage level. Operators in effect enjoyed a subsidy that hid the actual cost of the labor component. If *mita* had been ended, operators would have seen mining costs rise because the replacements would be hired at prevailing wage rates. The subsidy component resulted from the fact that the differential between what *mitayos* were paid and what regulars were paid kept the less efficient operators and more marginal in business. In short as Potosian mining entered its mature stage the character of the ore changed. *Pacos* or rich silver chloride ores predominated in the upper part of the Cerro de Potosí and then gave way to *negrillos* or less rich silver sulfide ores. It was this transition that result in describing ores as declining in quality. There were in fact more *negrillos* to be extracted than *pacos,* but the cost could be higher because they were less

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amalgamation had itself become more efficient than in Spanish-American milling.

pure, were harder to reach and were surrounded by water. As the miners worked their way through and down the Cerro the value of a unit of ore yielded less and cost more. Thus, the insistence that the *mitayos* whose pay scale was different from voluntary workers were needed to offset higher costs. One can sketch out a scenario in which the termination of *mita* labor forced marginal producers out of business and encouraged more efficient producers to undertake the necessary changes to recognize the real costs in operating their mines. Even as the number of *mitayos* declined and the number of free laborers grew over time the cost of labor had to increase. At the same time the cost of production was also increasing. In the most extensive study of the economics of the *mita* in late colonial Potosian mining the late Enrique Tandeter contended that even though the *mita* was close to being reform out of existence, the *azogueros* or mining entrepreneurs managed to keep it alive by arguing that a *mitayos* allotment had become so essential to the financial viability and sustainability of Potosí's mining that it could not be eliminated. The key was that they were be worked longer hours than the law permitted but custom dictated, and since they were paid less than regular wage earners the enterprise enjoyed a "surplus", which when added to any profits guaranteed a reasonable return. If the *mita* labor had been curtailed (enforcement according to the law) or eliminated, both the profit and the surplus would probably have disappeared for many operators.[21] The *mita*, then, helped to cushion the financial blow from declining ore quality and rising extraction cost. It may have come to symbolize the irreversible plight of Potosí: mining profits were increasingly untenable. Bakewell wrote about Potosí's third phase – the late colonial recovery – in less than positive terms:

> Voluntary labor was dearer, though its extra cost may have been offset to some degree by its greater expertise. As cost rose and the quality of ore still declined, profits inevitability fell, or disappeared. It would be logical to suppose that in such a situation new investment also declined; and

[21] Tandeter, *Coercion and Market, Silver Mining in Colonial Potosí 1691-1826* (Albuquerque, NM: University of New Mexico Press, 1993), especially 47-61. See also Bakewell, "Mining in Colonial Spanish America," in Leslie Bethell, ed., *The Cambridge History of Latin America, The Colonial Period*, 2 vols. (Cambridge: Cambridge University Press, 1984), 2:123-128 and *Miners of the Red Mountain: Indian Labor in Potosí 1545-1650* (Albuquerque, NM: University of New Mexico Press, 1984); and Jeffrey Cole, *The Potosí Meta, 1573-1700, Compulsory Indian Labor in the Andes* (Stanford, CA: Stanford University Press, 1985). The literature on *mita* is huge, and Tandeter's bibliography should be consulted for more information.

> indeed there is evidence that insufficient new adits (*socacones*) for mine drainage and access to deposits were cut in the seventeenth century, especially in the *Cerro Rico* of Potosí itself. Many of the dams and aqueducts built to provide hydraulic power for milling were allowed to fall in disrepair. Little new mining exploration was undertaken in the *Cerro*. Entrepreneurial energies were directed rather to opening up new mines in other parts of the district, with some success.[22]

Where were the new entrepreneurial energies in evidence in eighteenth-century Peru and how did they make a difference? The backdrop for the eighteenth-century revival of Andean mining were crown policies that lowered the *quinto* to the *diezmo* and the price of mercury along with some other administrative and financial reforms. These changes were bound to have a positive effect on the silver industry simply because it reduced the per-unit cost of mining and milling the ore. Potosí benefited, as did some "lesser mining centers" (Bakewell's phrase) outside of Potosí itself and beyond El Cerro Rico (but within the so-called Potosí District). The most prominent of these camps was Oruro (about 130 miles northwest of Potosí), which saw output exceed 1 million *pesos* during the middle decades of the eighteenth century for the first time since the early 1600s. But its resurgence was short-lived.[23] More impressive were the figures from Lower Peru in camps like Cerro de Pasco. It was the Andes most stellar camp after Potosí. Its output grew from ten of thousands of *pesos* in the late seventeenth and early eighteenth century to several million in the late eighteenth and early nineteenth century. Merchant capital that underwrote so much of the Mexican mining industry was lacking in Peru. Merchants who were probably less wealthy than their Mexican counterparts to begin with preferred to invest in short-term *avios* (advancing credit to purchase supplies against future silver registrations) rather than longer-term investment in exploration, drainage or reduction. Pasco witnessed an increase in *avios* that allowed miners more leeway in developing their mines with rather favorable results. But Andean mining in both Lower and Upper Peru lacked the capital investment needed to rehabilitate an

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[22] Bakewell, "Registered Silver Production in Potosí District, 1550-1735," *Jahrbuch für Geschitchte*, 12 (1975), 89.

[23] Bakewell, "Registered Silver Production in Potosí District, 1550-1735," *Jahrbuch für Geschitchte*, 12 (1975), 86-87.

industry long ignored by the moneylenders. John fisher, who has studied the recovery and expansion of late eighteenth-century silver mining in Lower Peru, has concluded that the despite the revival those lenders continued to treat the industry was treated as a "subsistence activity"[24]

Production in Mexico

Mexico followed a different script from Peru. In contrast to Peruvian mining, which achieved its great success in the first hundred years, Mexican mining attained its heights in the last hundred years. A few times during the first century Mexican output accounted for 50 percent or more of the annual colonial output, but more often it was in the 25- to 35-percent range. In the wake of Peru's mining collapse in the seventeenth century, Mexico's expanded slowly in the seventeenth century and then rapidly in the eighteenth century. By the early 1700s Mexico's yearly output exceeded 10 million *pesos*, and by the end of the century Mexico's silver industry pushed registrations into the range of 20 to 25 million. Starting at near 50 percent of the total colonial output in the middle of the seventeenth century Mexico's share grew to 70 or 80 percent by the end of the colonial period. Mexico's share over 250 years was 61.5 percent

The economics of mining evolved more favorably in Mexico than Peru. The growth was less spectacular and more volatile in the sixteenth century, but the contraction was less severe in the seventeenth century and the recovery more robust in the eighteenth century. After peaking in the early seventeenth century Mexican production fluctuated for several decades until it began to climb again. By the early eighteenth century it had surpassed its highs of the previous century, and after some mid-century adjustments it moved ever higher into the nineteenth century. At the end of the colonial period production was three to four times higher than in 1600 and two to three times higher than in 1700. Mexico surpassed Peru in the second half of the seventeenth century, and when the rebellions broke out around 1810 Mexican output was two and one-half times higher than Peruvian output after Peru's industry had undergone its late colonial recovery.

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[24] Fisher, *Silver Mines and Silver Miners in Colonial Peru, 1776-1824* (Liverpool, Eng: University of Liverpool, 1977; #7 in Monograph Series, Center for Latin American Studies), 98.

Mexico's silver industry proved itself to be highly durable. One reason for this was that Mexico benefited from better-quality ores. In Mexico the chloride ores containing silver were called *colorados* (iron-colored) and the sulphide ores were called *negrillos* (black-colored) The former were richer and easier to process than the latter, but the latter was in greater abundance in the mining regions. On the whole over the long colonial era Mexican ores yielded more silver per ton than Peruvian ores. For each hundredweight of ore Mexican miners may have gained an ounce or more over Peruvian miners. The advantage simply gave Mexican miners a higher return on capital. In addition beginning in the late sixteenth century Mexican miners paid lower bullion taxes – the *diezmo* instead of the *quinto* with some exceptions - than Peruvian miners, and while they too were saddled with high mercury prices, they received higher grades of mercury from Spain. All of these factors combined to reduce operating expenses and to attract capital from the colony's well-to-do merchants for new ventures as well restorations and rehabilitations of existing operations. It is hard to envision the level of performance in colonial Mexican mining without merchant capital. This did not mean that Mexican miners enjoyed unlimited success. What it does mean is that silver never lost its luster for Mexican investors even as the industry had to struggle through its own hard times.

For a few decades in the sixteenth century Mexico like Peru had a single, dominant camp in Zacatecas. Output in Zacatecas never came close to Potosí's, but it was large enough to influence the Mexican curve for almost a century. Prior to the eighteenth century Zacatecas could account for up to half of all the silver registered in Mexico. Other camps - Guanajuato, Pachuca, Taxco – opened and steadily added to the colony's total output. In the first half of the eighteenth century Guanajuato passed Zacatecas as the leader. Later in the century Zacatecas fell to third behind Guanajuato and San Luis Potosí. Unlike Peru, where Potosí even in its twilight remained the largest producer, Mexico's silver wealth was spread among a half-dozen camps. Despite changes in rankings as one camp supplanted another business of mining kept pushing the production curve higher and higher until the end of the colonial period. No Mexican camp would ever rival Potosí, but Mexican mining never was so heavily dependent on a single camp.

Mexico's growth over the two and a half centuries amounted to about 1 percent a year (R^2=74 percent). This would allow output to double every 70 years. Mining was much more volatile in the short term than this rate suggests. Sustained downturns were confined to the second quarter of the seventeenth century and of the eighteenth century. Not surprisingly, in contrast to Peru, the long-run trend tilted up, not down. There were some periods - the second half of each century - when growth exceeded 2 percent a year. And for periods comprising one or two decades rates could be 3 to 5 percent.[25] Some reports written for the industry or the Crown painted a bleak future for Mexican mining, and to be sure entrepreneurs confronted a wide array of daunting financial and technological problems. The resiliency of the Mexican silver industry cannot be ignored. With better technology, more capital, different work rules or royal policies the industry might have enjoyed greater success than it did. Still under the circumstances and in comparison with Peru it regularly overcame obstacles that some thought would doom the industry.

With more camps in play the dynamics of the Mexican mining industry over the very long haul is a more complex phenomenon. Using data assembled from the royal accounts of *cajas reales* the development of the various camps can be viewed in some detail. Mexico had more than a dozen *cajas* with silver registration between 1559 and 1810[26]. Some *cajas* served minor camps (Veracruz, for example, in the eighteenth century) and can be ignored for the purpose of this essay.[27] The major camps were in order of registered silver (with years in parenthesis): Zacatecas (263) 22 percent, Guanajuato (152) 18 percent, Mexico City (242) 15 percent, Durango (215) 13 percent, San Luis Potosí (183) 9 percent and Guadalajara (249) at 8 percent. Combined they

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[25] See Garner "Long-Term Silver Mining Trends in Spanish America," *American Historical Review*, 93:4 (1988), 903-907, 911-914, for a more comprehensive discussion of growth rates.

[26] The terminal years differ for the various *cajas*, and I have chosen to make 1810 uniform for all.

[27] Data series for individual camps drawn from several sources: the royal accounts published by Tepaske, Klein *et al*. in La *Real Hacienda de Nueva España,* and *Ingresos y egresos de la Real Hacienda de Nueva España* as well as Tepaske's recent revisions of earlier published *caja* data. The Mexican *caja* accounts have their own technical problems. The conversion from receipts of silver taxes to total silver-in-*pesos* values require several different equations, and they may been consulted in the Introductions of the aforementioned publications. The silver-tax receipts that appear in the individual *caja* accounts are not perfect. By Tepaske's own estimate because of variations in bookkeeping practices the conversions may understate the actual silver value by 10 to 15 percent. In the case of Zacatecas where I have recorded not the silver-tax receipts but the silver-mark values, I have found discrepancies in the range suggested by

accounted for about 85 percent of Mexico's colonial registrations. In this analysis Mexico City will figure less prominently than the other *cajas* because as the central treasury its silver-tax receipts were colony-wide rather than specifically drawn from a *caja* serving a mining district. There were a few mining camps within the immediate jurisdiction of the central treasury that would use the Mexico City *caja* as their treasury branch. In addition merchant capitalists with colony-wide mining interests might prefer to settle accounts for which they acted as *aviadores* or *fiadores* in the capital where their businesses were headquartered than in the *caja* of the mining district. As more branches were opened in mining districts, the direct role of the central treasury in the collection of taxes and payments diminished. A few account entries noted the origin of the silver, but most simply referred to payments of the *diezmos* without noting the origin.[28]

TePaske. I repeat here an earlier observation that my interest is analyzing trends, and the figures for that need not be perfect. TePaske revised dataset available at www.historydatadesk.com.

[28] The dataset on which I have based the analysis of individual *cajas* was compiled from TePaske and Klein's publication as well as TePaske's recent revisions to these published data.

