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TECHNOLOGY, LABOR, AND THE COLLAPSE OF CHILE'S NITRATE INDUSTRY

Paul Marr
Department of Geography
Shippensburg University
1871 Old Main Drive
Shippensburg, PA 17257

ABSTRACT: *The collapse of Chile's nitrate industry during the 1930s is examined relative to the nitrate extraction technology used and the available labor force. Results suggest that the nature of the extraction technology used (the Shanks system), the distribution and quality of the nitrate ore (caliche), and the makeup of the labor force limited producers' ability to increase profits and/or lower production costs. Specifically, the Shanks system of nitrate production required intensive use of labor, such that increases in technological capacity (e.g. production machinery) necessarily had to be accompanied by proportional increases in labor. Under such a system the ability to remain competitive by lowering production costs was severely constrained. Producers opted to lower wages while maintaining the size of the labor force. Ultimately this led to worker rebellion, hastening the demise of the industry.*

Keywords: Chile, nitrate, labor, wages

INTRODUCTION

The nitrate industry was first developed in the mid-1800s in southern Peru, southwestern Bolivia, northern Chile. Tensions in the region grew as the economic importance of nitrate resources increased, eventually leading to the War of the Pacific (1879-1883) and Chile's annexation of the region after its defeat of Peru and Bolivia. The collapse of the nitrate industry in the years following the 1929 global financial crisis had a tremendous impact on Chile. The Tarapacá region in the far north which had over 100 nitrate oficinas operating at various times during the nitrate boom was particularly hard hit. Chile is home to the world's only commercially viable source of naturally occurring nitrate, used in both fertilizers and high explosives. In the years prior to 1914, Germany had become the world's largest consumer of Chilean nitrate, accounting for nearly one-third Chile's output.[1] The older methods of nitrate production simply could not keep up with global demand, and foreign capital poured into northern Chile to finance the construction of new processing facility based on the Shanks system of extraction. This system dramatically increased nitrate output, with production doubling from 11 to 25 million tons between 1900 and 1920.[2] With the outbreak of the First World War and the British blockade of German nitrate imports, exports shifted to the United States, who by 1918 accounted for about 95% of Chile's production.[3] To fuel her munitions plants during the war, German scientist Fritz Haber developed a process to fix nitrogen from the atmosphere on an industrial scale, freeing Germany (and the world) from reliance on naturally occurring nitrate deposits.[4] After the 1918 armistice the Haber process took hold rapidly, and by the early 1920s world nitrate production using the Haber process surpassed Chile's nitrate mining output.[5] As nitrate supplies increase the price plummeted, and by the start of Second World War only a handful of nitrate plants (*oficinas*) were still operating in Tarapacá.

The causes for the collapse of Chile's nitrate industry form a nexus of the interaction of private industry, government, technology, and exogenous forces. Oficinas were private firms operating on Chilean governmental land concessions. The Chilean government used these concessions to fill its coffer through high export taxes—ranging from 30 to 70% of the price of nitrate—accounting for 60% of the government's revenues during the peak years.[6] Just as Chilean nitrate production peaked the Haber process and the global financial crisis put extreme downward pressure on nitrate prices, throwing the Chilean government and nitrate producers into crisis. Chilean nitrate producers struggled to remain competitive, decreasing prices even as taxes on nitrate exports stood unchanged.[7] The price of nitrate dropped by two-thirds globally between 1913 and 1937 while demand for Chilean nitrate dropped by a third.[8] The loss of tax revenues from the collapse nearly bankrupt the Chilean government and threw tens of thousands of nitrate laborers out of work.[9] However, unlike the global financial crisis which caught most countries off-guard, Chile's nitrate industry had long been sowing the seeds of its own destruction. Most oficinas in Tarapacá used the Shanks system of nitrate recovery, which relied on heavily on both machinery and labor. While much has been written concerning the role of taxes and the actions of the Chilean government in the collapse of the nitrate export industry, very little has addressed the role the extraction technology and labor played in the collapse.[10] This research will address the question: how closely linked were machinery (i.e. production capacity) and labor under the

Shank's system and how did this linkage impact the industry's competitiveness? The working hypothesis is that production capacity and labor were inextricably linked, to the extent that oficinas that used the Shanks system were unable to substitute capacity for labor. In fact, each increase in capacity would have to be accompanied by a proportional increase in labor, severely hampering the industry's competitiveness.