FIGURE 17
Mexican Silver Production and Colonial Trend

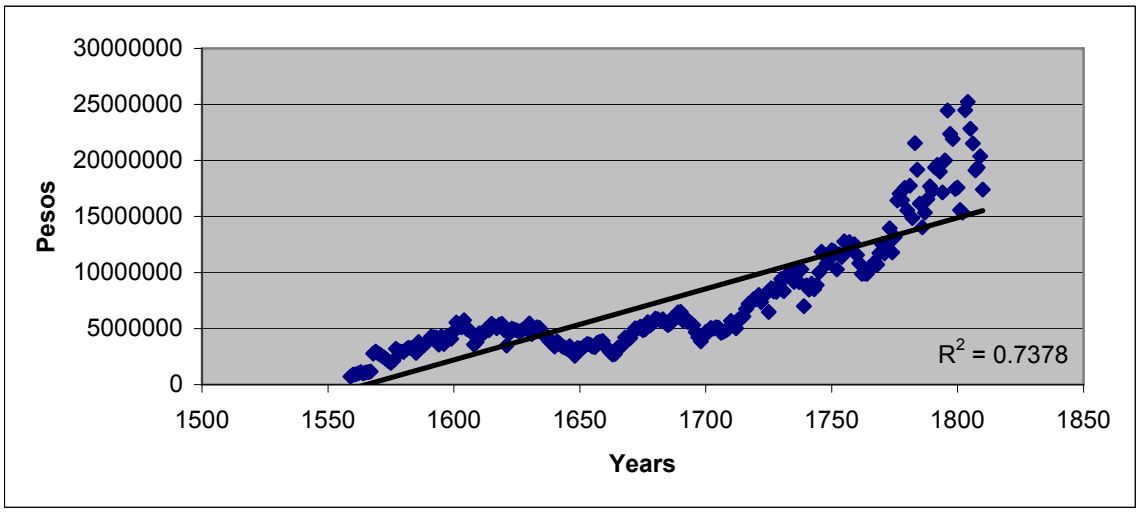


FIGURE 18
Mexican Silver Production and Colonial Trend
(Log Scale)

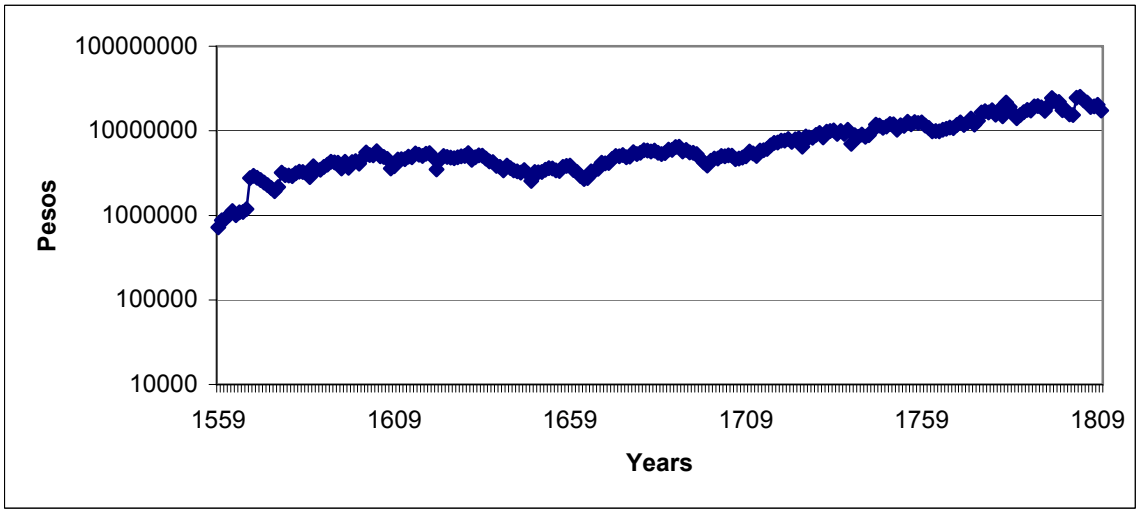
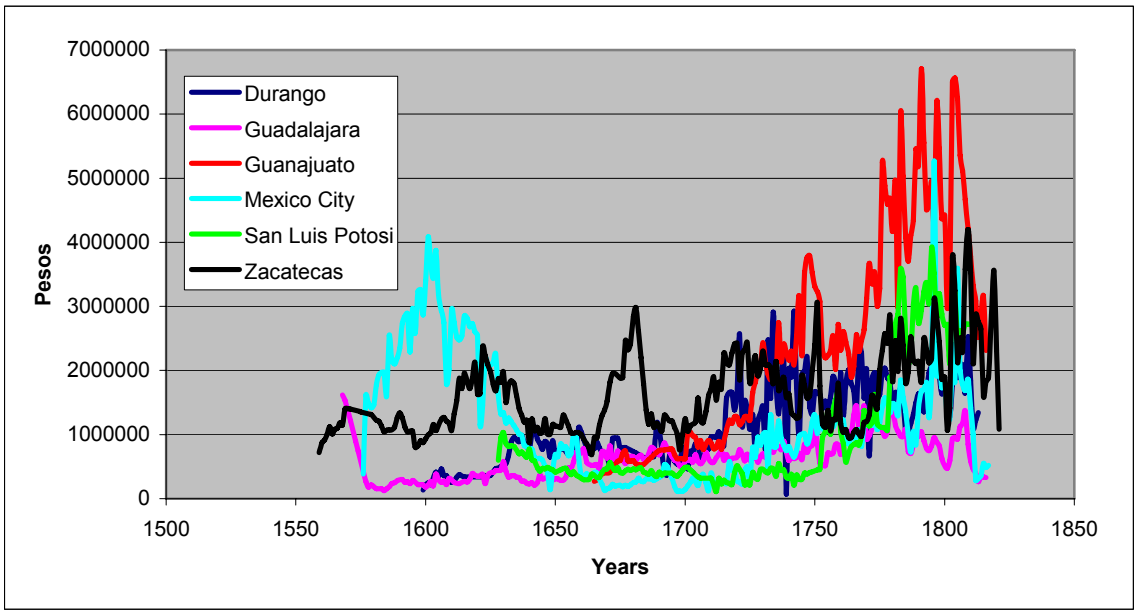


FIGURE 19
Silver Production in Major Mining Districts by Caja



The mining districts with the earliest treasury branches were Zacatecas, Guadalajara and Durango. San Luis Potosí was added in the first half of the seventeenth century and Guanajuato in the second half. Zacatecas will remain a ranking producer although it will slide in the rankings, and Guadalajara will not in part because other *cajas* were carved out of its region. Zacatecas registered 1.6 million *pesos* on average per year over 252 years whereas Guadalajara registered an average 0.6 million over 243 years. Durango's average fell between the two at 1.1 million *pesos* over 212 years. Both Zacatecas and Durango enjoyed higher output of silver at the end of the colonial period than at the start, but Guadalajara was about the same. Let me note, simply for the record, that Mexico City's silver registrations reached 4 million *pesos* around 1600, plummeted to 100,000 *pesos* around 1700 and then skyrocketed again to nearly 4 million around 1800. The roller-coaster shape of its silver curve was not dependent on treasury operations than mining conditions. Its average over 235 years was 1.2 million *pesos*.[29]

The addition of San Luis Potosí and Guanajuato in the middle decades of the seventeenth century was an indication of the growing importance of mining in the central

[29] Mexico City's *caja* did not reveal any silver-tax receipts until the fourth quarter of the sixteenth century.

zone between Zacatecas and Mexico City. San Luis Potosí more or less matched Durango's output for several decades before entering a long period of only moderate silver registrations. Major strikes in the middle of the eighteenth century pushed its registrations to the highest levels ever, and for several decades it ranked second behind Guanajuato and ahead of Zacatecas. Its average of under 1 million *pesos* per year reflected the effect of a century of annual registration often well below 500,000 *pesos*. In contrast was Guanajuato, the last of the major *cajas* to be established and the only *caja* (outside of Mexico City) to challenge and then to surpass Zacatecas in total registrations seven decades later. From the early eighteenth century to the end of the colonial period Guanajuato accounted for a quarter to a third of Mexico's output. Its average over 146 years was 4.2 million *pesos* per year. Zacatecas only broke through 3 million *pesos* per year and approached 4 million at the end of the colonial era, whereas Guanajuato flipped back and forth between 4 and 7 million *pesos* annually for most of the years between 1775 and 1810. Guanajuato came close to matching Potosí's performance during some of its best years. Although Guanajuato led the way during Mexico's eighteenth-century mining surge, all the mining districts participated (including Mexico City). After more than 250 years of mining silver ore Mexico reached and exceeded 25 million *pesos* per year in the first decade of the nineteenth century. This figure was more than 2.5 times greater than Peru's best years.

Recall that Peruvian mining, in particular Potosí, depended on draft labor. For the most Mexican mining functioned with resorting to *mita's* equivalent, *repartimiento*. In the early years Mexican miners used forced labor (*repartimiento*) because workers were scarce in the areas where mines were opened. Even though *repartimiento* survived until the end of the colonial period, miners turned to other forms to secure permanent laborers. Eventually the payment of wages (sometimes combined with *partidos* that allowed workers to keep and sell a share of ore that they extracted) proved to be the most efficient way to recruit and retain workers. Several scholars have pointed out that the shift to wages away from forced labor (including debt peonage) placed Mexican mining on a more solid financial footing. Even though mining wages were in part set by royal decree and the negotiations over wages probably favored the employer over the employee, the fact that owners had to hire workers meant that they had to account for the "real" costs

(despite the employees' disadvantages) of extracting, transporting or refining the ores and could not so easily fudge on those costs through subsidies such as represented by lower-paid workers under *repartimiento*. More accurate cost accounting whether relating to wages or other variables made it harder for the many marginal operations to stay in business. This may help to account for why investing in mining never acquired the stigma in Mexico that it did in Peru.[30]

In any comparative analysis of colonial silver mining in Mexico and Peru, one will eventually come face to face with an obvious and significant difference – the role of mercantile capital. The role of the merchant was not lost on earlier generations of scholars, but David Brading in *Miners and Merchants in Bourbon Mexico, 1763-1810* (1971) explicitly directed attention to the linkage between the two at-times-antagonistic economic classes. From the earliest decades the international merchants who controlled the lucrative overseas trade of exchanging bullion for merchandise became the colony's brokers and bankers. Of all the colonial business groups no group was better equipped in terms of wealth and experience with the interplay between risk and opportunity. International trade was filled trade-offs of this kind. Knowing something about risk-taking did not immunize the investors from losses, but it did make them willing investors in mining ventures even though some failed. The reason was simple enough: when conditions were favorable, results could be huge. Under the law merchants were not permitted to own mines, but they could own refineries and provide credit, supplies and other services. A normal arrangement was for a miner to work out an arrangement with a mercantile house, which would advance the capital needed to operate the mine, pay the workers, purchase the mercury and settle the taxes in exchange for the bullion at a specified price (*reales* per ounce). The aim of the merchant was to assume control of the bullion, which was crucial to his international business, and to do this the merchant was willing to underwrite the operation of the mines, to pay the wages, to purchase the mercury and to settle the taxes with the hope that the totals costs would not exceed the total proceeds. And like all such transactions the miner and the merchant might make a few *reales* per ounce or silver, and they might loss a few *reales*. There were several

[30] Bakewell, "Mining in Colonial Spanish America," in *Cambridge History of Latin America, The Colonial Period*, 2:126-130; Garner "Long-Term Silver Mining Trends in Spanish America," *American Historical*

variations to this basic model. Some merchants actually became refiners, thus separating the business of mining from refining. Called *restacadores*, they acquired ores from different miners, purchased (and accounted for) the mercury necessary to process the ores, paid the taxes, etc. without assuming a direct role in the mining of the ore. In still other cases merchants simply provided advances or credits for supplies that the miner would pay off with his silver. In short without merchant capital in one form or another, miners would have had to raise it on their own. To try to prevent the accumulation of silver in the hands of the mercantile houses, the crown made it legal to tax silver owned by merchants at 20 percent instead of the 10 percent that miners paid. The higher tax may have been assessed and collected in the earliest decades by over time it became anachronistic. Merchants could simply settle accounts with the *caja real* by claiming to be a proxy for the miners-owners, even though the bullion would eventually end up in the vaults of the merchants. The matter of mine ownership was even more difficult to prevent. As the miners' creditors merchants could claim a right to the property of miners who were in arrears or had gone bankrupt. The silver account and the accompanying mercury accounts maintained by the *cajas reales* are filled with names of *aviadores, fiadores* and other retail and wholesale merchants with stakes in mines and refineries. As Brading's study underscores in considerable detail, their presence was necessary and ubiquitous.[31]

The merchant-miner entrepreneur was not absent in Peru. Perhaps Spanish-America's richest miner, Antonio López de Quiroga, who seventeenth-century fortune was put at tens of millions of *pesos*, made his money in Potosí and related mines.[32] The difference between Mexico and Peru on the matter of merchant involvement was scale. As Peruvian mining continued to slide merchants, whose own wealth had been adversely affected by the collapse at Potosí, became bystanders. The risk-opportunity equation was slanted far too much toward risk. In Mexico, the ups and downs that afflicted all camps, did not lead to a relentless contraction in part because Mexican mining had a favorable cost structure and a dispersed mining network. Merchants could weigh the risk and

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Review, 93:4 (1988), 923-929.

[31] Brading's *Miners and Merchants in Bourbon Mexico* remains the best overview of the role of merchants in Mexican mining in the late colonial period. For the story of one merchant-miner, see Couturier, *Silver King,* a biographical study of the Count of Regla.

opportunity and see that even after many decades mining in Mexico could be profitable. Indeed for many entrepreneurs from those who were basically miners to those with feet in both camps large fortunes continued to be made. No one has attempted (to my knowledge) to codify who made mining fortunes and how they were made, but based on a large sample of 800 miners in eighteenth-century Zacatecas, those who came from merchant families or had background in merchant activities assumed a prominent and visible role, perhaps to the exclusion of those who simply saw themselves as miners.[33]

Gold Mining

Gold, of course, was the metal of choice. In fact the settlers found far more silver than gold across the New World. Prior to the discovery of huge silver despots in the middle of the sixteenth century much of the mining exploration and activity focused on gold. A flurry of discoveries in the Caribbean yielded about 20 million silver *pesos* worth in the first half century, but by the middle of the sixteenth century Caribbean gold mining was finished.[34] John TePaske estimates total gold production at about 1.1 billion silver *pesos* for colonial Spanish and Portuguese America with better than half that from Brazil.[35] Among the Spanish colonies New Granada produced more than 200 million silver pesos, or about a fifth of the total. Nearly half of that came in the eighteenth century. Peru and Mexico, the two silver giants, produced about 140 million silver *pesos*, and about 75 million was mined in Chile, Ecuador and other places for another fifth of the total. Spanish colonial gold production was higher in the sixteenth century than the seventeenth century, when it seldom reached or exceeded 5 million silver *pesos* in a decade, and then it was higher in the eighteenth century than the sixteenth century. The best decade for Spanish gold production was the last decade of the eighteenth century when it came in at about 50 million silver *pesos*. Whereas silver mining was often located in the high

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[32] See Bakewell's life and times of López de Quiroga in *Silver and Entrepreneurship*.

[33] Richard Garner, "Silver Production and Entre-Preneurial Structure in 18th-Century Mexico," *Jahrbuch für Geschitchte von Staat, Wirtschaft und Gesellschaft Lateinamerikas*, 17 (1980), 157-185.

[34] Kendall Brown is preparing a manuscript on colonial Latin American mining, and in his provisional first chapter he discusses the evolution of Caribbean gold mining. "The Lure of Gold: Mining in Colonial Latin America," provided to me by the author.

[35] John TePaske, "New World Gold Production, 1492-1810," contains a series of charts and graphs concerning total gold production and gold production by colony. This information was contained in a paper presented to a seminar at Duke University, 7-8 April 2000, and to my knowledge has not yet been published.

altitudes (Potosí, i. e.) gold mining was generally carried out at lower altitudes. Most of the New World gold was extracted from shallow workings, although gold could appear with silver and other minerals in deeper lodes. By and large the alluvial gold deposits resulted from erosion of quartz veins where gold had formed through a process of intrusion: molten rock known as magma slamming into hard rock and creating a fissure, which were filled hydrothermal solution that when cooled became quartz and could contain gold. Gold could appear in combination with many different minerals including silver (The Comstock Bonanza, i. e.), but it also appeared frequently in a pure or native form. While some gold was extracted through lode mining in the New World, most of it was extracted through placer mining in lowlands and riverbeds. Spanish colonial gold mining may be characterized as a form of surface mining that entailed many miners working small plots. What placer miners (as they were called) found were flakes and nuggets of basically pure ore that needed little or no refining and once dug up or panned out was almost instantly valuable. Silver ore on the other being far less pure had almost no instantaneous value. Gold was often traded on the spot or near the spot where it was extracted. Unfortunately since determining gold pureness and fineness required facilities not available in the mining areas. Some of what was traded as gold nuggets or dust was no more than shiny stones or worthless dust. Again merchants assumed a crucial role in moving gold from the mining site to the royal mint and into the world market. Since gold was traded in such small quantities, it was much harder for government officials to monitor gold mining for purposes of taxation and regulation. Most scholars believe far more gold escaped public scrutiny than silver, which had to be refined with the result that it was turned into bars and ingots of some weight. Gold was simply easier to hide than silver. Of course some mined gold had to be refined, and that was easier to track.

With the discovery of gold in colonial Brazil in the late seventeenth century the New World became the major producer of the metal for the next 100 years. From 1690 to 1810 nearly a billion silver *pesos* worth of was mined in Spanish and Portuguese America with nearly 70 percent from Brazil. In kilograms this added approximately 1.5 million to the world gold stock. The New World's contribution (in kilograms) to world-wide gold production in the 1680s was only about 10 percent; it reached more than two-thirds of the world output in the 1640s and remained between 60 and 70 percent through the first

decade of the nineteenth century.[36] Although Spanish American gold mining was more robust in the second half of the eighteenth century than it had ever been, it paled in significance to Brazilian gold mining. Because the mining industry emerged late in Brazilian colonial history, it proved difficult for the royal government, which was far less developed than its Spanish counterpart, to exercise control over the Brazilian gold fields. In addition the gold fields were located in the interior province of Minas Gerais, and this simply exacerbated the problem of establishing offices and dispatching officials to monitor the mining industry. Few large, integrated companies emerged in the Brazilian mining fields, and merchants and traders tended the dominate the business of processing and shipping the ores, at times in contravention of colonial rules and regulations.

Mercury: The Other Mineral

The "other mineral" that had to be mined in support of silver mining was mercury, also known as quicksilver and in its ore form as cinnabar. The introduction and the expansion of amalgamation (combining mercury with silver ore to extract the silver mineral) is often discussed in terms of the declining ore grades. In brief if amalgamation, which had been practiced for centuries, had not been adapted for New World ores the silver-mining boom would have faded rather quickly. The preferred technique for treating silver ore both in Europe and among New World natives was smelting.[37] While small furnaces or smelters were built to be used almost literally in people's backyards throughout the colonial era, they proved to be uneconomical for the types of ores found in Spanish-America because certain elements that had to be added were in short supply and therefore expensive.[38] Since it seldom appeared in a "native or pure form" (more common to gold than silver), it showed up in combination with many other different minerals. Those combinations more or less determined how the ores should be processed to separate out the silver minerals. Smeltable ores were often referred to as high-grade ores, but fact

[36] These figures are derived from TePaske's paper, "New World Gold Production, 1492-1810", Tables 3-1 and 3-2, and Figure 3-15.

[37] Abbott, M.B. and A.P. Wolfe, "Intensive pre-Incan metallurgy recorded by lake sediments from the Bolivian Andes, *Science* 301(26 September 2003), 1893-1895. Abstract available at ScienceNews On-Line: http://www.sciencemag.org/cgi/content/abstract/301/5641/1893. See Tandeter, *Coercion and Market*, (90-92) for a discussion of *trapiches*, rudimentary, backyard refineries.

[38] Bakewell, "Mining in Colonial Spanish America," in *Cambridge History of Latin America, The Colonial Period*, 2:119, for reference to these small operations.

amalgamation proved to be adaptable to so many different types of silver ores, even those could be smelted. Amalgamation became the standard protocol until the end of the nineteenth century and the introduction of the cyanide process. Amalgamation was crucial for the development an industry that had to process mainly low- or medium-grade ores. Smelting did not disappear (Sombrerete in northern Mexico smelted its ore), but it assumed far less prominence. One consideration for miners and millers was the higher the grade the more mercury was required. There was a point at which the quantity of mercury needed (at monopoly-determined prices) might prove more expensive than smelting costs. On the Comstock Lode in late nineteenth-century Nevada the ores were rich in gold and silver, and all of it was amalgamated because despite the need for large quantities of mercury the price of mercury in combination with improved technologies was not a handicap.[39] In the major Spanish-American silver mining camps smelting declined but never totally disappeared. The silver-tax accounts usually distinguished between *plata de azogue* (silver from mercury) and *plata de fuego* (silver by smelting), and in a camp like Zacatecas where miners after 250 years had passed through several different ore strata within its underground treasure house with ore qualities from poor to rich only a few smelters survived with 10 to 15 percent of the ore being classified as *plata de fuego* in the late colonial decades.[40]

Silver (Ag) is an element – 47 on the Periodic Table – but it is seldom found in its elemental or native form. Rather it commonly occurs in combination with other metals such as gold, copper, lead, and zinc. Some 60 different minerals, especially among sulfides, oxides and halides, contain silver. It may be most profuse among the sulfides.[41] The technology available today permits mining companies to extract silver in small concentrations from dozens of minerals, but the technology in the early modern period restricted the ores that could exploited profitably. Occurring as it did in combination with other elements it only acquired value when it could be separated from them. A unit of ore from a silver mine could contain a small volume of silver and a large volume of other

[39] See www.historydatadesk.com for a study of Comstock mining.
[40] Richard Garner, *Economic Growth and Change in Bourbon Mexico* (Gainesville, FL: University Press of Florida, 1993), 134-135. During mercury shortages, registrations of *plata de fuego* could jump to 25 to 35 percent of the total.
[41] The Silver Institute at www.silverinstitute.org/facts/element.php. Other websites on metals and minerals provide information on how and where silver occurs in nature.

minerals that had little value to colonial miners (although modern miners can exploit them profitably). In colonial mining except when combined with gold silver had the highest value but not necessarily the largest presence of all the associated minerals. In a native or elemental form silver along with copper, lead and zinc belong to the subclass of metals known as the Gold Group because they share certain characteristics of bonding and crystallization. But, since they have seldom been found in their elemental state, they only become important relative to their combination with other minerals. Spanish American silver mining was developed through the exploitation of ores that belonged to mineral classes known as acanthite, argentite, galena, sphalerite, proustite, pyrargyrite, chalcopyrite and pyrite. Others could be added to the list, but those listed represent the most common New World silver-bearing ores. The last two – chalcopyrite ($CuFeS_2$) and pyrite (FeS_2) – are copper and iron sulphides and are listed not because they contained much silver but because miners often confused them with galena, which could be rich in silver. (They are also known as "fool's gold" because of their yellow color.) Proustite (Ag_3AsS_3) and pyrargyrite (Ag_3SbS_3) were antimonies, that is, silver sulfides combined with arsenic and found in the same veins with other richer-yielding silver ores. Sphalerite (ZnS) was a zinc iron sulphide that could bear silver. The most valuable silver ores in colonial Mexico and Peru were acanthite, argentite and galena. Galena (PbS), a lead-sulfide ore, was the main source of the mineral lead, but it could also have silver concentrates up to 1 percent. In some classifications acanthite and argentite are listed under the galena group, and in others they are listed along with galena under the sulfide group. Acanthite and argentite carry the same symbol - Ag_2S – and although they have the same chemistry they have a different structure. At temperatures below 180 degrees Celsius argentite transforms into acanthite. For gemologists this change may be important because it affects the shape of the crystals, but for miners it may have little of no significance. It appears that argentite was discussed in Georgius Agricola's *De Re Metallica*, a manual on mining published in the sixteenth century that circulated in Spanish American mining camps, but argentite was not widely used to describe silver ore until the nineteenth century.[42] Both galena and acanthite/argentite have a metallic luster

[42] Georgius Agricola, *De Re Metallica* [translated from the first Latin edition,1556, by Herbert Clark Hoover and Lou Henry Hoover] (new York: Dover Publications, 1950). Also several web sites have

and are gray in color, although galena can be more bluish and acanthite/argentite more blackish. Ores that technically belong to the acanthite/argentite class may be richer in silver than galena. The very large, deep veins of silver ore at Zacatecas (Mexico) and the very, large underground chambers of silver ore at Comstock (Nevada) may have been acanthite/argentite rather than galena. What colonial miners understood was that some silver ores – usually high in lead - could be smelted and some could not. Since galena was a lead sulfide, it acted as a flux to separate the silver from other impurities. The lead could then be dissolved with the result, purified silver. In the absence of lead or sufficient lead it or some other flux had to be added often at considerable expense. Acanthite/argentite ores lacked lead, and although they could be rich in silver they were expensive to smelt. The fact is Spanish-American silver mines could contain different type of silver ores, some of which were smeltable and others not. Using mercury in effect to cleanse silver of the other elements and impurities found in ores proved to be more efficient and effective than cooking the ore with fluxes like lead.

Like other ores mercury was mined and then refined. At normal temperatures it has the attributes of a liquid, or perhaps more accurately a gel, that can be placed in a container and shipped to a refinery where it is combined with the ore. Mercury mining in Spain and in Spanish America has been the subject of numerous studies, but my interest with respect to this essay is not how it was mined but how much of it was mined.[43] The question at hand is obvious – given the dependence on mercury, what is the relationship

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summaries of Agricola's life and work. See www.ucmp.berkeley.edu/history/agricola.html. Argentite also appeared under names glaserz, silver-glance and vitreous silver.

[43] Guillermo Lohmann Villena, *Las minas de Huancavelica en los siglos XVI y XVII* (Seville: Escuela de Estudios Hispano-Americanos, 1949); Kendall Brown, "The Spanish Imperial Mercury Trade and the American Mining Expansion under the Bourbon Monarchy," in Kenneth Andrien and Lyman Johnson, eds., *The Political Economy of Spanish America in the Age of Revolution, 1750-1850* (Albuquerque, NM: University of New Mexico Press, 1994, 137-167; Kendall Brown, "Worker's Health and Colonial Mercury Mining at Huancavelica, Peru," *The Americas*, 57:4 (2001), 467-496; Rafael Dobado González, "Labor Force and Mercury Production in Almadén, Spain, 1759-1808," in Alan Craig and Robert West, eds., *In Quest of Mineral Wealth: Aboriginal and Colonial Mining and Metallurgy in Spanish America* (Baton Rouge, LA: Geoscience Publications, Department of Geography and Anthropology, Louisana State University, 1994), 213-231; Rafael Dobado González, "Las Minas de Almadén, el monopolio del azogue y la producción de plata en Nueva España en el siglo XVIII", in Sánchez, Mira y Dobado, eds., *La savia del Imperio. Tres estudios de economía colonial* (Salmanca, Spain: Ediciones Universidad de Salamanca, 1997,) 401-495; Rafael Dobado Gonzalez, "El monopolio estatal del mercurio en Nueva Espana durante el siglo XVIII," *Hispanic American Historical Review* 82:1 (2002), 685-718; and Arthur Whitaker, *The Huancavelica Mercury Mine: A Contribution to the History of the Bourbon Renaissance in the Spanish Empire* (Cambridge, MA: Harvard University Press, 1941).

between mercury supplies (and indirectly mercury prices) on silver mining? It turns out that even though much is known about mercury production, sale and distribution in the New World, measuring the relationship between supplies of mercury and registrations of silver is more complicated than first appears.

The Spanish mining camps had three sources of mercury: Almadén in northern Spain (mercury mined since Roman times); Huancavelica in central Peru (cinnabar used by indigenous people for cosmetics); and Idria in Serbia (part of the Hapsburg Empire).[44] A fourth source was China, but it never became a major supplier. Periodically mercury from Almadén was shipped to Peru, and mercury from Huancavelica was shipped to Mexico. By and large Huancavelica supplied Peruvian mines and Almadén supplied Mexican mines. Unlike the mining of silver, basically a private undertaking (with the approval of the Crown), the production and distribution of mercury shortly after the introduction of the so-called patio system were put under the control of a royal monopoly. From time to time the Crown assumed direct management of the mines at Almadén and Huancavelica, but it preferred to lease the operations to contractors who produced the mercury that the government then distributed at mandated prices to the mining camps. Those who have studied these mercury operations have uncovered many examples of incompetence, inefficiency and corruption, and given the pervasiveness of these conditions one may be permitted to express the modest surprise that the system functioned well enough over the long term to allow the production of billions of ounces of silver. One can certainly make a case that the monopoly posed many problems to the Crown and to the silver industry, and yet one cannot substitute a discussion of what might have been for an analysis of what was. Although the mercury monopoly underwent many changes, some fundamental and some cosmetic, it survived until the end of the colonial period. The silver business did not wither away because of the monopoly and by some measures expanded in spite of the monopoly.