NITRATE PROCESSING USING THE SHANKS SYSTEM

The most common method of nitrate mining in Tarapacá was the Shanks system, and was used by all oficinas examined in this research (Figure 1).[11] While the Shanks system increased production levels dramatically, the system was inherently inefficient in terms of nitrate extraction from nitrate ore (*caliche*) and relied heavily on manual labor. It remained popular through the 1930s primarily due to its low capitalization costs[12] and was the only

Figure 1. Northern Chile (Tarapacá) study area. Major ports, study oficinas, and nitrate railroads are also depicted.

option to remove nitrate from caliche until the development of the more efficient but costly Guggenheim process in 1926.[13] The technique involved laborers hand-drilling a small hole through the overburden to a point below the nitrate ore bed and blasting out a small chamber. This chamber would be filled with black powder or dynamite and ignited, with the force of the blast throwing the ore to the surface. Higher grade ores would be hand sorted, broken in the manageable pieces, and hauled by donkey-cart to the processing plant. At the plant the ore would be crushed to ≈2 inch pieces and the finer material removed and discarded. The crushed ore was then be boiled for 8-9 hours, after which the nitrate-rich liquid would be drained from the bottom of the cooking vessels into crystallization pans and finally into evaporation pans. Once dried, the crystalized nitrate was packed into sacks, sewn closed by hand, and loaded onto railcars. Although poorly paid, the workers were skilled at their jobs and could not be replaced easily by unskilled or untrained workers.

The extraction process was equally inefficient. Boiling tended to disintegrate the nitrate ore which then clogged the cooker drains. This fine sludge would have to be removed after each extraction run, slowing the process. To compensate, the nitrate ore crushing process was relatively coarse. This left much of the nitrate at the center of the ore pieces unexposed to the cooking liquid and non-recoverable. The Shanks system used simple equipment that could be readily obtained and repaired, making it attractive to local operators and distant financiers. However, the nitrate recovery rates were typically so low that only ore grades containing higher than 15% nitrate could be profitably processed, and even then the margins were extremely tight.

The Shanks system was similar to the earliest nitrate recovery techniques with a few important modifications[14], but the scale of the operations was much larger. The early small scale operations could easily improve profits by 'high grading'.[15] Additionally, these small operations were mobile, and when the nitrate ore became unprofitable in one location the operation could be relocated. The Shanks system was developed to meet the increasing demand for nitrate for both fertilizer and weapons manufacture during the lead up to the First World War.[16] With the increase in the scale of the extraction operations mobility became impossible, and when the highest grade ores were exhausted the oficinas would be closed. The fortunes of these operations often relied on either increasing their nitrate concessions in the hopes of capturing additional high grade ore or increasing capacity.

DATA AND METHODS

Since the nitrate works were privately held companies, official Chilean reports of sufficient detail to address the questions posed by this research do not exist. However, data detailing many of the nitrate oficinas can be found in contemporary publications aimed at promoting Chile's nitrate industry, most importantly *Album Zona Norte de Chile*, published in the mid to late 1920s.[17] Data concerning processing equipment, nitrate production statistics[18], transportation, services, housing, food staple consumption, and population are listed for 70 of the 114 oficinas known to have operated in the Tarapacá region and offer a snapshot of industry during its decline.[19] Housing data includes unit size and construction material, as well as the number of units for single and married workers. Population data are limited to total population and the number of workers, with no breakdown for whether they were single or married workers. Ultimately 23 of the 70 oficinas listed had complete data and were used in this study[20].

The data for nitrate processing equipment included the number of boilers, ore crushers, ore cookers, and crystallization pans. Additionally, the dimensions (length, width, and depth in feet) of the ore cookers and crystallization pans were also listed and were used to calculate their volumes. One equipment variable that was not significantly correlated with the others was the number of boilers per oficina. The nitrate processing equipment and worker variables were found to have non-normal distributions with several outliers, therefore non-parametric correlation analyses were performed. This may be due to the boilers use in the nitrate recovery process but also in providing power for the machine shops and other needs. The remaining nitrate machinery variables were highly correlated (Table 1). This was anticipated, in that it is reasonable to expect that, for example, as the volume of the ore cookers increased there would be a necessary increase in the capacity of the rest of the processing equipment.