With the mercury data currently published it is possible to estimate that at least 2.6 million *quintales* (1 *quintal*=100 pounds) or 130,000 tons of mercury were made

[44] In the eighteenth century during his *visita* to Mexico José de Gálvez urged the development of mercury mining in Mexico. At least one small mine was opened but it added nothing of any significance to the colonial mercury supply. Mexico depended Spanish mercury supplemented from time to time with Peruvian mercury.

available to Peruvian and Mexican mining camps for refining during the colonial period.[45] The number could be higher because some gaps exist in the datasets. Between 50 and 55 percent of the available mercury came from Europe and the remainder from Huancavelica. Shipment of mercury from Europe entailed greater risk and expense than shipments from Huancavelica to Peru's camps. With few exceptions mercury arrived with sufficient regularity at Veracruz to keep mining camps in business. Mercury was stored in a central warehouse and once or twice a year was allotted to the *reales cajas* in the mining camps on the basis on demonstrated past need. In Peru mercury was shipped directly to the *cajas* from Huancavelica. The system of allocation was far from perfect, and camps might find themselves with more or less mercury than they required. Shortages because of production disruptions or transportation bottlenecks have been fairly well documented. In most years, however, colonial mercury administrators could meet the demand. In the late eighteenth century when Mexican output surged the central warehouse reported surpluses after mercury allocations had been approved and implemented. And even in the worst shortages (1800-1802, for example) the supply of mercury never completely dried up. The government could control deliveries to the *cajas* and sales to the miners, refiners or their agents, but it could not control how the mercury was used once it left the *caja*. Mining entrepreneurs found ways to stretch mercury supplies and to adjust amalgamation protocols. Though prohibited (but not always enforced) private sales within and between camps tended to spread out supplies. Since merchant houses or their representatives advanced the cash necessary for the miners and refiners to purchase mercury, they controlled huge inventories within a camp and among

[45] These are my calculations based on archival data that I have collected plus printed and archival data assembled by other scholars. My appreciation to Rafael Doloso González for sharing his series on Almadén, some which has since been published, and to John TePaske for sharing his series on Peru. Printed sources with mercury series include Guillermo Lohmann Villena, *Las minas de Huancavelica en los siglos XVI y XVII* (Seville: Escuela de Estudios Hispano-Americanos, 1949), 452-475; Pierre and Huguette Chaunu, Séville et l'Atlantique. 8 vols. in 11 vols. Paris: Colin, 1955-1960, 7:2, (pp.) 1958-1971; Antonia Heredia Herrera, *La renta del azogue en Nueva España: 1709-1750* (Seville: Escuela de Estudios Hispano-Americanos, 1978); Brown, "The Spanish Imperial Mercury Trade," in Andrien and Johnson, eds., *The Political Economy of Spanish America*, 152-153; John Fisher, "Mining and the Peruvian Economy in the late Colonial Period," in Nils Jacobsen and Hans-Jürgen Puhle, eds., *The Economies of Mexico and Peru During the late Colonial Period, 1760-1810*. Berlin: Colloqium Verlag, 1986, 51; María Fuentes Bajo, "El azogue en las postrimerías del Perú colonial," *Revista de Indias*, 46:177 (1986), 80-81; Bakewell, *Silver Mining and Society*, 254; María Romero Sotelo*, Minería y guerra: La economía de Nueva España, 1810-1821* (Mexico: El Colegio de México, Universidad Nacional Autónoma de México, 1997), Appendix; and a

the camps. The role of the merchant in allocating the supply of mercury outside the *caja* has not been thoroughly studied but even so it should not be underestimated. Monopolies and regulations, as extensive as they were in New World mining, had loopholes that experienced operators and dealers could exploit at times to their advantage.[46]

Amalgamation with mercury had been known since ancient times but not widely used. The contribution of Bartolomé de Medina was to devise a procedure that made it possible to process an array of ores found in the New World through amalgamation. Metallurgists had only a modest understanding of the chemistry of ores and of the chemical interaction between silver and mercury. Miners and refiners might possess and consult manuals on metallurgy, known to circulate in the New World, but more than likely they gained their knowledge from experience and observation. Bakewell concluded that "Their knowledge was purely empirical. Rapidly there emerged from experience a series of accepted steps to be followed if ore of this or that appearance, or if mercury took on this or that colour during amalgamation. These practices, often effective, were the outcome of continual experimentation."[47] Specific information about amalgamation improvements could spread quickly through the mining regions. If, as Bakewell believed, the addition of magistral or copper sulphate to the mix of silver and mercury to improve amalgamation was first experimented with in Potosí in the 1580s, it was evident in Mexican mining by the early 1600s. Of course, Mexican miners may well have figured out on their own that magistral was a useful ingredient.[48] In general, though, few major improvements in refining ore through amalgamation with mercury and other minerals can be documented during the colonial period. Small changes may have been introduced on the local refinery level by the owners or their managers, and some of these changes may have found their way into other refineries and camps. By and large the process set forth by Medina of crushing the ore, incorporating mercury (and other ingredients), adding

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manuscript entitled "Relación del estado…," (1726) by the Marqués de Casa de Concha and housed in the Clements Library, University of Michigan, has production figures for Huancavelica in Peru.

[46] See Richard Garner, *Economic Growth and Change*, pp. for an analysis of late eighteenth-century mercury data.

[47] Bakewell, "Mining in Colonial Spanish America," in *Cambridge History of Latin America, The Colonial Period*, 2:117.

[48] Bakewell, "Mining in Colonial Spanish America," in *Cambridge History of Latin America, The Colonial Period*, 2:117. Bakewell makes the point that refiners may have observed that the natural presence of copper sulphates in their ores seemed to have a positive effect on the amalgamation process.

water, flattening and stirring the *torta* (in a patio that could be nearly 100 feet in diameter), assaying for fusion of silver and mercury, shoveling the amalgam after six to eight weeks into a vat, washing off residue (including mercury) and then cooking off remainder of the mercury in a hooded furnace. What remained was silver. The process was greatly sped up in the American West during Nevada's Comstock boom by further pulverizing the ore and by incorporating the ore, mercury and other ingredients in heated metal pans with agitators. These and other improvements reduced amalgamation from six to eight weeks down to several days.[49] But it would appear that while amalgamation represented a major turning point in Spanish-American mining, experimenting with alternative procedures and technologies had little appeal. Because of the cost and sometimes the scarcity of mercury refiners should have had a direct interest in trying to salvage as much mercury as possible to be used again.

A most knowledgeable "amateur" metallurgist in seventeenth-century Peru was the curate of the St. Bernard's Parish in Potosí, Alonso Barba. His book in translation was called *The First Book of Metals* and was first published in 1640. He took an interest in learning as much as he could (largely through observation and experimentation) in science of metals and in particular the reduction of ore through amalgamation. How widely his book was consulted is not known, but it was extensive enough that he published a second edition in 1674. With respect to the use and misuse of mercury he declared unequivocally that through procedural errors "for so many years the best refiners in these Kingdoms have wasted at the least so much quicksilver, as they have gotten plate [silver]…." He observed that if too much salt and magistral are added to the water containing mercury and silver the water becomes too thick and the mercury instead of sinking to the bottom will float on top and when the water is released will simply float away with the water. More care was needed in how the mixture was composed and how the drainage was accomplished. In the final stage when the mercury and silver had be separated Barba urged the construction of a furnace to heat a iron vessel that contained the pellets (also called pineapples) of silver and mercury over which was built a hood made of hammered copper or iron or very good earthenware to catch and condense the vaporized mercury that would then be funneled through a pipe into a bucket of cold water

[49] Garner, "Bonanzas, A Comstock Mining History," forthcoming.

that reconstituted mercury to a solid form to be used again.[50] The extent to which refiners were willing to invest in these small furnaces and other techniques recommended by Barba is difficult to determine, but evidence they did try to salvage some mercury is not totally absent, even from the earliest decades. Privately-held mercury ended up being sold to refiners with low inventories, especially in periods of shortages, and the fact that the Crown worried about these unreported inventories and sales of mercury would be an indication that the trade existed.[51] Moreover, given what is known nowadays about ratios of silver to mercury in order to complete the amalgamation of typical New World ores, far more mercury would have been needed than the total volume cited earlier. That difference was made up, no doubt, through inventories of used and reserved mercury.

The survival of a set of accounts from a Mexican refinery allows a glimpse at how the refiner accounted for mercury. The refinery had 12 *arrastres* or stamps for crushing 193 loads of ore weighing 58,000 pounds (580 hundredweights) and separated into 29 *montones* of ore each weighing about 2,000 pounds or 1 ton. (It is doubtful that any of the reported weights were precise.) From this volume of ore the refiner averaged about three ounces of silver per hundredweight, 60 ounces per *monton* for a total of 1,740 ounces. From the refinery records it is clear that the refinery added salt (more than 65 *fanegas* or 100 bushels) and copper pyrites (more than 900 pounds) to the mounds of silver and mercury. It also paid for charcoal to heat and separate the amalgam (in line with Barba's recommendations) And with respect to mercury the records indicated that to refine ore weighing 58,000 pounds only 174 pounds of mercury were lost, that 0.3 pounds of mercury for each pound of ore. How much mercury did the refinery have to incorporate with the 58,000 pounds to ore to complete the amalgamation? That figure is elusive, at least in these accounts. In late nineteenth-century Nevada mining (on the very rich Comstock Lode) each pound of ore required about one-tenth of a pound of mercury, although ratios could vary widely. The "richer" the ore was in molecules of gold and silver, the more molecules of mercury were needed to attach to the gold and silver molecules. Some of the most efficient mills processing some of the richest ores had to replace two to three pounds per hundredweight of ore in contrast to the 0.3 pounds in the

[50] Alvaro Alonso Barba, *The First Book of Metals*…. 2nd edition (London: S. Mearne, 1674) 73-74, 76-78, 86-89.

Zacatecan refinery.[52] Barba noted that given the existing technology in the seventeenth century richer ores combined with mercury tended to be "spongier" and therefore harder to squeeze through "wet cloth" to create the pineapples of silver and mercury than lesser ores.[53] (That would explain in part why some ore types continued to be smelted rather than amalgamated.) The losses of mercury were far greater at the beginning of the mining period than at the end, and the evidence suggests that because of the cost of mercury salvaging it became an imperative as mines began to extract ores that yielded less than the original ores. If the Comstock average was even close to the average of Spanish colonial refineries, then the aforementioned Zacatecan mill needed about 6,000 pounds of mercury for 60,000 pounds of ore with a loss of about 3 percent.

A crucial component has been ignored thus far in this discussion of the role of mercury in mining. As a royal monopoly the Crown set the price of mercury, and that price while varying over time represented a substantial portion of the total refining costs. In the Zacatecan mill above the lost mercury was one-quarter of the total costs. (An interesting accounting question is how should refiners who salvaged mercury amortized that cost over time.) In fact, though, the price of the mercury was higher than the prevailing price because a shortage of Almadén mercury necessitated the use of more costly Idria mercury. If Almadén mercury had been available the cost would have dropped to about 19 percent of the total. In the first decade or so after the introduction of Medina's system and before the creation of the monopoly mercury had to be purchased from primarily European mining companies or through merchant who represented those companies. Its importance was quickly and readily acknowledged in ever-rising prices. A *quintal* (hundredweight) could sell for several hundred *pesos* plus the purchaser had to pay the cost of shipping the mineral from Europe to the mining camps. Indeed because of the growing dependence of New World mining on mercury cartels of producers and dealers sprang up to try to monopolize the trade in and control the price of mercury. The Crown clearly foresaw the risks in an unregulated mercury markets as well as the opportunities in a state monopoly. The price of mercury remained high and volatile for decades after the monopoly was organized, and eventually as the cost of mining and

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[51] Bakewell, *Silver Mining and Society*, 173.
[52] "Bonanzas and Borrascas" at www.historydatadesk.com.

processing began to weigh on the industry the government came under pressure to moderate their exorbitant pricing both for European and Peruvian mercury. In part the prices reflected the difficulties in organizing and managing a monopoly and in part the greed of the Crown. The leveling off of production in the first quarter of the seventeenth century followed by a downturn especially in Peru persuaded the Crown to reduce prices. Almadén mercury fell from 120 *pesos* (and higher) in the late sixteenth century to 82 *pesos* per *quintal* in the early seventeenth century where it remained for a century and a half. Peruvian mercury was set at about 104 *pesos* per *quintal* in the late sixteenth century and dropped to 97 *pesos* per *quintal* in the middle of the seventeenth century with no further revision until the end of the eighteenth century.[54] Prices were revised downward again in the eighteenth century: a *quintal* of Almadén mercury was reduced to 41 *pesos* and a *quintal* of Huancavelica mercury was reduced in a series of steps to 79, 71 and finally 50 *pesos*. Mercury from Idria (also called Idrija and referred to in treasury records as Austrian mercury) was more expensive, settling at about 62 *pesos* per *quintal* in the eighteenth century. Miners, refiners and merchants complained frequently to the Crown about the heavy burden that the monopoly prices imposed on the industry. It is not the role of this essay to examine mercury-mining costs in relation to mercury-monopoly prices, but over the long run it appears that the Crown intended to use the monopoly to make money. Therefore, prices could be set well above costs to insure those profits. At times the mercury mines lost money and the Crown earned no profits. In the second half of the eighteenth century Almadén's costs were said to average about 30 *pesos* per *quintal* so that at 82 *pesos* the profit margin could be two-thirds of the costs and at 42 *pesos* per *quintal* it could be two-fifths of the costs Every reduction in the price of mercury was welcome because it could affect the types of ores that could be profitably reduced and could affect the investment in extracting and reducing such ores. Occasionally to stimulate the rehabilitation of potentially productive mines the Crown sold mercury at cost or about 30 *pesos* per q*uintal* for a specified period of time.[55] To the

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[53] Barba, *The First Book of Metals*, 79-80.
[54] Bakewell, "Mining in Colonial Spanish America," in *Cambridge History of Latin America, The Colonial Period*, 2:122.
[55] For examples of mercury concessions see Garner, *Economic Growth and Change*, 124-127.

end of the colonial period the mercury monopoly was to guarantee if possible income to help pay for its ever-mounting public outlays.

FIGURE 20
Annual Percentage Change in Mercury Supplies, 1558-1816

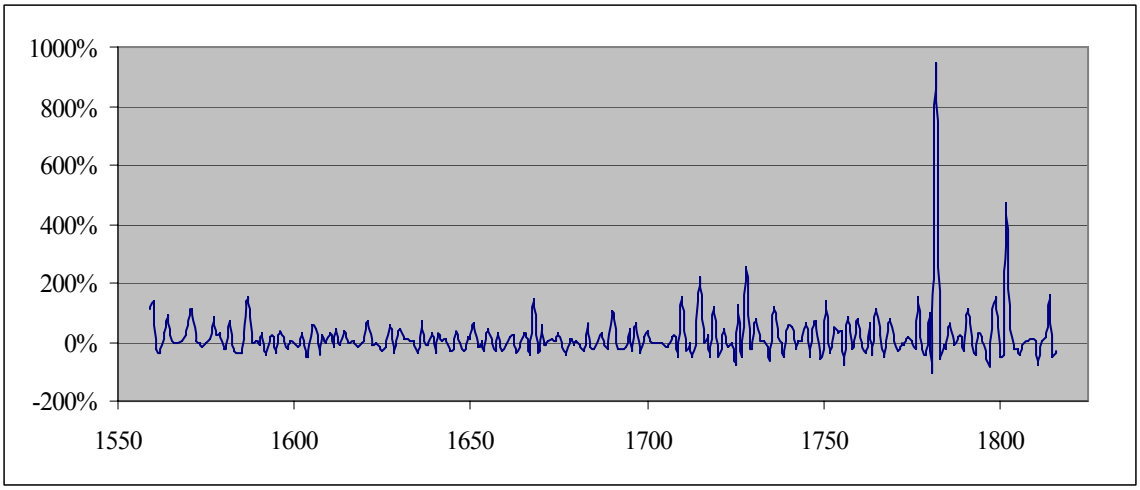


FIGURE 21
Colonial Mercury Supplies

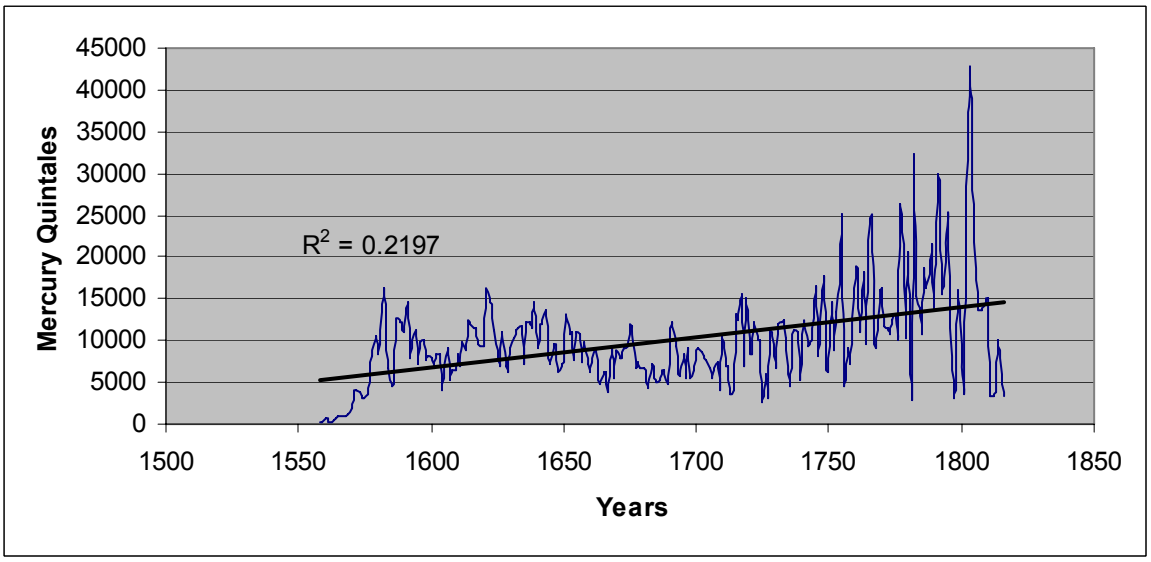
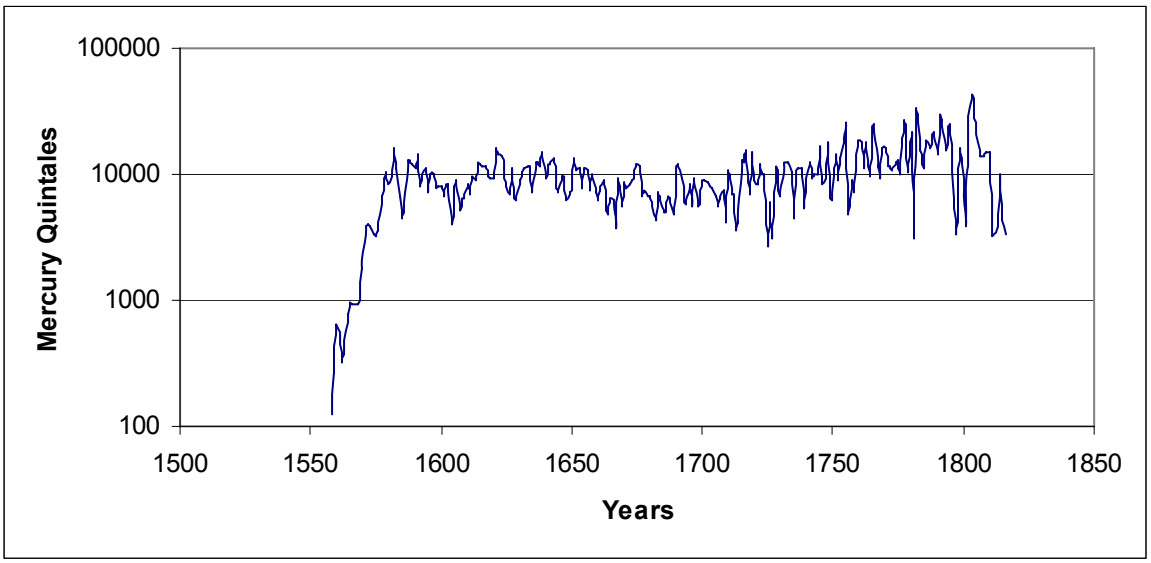


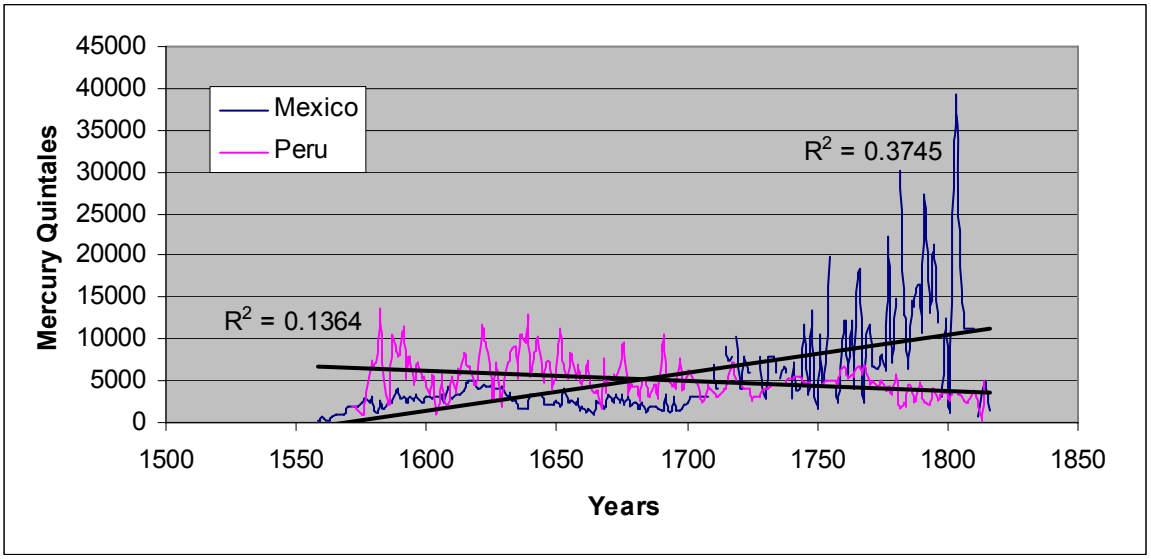
FIGURE 22
Colonial Mercury Supplies
(Logarithmic Scale)



The trends in mercury supplies can be observed in the preceding charts. These data represent the total supply available from production of mercury in Europe and Peru. Recall, though, that since several series exist for imports from Almadén and other European mines and for output of Huancavelica in Peru, single series for total colonial supply as well as total supplies in Mexico and Peru had to combine the existing but differing datasets. I computed averages based on different combinations of annual series, and then I calculated "an average" for the different averages. In many cases where the annual data points were consistent from series to series the average of average was predictable. Where variations occurred, the average of averages was less convincing and may either overstate or understate the actual volume. The aim was not to create a perfect dataset, but rather to create one that comes closest to reflecting the availability of mercury in the New World. First the total availability of European and Peruvian mercury fluctuated between 5,000 and 15,000 *quintales* with an average of 7,900 for 150 years and then beginning around 1700 it climbed to 25,000 in 1750 and to nearly 43,000 *quintales* in 1803 for an average of more than 12,000. For the entire period of 260 years the annual average supply of mercury was about 10,000 *quintales*. The trend line points upward, but according to the R^2 value of 22 percent the trend line, as calculated, does not

capture much of the data. The reason for this can be seen by closely observing the mercury-supply on a log scale. In the first 30 years, as the use of amalgamation spread, the supply of mercury rose by 100 fold. Over the next 100 years the trend followed a fairly notable downward slope. Finally in the last century the trend turned sharply upward. In short with changes in direction such as these an overall trend is difficult to ascertain. What the eye sees is a rise, a plateau and decline and a rise again until a falloff at the beginning of the independence period. Volatility was a factor in that mercury supplies could change significantly from year to year. A coefficient of variation of 58 percent lends credence to such a conclusion.

FIGURE 23
Trends in Mercury Supplies, Mexico and Peru



How did supplies trends in the two viceroyalties match up with the colonial trend? The foregoing chart of trends in Mexico and Peru helps to explain the colonial trend line. In Peru mainly because demand at Potosi mercury supplies topped 10,000 *quintales* annually in the last quarter of the sixteenth century but then settled back into a range of 5,000 to 10,000 *quintales* per year for the next century. In contrast during the same period Mexican mercury supplies seldom reached or exceeded 5,000 *quintales* per year. An obvious bifurcation in the two series occurred during the eighteenth century as yearly supplies in Peru stayed close to the 5,000-*quintal* level while in Mexico they reached as high as 40,000 to 45,000 *quintales*. Peru consumed about two-thirds of the total colonial

supply through the seventeenth century but only a third in the eighteenth century. Overall Mexico required about 53 percent of the total colonial supply. Not surprisingly given the patterns of the two mercury series Mexico's was more than twice as volatile as Peru's – 105 percent to 44 percent (as measured by the coefficient of variation). The Mexican series in the eighteenth century gives the appearance of considerable variation in year-to-year supplies, but in fact when tested the Mexican mercury-supply series has more volatility before 1700 than after 1700. When a comparison is made between mercury-supply variations in Mexico and Peru for the whole colonial period and for segments before and after 1700 the Mexican series are all more volatile (in percentage terms). Intuitively one might argue that this should not be surprising. Given the distances Mexico's mercury supplies may have been subject to more delays and interruptions than Peru's supplies. Both Almadén and Huancavelica suffered from production shutdowns and distribution bottlenecks that could have affected the supply of mercury. But the distances in the case of Almadén mercury – from the mining center in the north to the Spanish ports in the south, across the Atlantic Ocean and from the port of Veracruz on the east-central coast to the silver camps mainly in the north and west – could exceed 4,000 miles compared to 1,000 in Peru. The difference suggests (but does not demonstrate unqualifiably) that delays and mishaps were more likely to occur where the distances were greater. By the eighteenth century, however, despite the distance Spain managed to boost mercury shipments by as much as a factor of ten. Over time if distance played a role it became less and less a deterrent to supplying both Mexico and Peru with mercury. The greater variation in year-to-year figures in Mexican mercury supplied was matched a greater variation in the year-to-year changes in Mexico's silver series compare to Peru's silver series.

Was it possible that the relationship between mercury and silver was a two-way street: the supply affected the output of silver and the demand for mercury was affected by the state of mining and the level of production? It is much easier to analyze the supply side of the mercury-silver equation than the demand side. The supply can be determined from the volume of mercury arriving in Mexico from Spain and the output of Huancavelica in Peru plus any mercury imported from abroad. Demand, on the other hand, requires knowledge of how much miners and refiners estimated that they needed to

buy to process their ores. The latter figures could be assembled indirectly from accounts on mercury sales to individual miners, refiners or their agents kept by the individual *cajas* a laborious task. (Recall that the quantities sold by the *cajas* did not represent all the mercury to which miners and refiners had access.) Colonial records on how much of a year's supply remained undistributed may serve as a proxy for commenting on the relative strength or weakness in the demand for mercury. Kendall Brown has assembled a series of *quintales* of mercury distributed from the central warehouse (in Puebla) and *quintales* reserved. The total supply in any given year was the balance from the previous year plus new arrivals, and the new balance was the total minus any distribution. Brown's series covered the period form 1714 through 1800, and it showed that at the end of 1714 more than 2,700 *quintales* were on hand. At the end of the period (1800) the warehouse had more than 2,000 *quintales* in reserve. During the period the warehouse received over 723,000 *quintales* from Spain and other places and distributed more than 725,000 quintales. In other words Mexican miners and refiners consumed nearly all the mercury they received. But when the reserves are examined on an annual basis they reveal a more complex pattern. The mercury administration reported reserves in almost every year from 1714 to 1800. The average reserve was more nearly 7,400 *quintales* per year. In order to categorize the reserves I have arbitrarily created groupings based on small (0-4999), moderate (5,000 to 9,999) and large (10,000 and above). The small category contained 42 years or 48 percent, the moderate 21 or 24 percent and the large 24 or 28 percent. In only four of the 87 years a zero balance was reported, and five of the years a surplus exceeded 20,000 *quintales*. Since the mercury administration distributed on average slightly more than 8,300 *quintales* per year, the numbers thus reported suggest that real shortages were few and far between. About a third of the surpluses equaled or exceeded the average annual distribution. There were always questions about whether mercury was sent to the camps that needed it the most at a specific time, but on the whole Mexican miners and refiners had an ample supply of mercury in the eighteenth century.[56]

[56] The dataset on mercury distributed and reserved was assembled by Kendall Brown and published in "The Spanish Imperial Mercury Trade," in Andrien and Johnson, eds., *The Political Economy of Spanish America*, 145-146.

FIGURE 24
Frequency Distribution of Annual Reserves of Mercury Supplies (quintales)

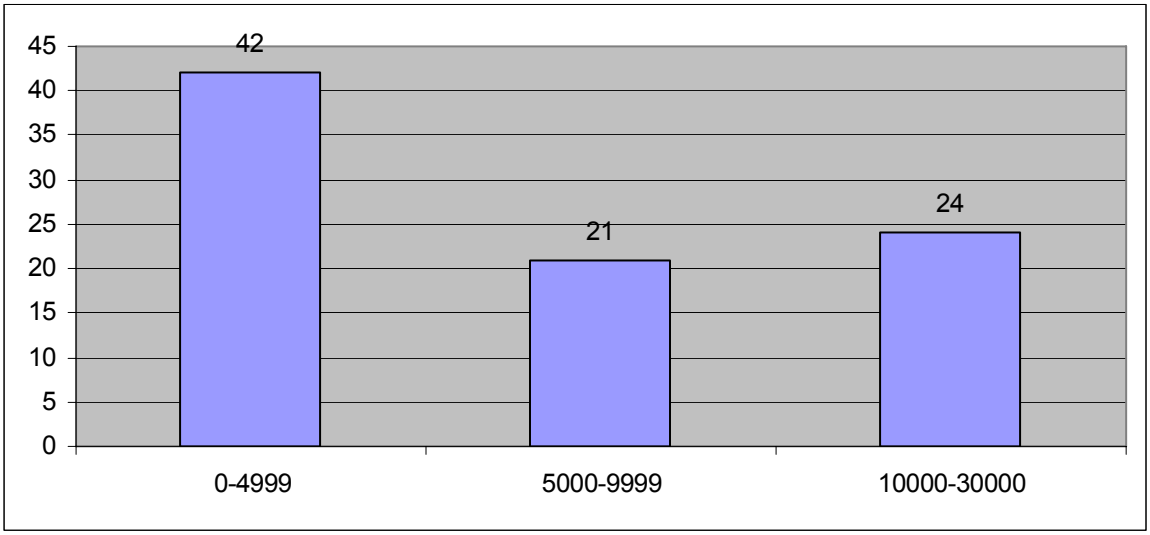


FIGURE 25
Production of Silver (in Marks) and Distribution of Mercury (in *Quintales*) with Trend Lines and R-Squared Values

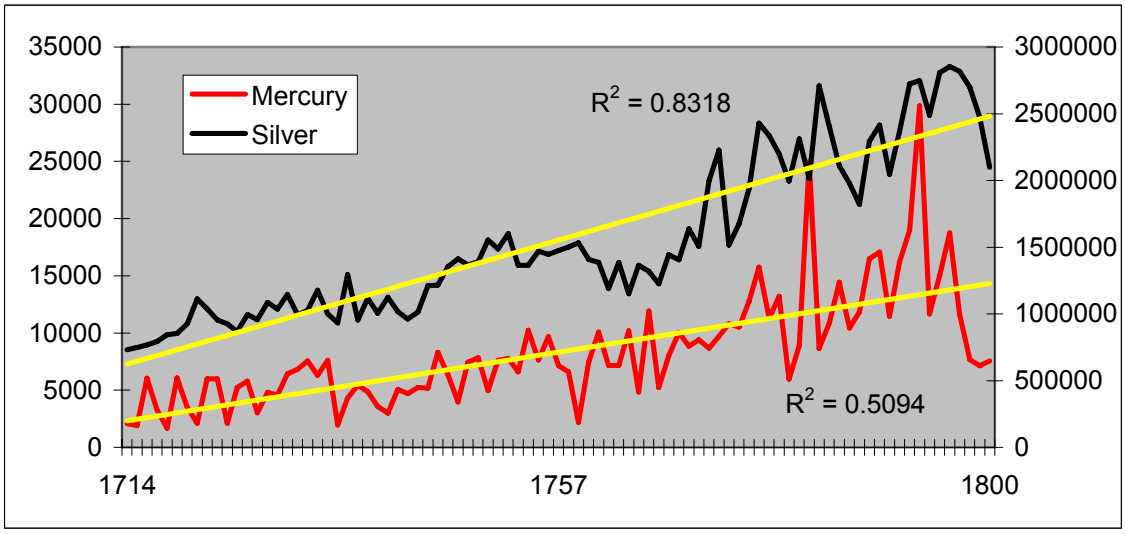
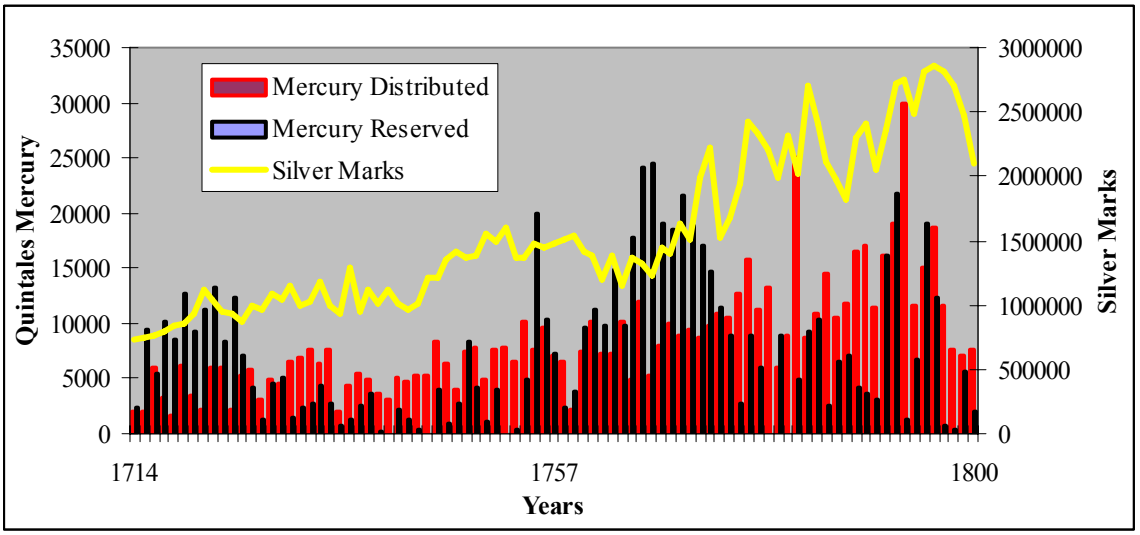


FIGURE 26
Mercury Distributed and Reserved, Mexico



When the mercury distributed and mercury reserved are plotted and then compared to silver marks a pattern worth commenting upon emerges. The most substantial surpluses were identified with two periods: the second half of the first quarter and the third quarter. In the first quarter as silver production rose so too did mercury surpluses. After silver production turned downward in the early 1720s, the mercury surpluses eventually began to shrink. Surpluses continued to shrink even as silver production reversed course and moved to new highs through the second quarter and into the third quarter. Several times the surpluses were recorded as zero. In contrast to the first quarter, second-quarter mercury distributions significantly (and noticeably) outpaced reserves. In the third quarter as production slowed, dipped and then recovered reserves zoomed until they exceeded 25,000 *quintales*, a level that exceeded the consumption of mercury by two to three times. In the final quarter of the eighteenth century mercury reserves had a wide range between zero and 22,000 *quintales*. At the same time silver production reached its highest sustained level of the entire colonial period. The annual average surplus fell to about 6,700, but except for a few years mercury supplies managed to accommodate the demand and to maintain a small to moderate inventory.

Mercury shortages did occur in Mexico and could do damage. By the end of the colonial period the Crown had developed a plan for managing shortages that basically

allotted mercury on the basis of need.[57] Few if any of the interruptions or delays in shipments of mercury to Mexico in the eighteenth century resulted in industry-wide shutdowns because some reserves were almost always available at the central warehouse or in the mining camps and also because smelting was still an option. It helped of course that most of the disruptions in the supply line were temporary. In most cases shipments resumed in a year or two. Less is known about the period before 1700 because the database is not as strong. On the one hand reserves may have been harder to maintain, but on the other smelting was more widely practiced before 1700 than after. Miners, refiners and their allies often complained about the supply and the price of mercury, and from time to time their complaints led to positive changes in procedures and policies. Over the long term, however, the mining industry with the support of the merchant community gained experience in accommodating the risks associated with the mercury monopoly as it had accommodated other risks associated with mining. That the mercury monopoly itself with respect to its Mexican operations became more efficient made accommodation easier but did not ever completely eliminate the risk.

In Peru with its own domestic mercury production the script will be different. Huancavelica may have been a more troubled mining operation than Almadén or other European sites, and even though reforms and improvements could be hailed from time to time, they never came together in a way that would transform and modernize mining operations. Kendall Brown has shrewdly observed that the problem at Huancavelica was that government officials failed repeatedly to articulate their priorities without which plans for upgrading and overhauling operations lacked coherence and consistency. The Crown's deliberate approach at Almadén that helped to revive and expand its operations was tuned upside down at Huancavelica where "competing priorities and shifts in policy interfered with operations…and contributed significantly to the great Huancavelica cave-in of 1786….In short, the crown's handling of Huancavelica during the eighteenth century was neither coherent or farsighted, and it left the Peruvian silver refiners dependent on a declining source of mercury."[58] But Brown raises an even more

[57] See Garner, *Economic Growth and Change*, 132-140 for a discussion of the plan especially with reference to one of the worst shortages from 1799-1802.
[58] Brown, "The Spanish Imperial Mercury Trade," in Andrien and Johnson, eds., *The Political Economy of Spanish America*, 150-151.

intriguing idea to explain the failure to revitalize Huancavelica against the backdrop of what had been accomplished at Almadén. For the lack of a better term, incentive was lacking in Peru. Take a close look at Figure 27, which tracks relative change from year to year in the supply of mercury and in the output of silver between 1571 and 1816.[59] Every point above 100 reflects an increase (that can be expressed in percentage terms), and conversely every point below 100 designates a decrease. After 1750 the two indices diverge significantly, as noted earlier that mercury supplies did not correlate with silver registrations for more than a half century. Before that, however, the two series move in tandem, not exactly in lock-step but in the same direction. This is significant to the extent that the mercury administration whether by luck or prowess managed to keep a supply of mercury flowing that apparently satisfied demand. Clearly shortfalls existed, but in relative terms the supply of mercury registered larger percentage increase in some years than the output of silver. This observation is not intended to diminish the importance of the many problems that scholars have identified at Huancavelica and the impact that those problems had on Peruvian silver mining. What the indices suggest, however, is that until the middle of the seventeenth century there was no lack of incentive to try to produce more mercury whatever the cost because the ultimate consumers – miners and refiners – had not yet embraced a bearish behavior. Before 1650 both indices counted more years above 100 than below, although the mercury series demonstrated serious weaknesses around 1600 and again around 1625.[60] Beginning in the middle of the seventeenth century both indices began to fall below the 100 level far more consistently with the silver index leading the way downward. Again Kendall Brown captured the significance of this converging pattern: "El consume puede haber disminuido tanbién debido a la falta de demanda para mercurio. Los azogeros [refiners] no lo necesitaban sí no tenían metales listos para beneficar. En Potosí, por ejemplo, las secas hacían difícil moler metales. Muchas veces las descubiertas ricas duraron poco."[61] Neither the Crown, which was presiding over a colony in deteriorating financial shape, nor the merchant

[59] Since some silver was smelted, the silver index includes more silver than was actually amalgamated. If smelted and amalgamated silver could be separated, the silver index would look different. How different is difficult to describe. More than likely the trend would not change, but how much the index rose or fell in any year would.

[60] See Lohmann Villena, *Las minas de Huancavelica*, for a discussion of mining conditions.

community, which served as the colony's investment bankers, could enthusiastically underwrite the rehabilitation of Peruvian mercury mining. (In contrast Mexican silver mining, even in the second half of the seventeenth century, offered a stronger rationale to expand mercury supplies and therefore to upgrade Almadén facilities.) As much as the Crown may have hoped to turn around Huancavelica they needed help from the silver mining sector and especially Potosí, which had traditionally consumed most of Huancavelica's mercury. Indeed during the second quarter of the eighteenth century the turnaround engineered at Potosí had a corresponding effect at Huancavelica. By computing average output per week (because the annual data are grouped into units of tow and three years) Brown calculated that after a half century in which weekly output had averaged about 60 *quintales* per week Huancavelica doubled it average weekly output for the next half century. Beginning in the 1760s, however, a declining trend in output at Huancavelica set in and could not be reversed, even as Peruvian silver registrations continued to rise with the opening of new mining centers in Lower Peru. Although plans for rehabilitating Huancavelica continued to be drawn up, the cost to do so soon dampened any enthusiasm for the plans. And the merchant community, which had shown little interest in investing in a recovering silver industry had no interest in a downtrodden mercury sector. Whether the calculations were ever made formally or not importing mercury from Almadén may have been cheaper than renovating Huancavelica. Without a Huancavelica that could boost its production as it had in the past to meet the demand at Potosí, however and even with an Almadén that could bolster the supply of mercury, Peruvian miners and refiners may well have endured a more restrictive environment than Mexican miners and refiners. Large mercury reserves may not have existed. Peru's eighteenth-century recovery had to contend with significant headwinds including an imperiled mercury-mining sector.

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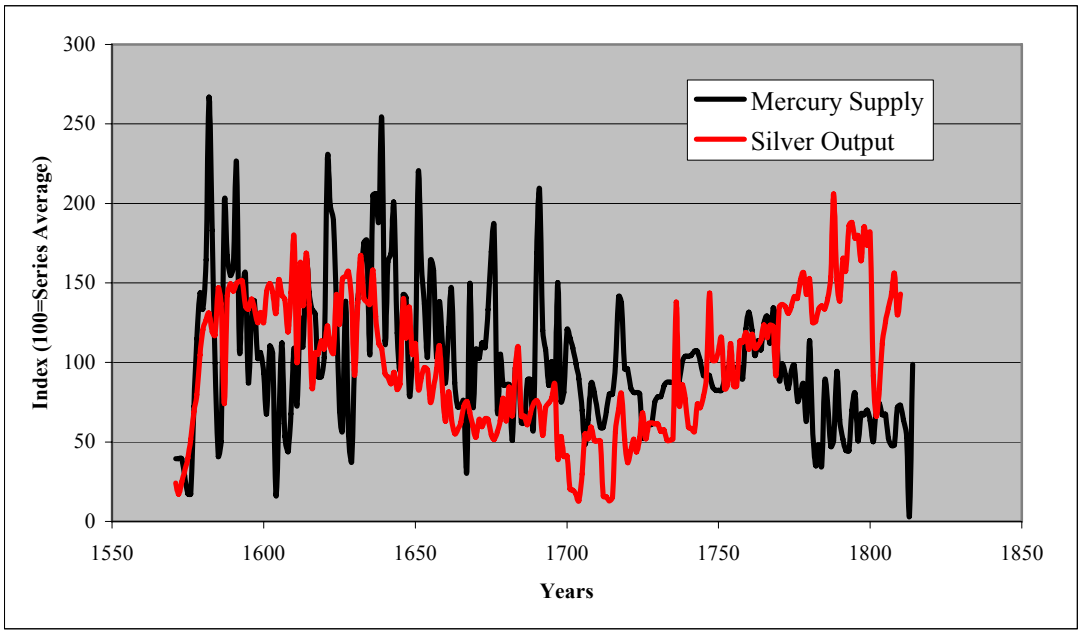
[61] Brown, "La crisis financiera peruana al comienzo del siglo xviii, La minería de plata y la mina de azogues de Huancavelica," *Revista de Indias*, 48:182-183 (1988), 362.

FIGURE 27
Index of Supply of Mercury from Huancavelica
(Base=Average of Series:
5,100 Quintales of Mercury and 2.6 Million Pesos of Silver)



Given the importance of mercury one might expect to find a high correlation between mercury supplies and silver registrations. When the broadest possible correlations calculated – colonial mercury supplies versus colonial silver registrations – the result is .66 (66 percent) positive but not especially high. If the silver series is lagged by one year to try to account for the time required between amalgamation and registration of the ore the correlation improved to about .70. The surprise is that most of the correlation existed between the supply of mercury and the output of silver in Mexico (.77) and virtually no correlation existed between mercury and silver in Peru (.08). If regressions are employed to determine any linear association between units of mercury yields and units of silver the results show a relationship between mercury and silver in Mexico with the coefficient of 709 with a R^2 value of .60 and no relationship between mercury and silver in Peru with a coefficient of 73 with a R^2 value of .01. Since the regression equation asks how dependent was the silver series (in *pesos*) on the mercury series (in *quintales*)? The results suggest the predictive values of dependency on mercury in Mexico are much higher than in Peru. In other words if one were trying to ascertain the role of mercury in the refining of silver, one would look more closely at Mexico than

Peru. For the purposes of this discussion (and not to put too fine a point on the results) the connection between mercury and silver is much harder to determine in Peru than in Mexico. Observe Figures 28 and 29. Silver data points are more closely bunched around the trend line in the Mexican series than in the Peruvian series; if one were to look at the Peruvian series without a trend line one would conclude that no relationship between the two series could be observed. Even though the Mexican series has the heavy bunching of data points around 5,000,000/2,500 (because those are the most frequent data points in the series), as one moves out the curve (more silver and mercury) a relationship can still be observed. One might expect a higher R^2 values in Mexico than the .50. That they are not higher over the long term is not difficult to explain. The silver series included both smelted and amalgamated ores, and while amalgamation became the dominant technique smelting never completely disappeared. Smelting may not have developed as fully in Peru as in Mexico, and therefore one would expect the relationship between silver and mercury in Peru not to be affected by smelted ores. The evidence at hand does not bear that out. Intuitively scholars know that Peruvian miners and refiners were every bit as dependent on mercury as Mexicans. Are these flawed datasets or was the relationship between the input of mercury and the output of silver somehow different in Peru than Mexico? Did the presence of a mercury mine within the viceroyalty have an influence on how the channels of distribution evolved? Were stockpiles of mercury accumulated in the mining centers in ways that cannot be captured by comparing figures on mercury supply with silver registrations? The Mexican series on both silver and mercury are much more readily adaptable to statistical analysis. Although they are more volatile (measured by the coefficient of variation) than the Peruvian series, they more or less tend to move in a unitary, upward direction, not in every year or decade but overall. The Peruvian series, on the other hand, change directions several times. It almost becomes necessary to study Peruvian mining as a series of intermediate-term trends.

FIGURE 28
Regression Silver Against Mercury, Mexico

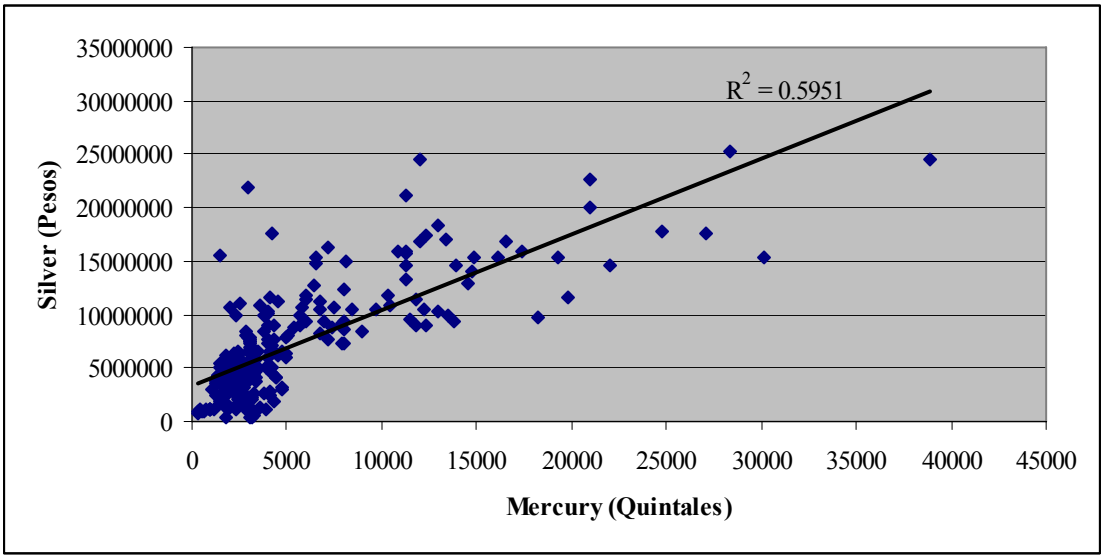
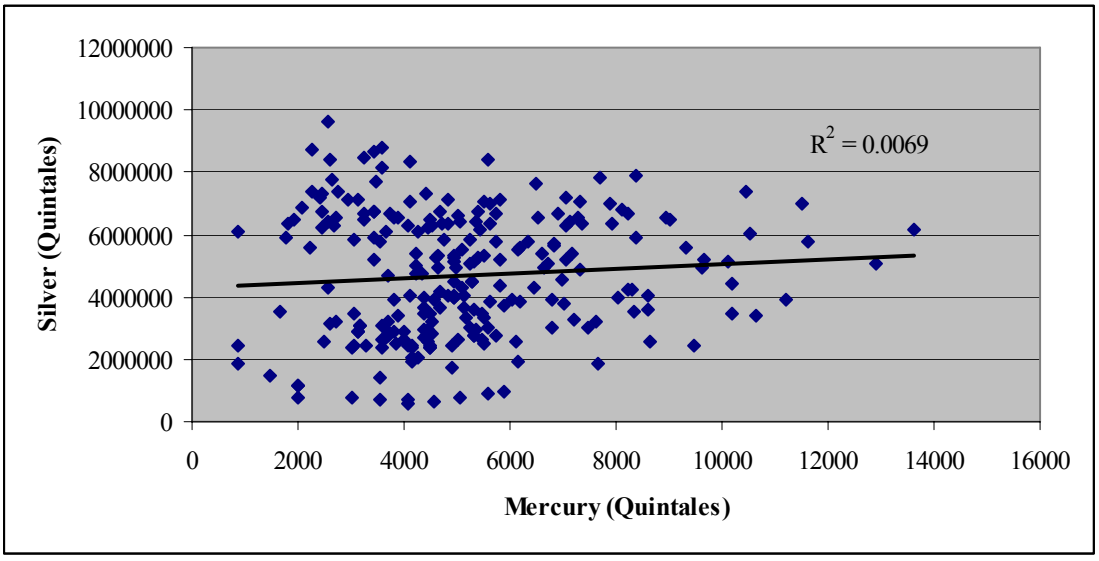


FIGURE 29
Regression Silver Against Mercury, Peru



The Crown used something known as the *correspondido* to try to track the consumption of mercury. The Crown applied a calculation based upon what one *quintal* of mercury should yield. Over the whole colonial era the standard yield was 100 marks (800 ounces) of silver for each *quintal* of mercury, and if that ratio were applied on the basis of 2.6 million *quintales* of mercury delivered from the mines in Europe and Peru, it would yield a total of 2 billion ounces of amalgamated silver, a result that is not far

removed from what the volume of *plata de azogue* if it could be separate from the *plata de fuego*. The fact is that the ratio between mercury and silver could vary widely because the quality of the ores and the efficiency of the refineries varied. Presumably, as noted above, the one *quintal* or 100 pounds of mercury could be made up of mercury on hand plus mercury recently purchased, the ratio took into account the presence of both. According to the rules, revised in the eighteenth century, a purchaser could buy no more new mercury than the quantity of marks registered from the previous purchased based upon whatever ratio was in effect. Thus, if the *caja real* expected local miners and refiners to present 100 marks per *quintal* of mercury and they presented less than the standard, say 80 marks, they were said in effect to "owe" the *caja* marks. With a purchase of 1,000 *quintales* of mercury, the *caja* would record in the mercury accounts the anticipated marks to be 10,000 (on the basis of 1 *quintal* to 100 marks). If only 5,000 marks were registered, the next purchase of mercury would be reduced to 500 *quintales* even if the purchaser needed an additional 1,000 *quintales*. Miners and refiners were penalized if their "manifestations" of marks fell below the ratio, but they were also rewarded to the extent that they could make larger mercury purchases if the "manifestations" of marks exceeded the ratio. From the mercury accounts that I have studied in Zacatecas the ratios were not always consistently and systematically enforced. The *caja real* of Zacatecas kept at least two sets of documents concerning mercury transactions for the eighteenth century and perhaps earlier. One set concerned the number of marks of silver reported the producer against the last mercury purchase. Another set concerned the terms of payment for that purchase of mercury. Many of these documents survive in the large collection of Zacatecas records, recently moved from the Clements Library, University of Michigan to Zacatecas.[62] The ratio still mattered because based on the purchases of mercury and the manifestations of silver the ratio was boosted at Zacatecas from 1 to 100 to 1 to 125 in the early 1800s. But more and more mercury was sold on the basis of need, even in once forbidden quantities below a *quintal*, so long as the arrangement of payment was satisfactory. The sale of mercury had moved away somewhat from the more restrictive policies based on control of the inventory of mercury

[62] I used the collection at the Clements Library, and I do not know if the archives have been reorganized in Zacatecas. When the archives were housed at the Clements Library, the *azogue* accounts were located in

to making mercury as readily available as possible. Recall, though, that in Mexico and in particular in Zacatecas an expansion was underway, and perhaps in a different setting where the economics were less favorable control of mercury remained the predominant feature.

The administration of the mercury monopoly proved to be a complicated business for the government. Mercury was expensive for miners and refiners, and the government had to provide ways for miners and refiners to acquire the mercury before they might actually have the cash to pay for it. By the eighteenth century at least four categories of payment existed in the *caja* at Zacatecas: the miner or refiner could pay cash, present a *libranza* (bill of exchange), deposit silver or request credit for a period usually no more than six months with the signature of a *fiador* in case of a default. Whether these categories existed in other *cajas* in Mexico or Peru, but no doubt some combination of schedules of payment was common to all *cajas*. The purchasers of mercury consisted of miners and refiners, of course, but also of merchants with array of connections to mining as owners or part owners of mines and refineries or as backers of the owners. Persons buying mercury might pay cash for one batch and accept credit for another batch. The size of the purchase did not seem to determine how it was to be paid for: some purchases in the thousands of *pesos* were paid for in cash and some of less than 100 *pesos* were accorded six months of credit. Purchasers and *fiadores* readily exchanged roles: purchasers served as *fiadores* for other purchasers and *fiadores* became purchasers themselves. In some instance a single *fiador* was presented, and in other instance three or four would be presented. One notable change given the long history of the mercury administration was that the *correspondido* (ratio of mercury to silver) although still recorded not longer determined the maximum purchase. In Zacatecas, for example, Joseph Ylario Carrillo, a miner-refiner-*aviador* but not among the grand entrepreneurs, purchased 96 *quintales* of mercury in 1769 and under the ratio of 1 to 100 he owed 9,600 marks of silver. He manifested only 5,700 marks for a deficiency of 3,900. In the following year he was allowed to purchase 100 *quintales* instead of just 57 *quintales*, and again he had a deficit of 2,100 marks. And this continued through the 1770s: deficits between the marks owed and the marks reported did not reduce the purchases. It is worth

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the Treasury Records and Correspondence section of the Zacatecas Collection by decade.

noting that the *caja* may have been less concerned about them deficits than would have been true 50 years before because the excess of marks was rising faster than the deficit. For the seven years for which data exist between 1769 and 1777, the excess of marks was 2.1 times greater than the deficit. This surely made it easier to ignore the *correspondido*.[63] In spite of precautions taken by the government to provide flexible terms for the purchasers as well as to avoid, if possible, the accumulation of debts by purchasers unable to meet their obligations. At times the *caja* carried tens of thousands to hundreds of thousands in unpaid mercury debts. By the end of the eighteenth century the *caja* had very few past-due accounts. The late colonial mining recovery at Zacatecas plus the reduction in the price of mercury and the relaxation of the rules governing purchases and payments contributed to declining debt levels.[64] In camps that were in decline rather than expansion the royal officials probably continued to have contentious relations with producers and their *fiadores* over mercury sales, consumption and payments. The examples cited in Zacatecas may not be apply to other camps so that the impact of mercury upon mining will always remain in concrete terms a camp-by-camp investigation. Still the general observations that have emerged from studying the trends in both silver and mercury indicate that the supply of mercury did not dictate solely how the industry should evolve.

One final point to make about the relationship between silver and mercury was that the correspondence between silver and mercury was higher in Mexico 217 marks per *quintal* than Peru 153 marks per *quintal*. This is not a clean figure by any means. It does not distinguish between *plata de azogue* and *plata de fuego*. And as noted many times the reliability of the mercury series is open to question. It is clear, though, from the silver series (as well as other evidence) that a serious disparity developed between silver mining in Mexico and Peru. It concerned the quality of the ore as well as the quality of the mercury, the cost of mining, the formation of capital, the role of labor and the ebb and

[63] There was also revision of the rules that permitted less attention be paid to the *correspondido*. These data were taken from *repartimineto de azogue* records of the *caja real* of Zacatecas. In the Clements Library they were housed under Zacatecas Collection, Treasury Records and Correspondence, 1770-1779, Box B.

[64] In some cases the *cajas* themselves proved to poor administrators. Most of what is known about mercury indebtedness is based on research on Zacatecas by Bakewell, *Silver Mining and Society*, 197-199, 202-208 and Garner, *Economic Growth and Change*, 128-131. Much of the indebtedness of the eighteenth century was associated with the second quarter when several important mines were abandoned with the owners unable to clear their mercury debts.

flow of government in the respective colonies. In simplest terms the difference underscores a reality that Peruvian producers after the sixteenth century faced persistent mining, financial and governmental problems that made profitable operations harder to achieve and maintain. These calculations indicate that differences in mining conditions existed between Mexico and Peru, but how much emphasis to place on these differences remains an open issue.

A Long View

Gold became the proxy for what made the New World attractive. Once the Spiritual Conquest waned by the middle of the sixteenth century the prospect of acquiring wealth – great wealth – primarily through mineral extraction was firmly established. Over the course of the next 250 years mining in the New World would add more than 100,000 tons of gold and silver to the world's money stock. No one doubts that these additions boosted economic activity worldwide. Some economies were transformed and most were affected in one way or another. Weighing the impact of New World mineral mining has produced a huge literature that no single study can ever embrace. In this essay I have focused mainly on how the mining economies performed over the long term. Within every long or very long trend are many points of interest that reflect on how the mining industry pursued the business of extracting, processing and allocating ore. There was not a single model that encompassed all New World mining. There were significant differences in the mining of gold and silver, and there were also significant difference in how gold and silver miners organized their operations. In addition the mining of precious metals required the mining of other minerals like mercury. But mining whether in precious metals or ancillary metals required allocations of other resources. Technology in the extraction of ore was modest at best, and therefore underground operations required lots of workers. The technological base in smelting and refining ores was somewhat more amenable to adaptation over time, but once the basic protocols were in place improvements often depended on local customs and entrepreneurial attitudes. Some operators had a more welcoming outlook to change than others. All operations, however, even the more efficient and entrepreneurial, were constrained by environment, location, capital, labor and other factors that might rest outside the control of the operators

themselves. Against this backdrop, then, the universal urge to get rich by exploiting minerals precious and otherwise required a degree of risk, skill and perseverance that was not always abundant but was abundant enough over the long or very long haul to yield the results that have been described and analyzed here. Silver mining developed differently from gold mining, although gold always remained the more valuable of the two metals. It was in the silver-mining subsector with an ore that was dug from deeper underground with all the problems attendant thereto and was far less valuable without smelting or refining than gold where performance is somewhat more telling about how miners, processors, creditors and bureaucrats interacted to keep an industry not always profitable in a productive mode.

The production curves based on treasury data have been assembled and published before, and these revisions in this essay do not significantly change the prior publications. It can be argued that when all of the treasury figures are combined into a single dataset over the 300 years the curve points upward. Any plot of ore data (as expressed in *pesos*) will show that New World production was 30 to 40 times higher at the end of the colonial period (excluding the independence decade) than in the early 1500s. Of course the great silver discoveries were just beginning to show up in the treasury dataset by the middle of the 1500s, and if the one compares output from the middle of the 1500s to the end of the colonial era, the magnitude shrinks to a factor between six and seven.

Not only does the duration (three centuries and more) of the New World mining curve look impressive when plotted, but also the slope of the curve looks equally impressive. Despite a brief slowing and flattening of the slope in the middle decades of the seventeenth century, the curve followed an upward path over the long haul. It is well known that output of silver (in metric tons) far exceeded that of gold. In the early decades gold was the most important metal, and after 1550 silver reigned supreme. From the end of the seventeenth century through the eighteenth century the ratios between silver and gold fell dramatically as output of gold in Brazil and in northern South American rose for the first time since the early sixteenth century. The driving force behind the mining of precious metals in the New World was silver; even in the eighteenth century after the resurgence in gold mining silver held an edge of 2 to 1 when decennial totals are compared. Gold was of much greater value than silver, about 16 times greater (although

the ratios change over time) so the volume of gold versus silver (in metric tons) was much smaller. A curve of silver without gold would show a less severe downturn in the middle of the seventeenth century because gold production had fallen to almost zero, but on the other side the curve would reveal a more moderate upswing in the late seventeenth and in the eighteenth century. The main player was silver, but as a minor player gold should not be ignored in trying to describe the total output of precious metals in the New World during the so-called early modern period when Atlantic economies were in the midst of significant structural changes. Control of the flow of bullion in the form or gold or silver from the New World became a contest among the European powers whose ventures political, financial or imperial depended on access to the ever-expanding money stock. Even a mineral with almost no intrinsic value, mercury, became part of the drama. No mercury, no amalgamation, and vast quantities of extracted ores, principally silver, would have become waste rather than money.[65] From a narrative standpoint, gold mining is more compelling tale: gold often appeared in pure form with panners working stream beds or diggers cracking surface veins, almost shoulder-to-shoulder and not always peacefully, in search of nuggets no bigger than grains of sand or luckily as big as pebbles. In the stories that were told, small pouches of gold nuggets of nearly pure gold made one wealthy, temporarily at least. This was seldom the story of silver, although extraction of a bluish (oxidized) silver ore near the surface might inspire similar. Gold was also mined usually in conjunction with silver. At the great Comstock Bonanza in Western Nevada in the second half of the nineteenth century, often referred to as a silver bonanza, with ores extracted from as deep as 2,000 feet, 40 percent of the ore was gold. It is often said that the statistics on gold mining are unreliable because so much gold was smuggled out of the gold fields (fields rather than mines) in small pouches (I suppose). The fact is that mining gold and silver in the New World before the nineteenth century entailed different protocols. Most of the gold came from surface or near-surface operations, while most of the silver (after the initial discoveries) came from deep mines. Deep mining required what might be referred to as "corporate strategies" – managers, schedules, cost accounting, deep pockets. Surface mining could continue to inspire a much more free-

[65] I have ignored other minerals such as diamonds in Brazil and salt, bluestone, etc. that made the amalgamation more efficient.

wheeling approach – more like Silicon Valley than Wall Street - even though the gold fields had their CEO's – in particular moneylenders and commercial houses – who provided the supplies, even the workers, and assembled the gold for processing, taxing and shipping. Still, even if the gold fields were more business-like than their portrayals, there remained an essential difference – volume. Silver mining entailed removing tons of rock and debris and containing or draining water in order to reach the ore; and since silver came in combination with other elements, the extraction of the ore was recorded in tons as well. Silver mining was an earth-moving operation to a far greater degree than gold mining. Although silver mining appeared to be in the hands of "gray-suits" (in opposition to the "slacks and loafers" crowd) it was from an economic perspective a more interesting story. It is more interesting not only because of the distinctions between the gold and the silver curves, but also because the silver curve could only show off its achievements if the miners as individuals or companies figured out how to be (in a pre-modern context) business executives.

Nature played a role in how the long history of silver mining in the New World played out. Some rocks were harder than others, some underground water reservoirs were easier to manage than others and some ore grades were more profitable than others. Over the long haul, Mexico may have had distinct advantages in terms of its natural endowments than Peru. In other words geology favored Mexican silver mining because the various obstacles were overcome not all at once but in successive generations. That shows up in the comparison the silver curves in Peru and Mexico. It is clear now that Peru was hare and Mexico the turtle, and the turtle won. Won in the sense that Mexico accounted for more than 50 percent of all the recorded silver and Peru for less than half. Perhaps if the unregistered, untaxed silver could be counted different results would emerge. It may have been easier to smuggle silver out of Peru through Buenos Aires while the port more or less functioned on the periphery of the empire. But the volume of smuggled silver will never be recoverable. Since there were fairly well established ratios between mercury incorporation and silver yield some investigators have suggested that more silver should have been produced than was recorded. That numerical difference between what should have been recorded and what was recorded could point to the magnitude of the contraband silver. Perhaps, but not necessarily. The quality of the ore

and the mercury mattered in calculating the yields as well as the technical efficiency of the milling operation. It came down to per-unit costs, and they were higher in Peru than in Mexico, and the cost structure was further distorted in Peru because it did not enjoy the relief that Mexico did until well into the eighteenth century. In any event Peru's brilliance began to fade in the second quarter of the seventeenth century and remained in a diminished state until the middle of the Eighteenth century. In the meantime Mexico climbed gradually (with some interruptions) until the eighteenth century when it produced two to three times what Peru produced. Mexico never had a Potosí but it had several camps that proved to be highly productive. When Potosí mining fell on hard times after 1650 no other camp came the rescue. In Mexico a boom at one camp might counterbalance a contraction at another camp. And of course when all the major camps were in synch, the results could be spectacular.

The New World produced more gold and silver than the rest of the world for several centuries. The Spanish colonies produced less gold than Portugal's Brazil, but they accounted for almost all the silver. Mexico started behind Peru in silver production, but half through the colonial era positions reversed with Mexico outpacing Peru. In total metric tons recorded silver was 65 to 70 times higher. I would remind the reader that the data from which these generalizations are drawn are largely estimated from a fairly narrow database. Treasury records where maintained kept track of the taxes collected, and in some local treasury offices the assays in marks (a weight of eight ounces) were recorded. But because tax receipts are more widely preserved and accessible they serve as the basis by which a metal's monetary value is calculated. From the monetary value the volume in kilograms or metric tons is calculated. These calculations can be checked against some other sources, and where they agree there is relief and where they do not indifference or despair. (Estimated numbers tend to favor a longer rather than a shorter view.) When I have compared silver in marks collected from the *caja* records of Zacatecas with silver in *pesos* computed from tax receipts, there were year-to-year difference but over time they yielded similar curves. The numbers are still useful so long as they are not pushed too far.

Silver mining could not have attained the heights that it did without the introduction of mercury-based amalgamation process. Smelting was widely practiced in

Europe at the time of discovery, although amalgamation in some form had been known since ancient times. Smelting was too expensive and inefficient given the type of ores found in the New World. Smelting did not disappear but came to serve a marginal role. By the end of the colonial era perhaps no more than 10 to 15 percent of the ore was smelted. Supplying the New World with mercury to keep the mines and mills in operations was of utmost concern to the royal government. Indeed the government created a monopoly to mine, process, distribute and sell the mineral (unlike silver mining that was a private undertaking.) The monopoly went through many reincarnations but remained a government business that despite serious interruptions, delays and shortages managed to keep the supplies flowing into the mining camps. The eighteenth-century boom in production of silver was accompanies by a "boom" in output of mercury. Tens of thousands of *quintales* were needed in Mexico and Peru, and the mines in Spain and Peru more or less met the challenge. Over time the Crown grew more enlightened about how to administer the monopoly not just to maximize profits, which accrued to the royal treasury, but also to take into account the impact of the monopoly on milling operations, in particular milling costs. This was not by any means a perfect marriage between miller and monopoly, but the prospects for the marriage improved over the second half of the colonial period improved as the monopoly took the concerns of its partner more seriously. It has been argued that with looser controls over the production and distribution of mercury, the silver industry would have enjoyed greater prosperity. That is hard to quantify. There were periods when the monopoly's presence strangled rather than supported mining, but given the royal attitude toward control of wealth in the New World the idea of a free and open market in mercury was never seriously entertained. Adjustments were the best that miners and refiners could expect, and even if their wildest expectation had been met (and it is not clear that they ever entertained wild expectations), silver mining faced other problems both underground and aboveground that a reconstituted mercury operation could not have solved. The extent to which the mercury monopoly acted as a deterrent to a more expansive and profitable silver enterprise remains a debating point.

To establish the trend in New World mining presents only part of the story. That part of the story represents the foundation from which other inquiries may follow. It is

important to know not only what the production trends were and how they changed over time, but also what circumstances may account for how the mining sector performed. The New World was the principal source of gold and silver for three centuries, and the production trends, even when derived from less than perfect data, have a bearing on economic events across the globe. In fact little gold and silver remained in the New World, for better or for worse. With respect to silver eighty percent or more was exported with about 90 percent directly headed to Europe and 10 percent to the Far East. Large quantities of European-bound silver also found its way to the Far East. (The export of gold may have been even higher.) What emerges from the study of the trends is that over the course of three centuries long-term expansion rather than contraction characterized the total-output curve in the New World. Gold mining to be sure went through a long contraction between the early discoveries in Spanish America and the boom in Brazilian and the recovery in Spanish America a century a half later. Silver had a modest downturn in the middle decades of the seventeenth century in large part due to the derailing of the Potosí engine, although Mexico mining pushed ahead to new heights and Peru eventually recovered. In some places the ores were simply exhausted. In other places costs relative to the value of gold and silver made mining unprofitable. But the risks were apparently assumable in many different places over the very long term to allow total production to grow. In some cases government policies helped to lessen the risks. In other they may have heightened risks to such a point that mining was abandoned. If one simply accepts a centennial view of New World mining, total production was many times higher in 1600 than 1500, marginally higher in 1700 than 1600 and significantly higher in 1800 than 1700. Not a bad record, indeed.