Table 1. Spearman's correlations for nitrate processing equipment.*

	Crushers	Cookers (ft^3)	Evap Pans (ft^3)
Crushers	--		
Cookers (ft^3)	0.892	--	
Evap Pans (ft^3)	0.663	0.681	--

* All correlations were significant at the 0.01level (2-tailed)

To remove this multicolinearity from the independent variables, the dimensions of the production equipment variables were reduced to a single dimension using principal component analysis. The resulting dimension accounted for 87.5% of the total variation in the three production equipment variables, and all loaded highly on this component (Table 2). The resulting component variable was interpreted as 'capacity' and was then regressed upon the number of workers. It was hypothesized that the amount of variation in capacity explained by variation in labor would be very high, and that oficinas which deviated from this trend would be located in areas where the percentage of nitrate in the ore was either particularly high or low, depending on the direction of the deviation. Regression residuals were then mapped to determine if there was a spatial component to any deviations.

Table 2. PCA loadings for the variables interpreted as 'capacity'.

	Crushers	Cooker (ft^3)	Evap Pan (ft^3)
Component Loadings	0.949	0.954	0.870

RESULTS

The regression results for the number of nitrate workers and capacity factor for the study oficinas suggest that 80% of the variation in production capacity is explained by the number of nitrate worker per oficina (Table 3).

Table 3. Regression results for nitrate workers and 'capacity'

Model Summary:

$R^2 = 0.80$ Standard Error = 116.1

Model:	*Sum of Squares*	*df*	*F*	*Prob.*
Regression	1114981	1	82.7	<0.001
Residual	283135	21		
Total	1398116	22		

Coefficients:	*b*	*Standard Error*	*t*	*Prob.*
Constant	514.3	24.2	21.24	<0.001
Capacity (Factor 1)	225.1	24.8	9.09	<0.001

The standard error of the estimate is relatively low (116.1 workers) and the R^2 (0.80) is relatively high, suggesting that size of the labor force was closely related to production capacity. The scatter plot of capacity and nitrate workers (Figure 2) illustrates this point more clearly.

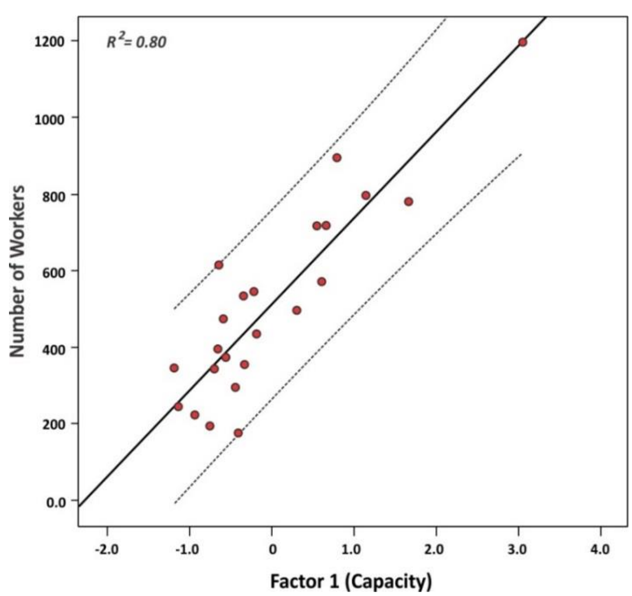

Figure 2. Scatter plot of production capacity (Factor 1) and the number of workers per oficina with 95% CI.

Negative residual values occur where the model over-predicted the number of workers, suggesting that these oficinas needed fewer workers relative to their production capacity. Positive residuals suggest that these oficinas had more workers than should have been needed for their production capacity. The general trend in the data suggests that in the north fewer workers were needed for a given level of production capacity, while in the south more workers were needed (Figure 3). However, it should be noted that none of the residuals were particularly large. While it appears that nitrate quality in general declines north to south, it appears that there was little ability to capitalize on this. A plot of nitrate output per worker (quintales) in 1926 by the latitude of the oficina shows no clear trend (Figure 4). This suggests that while nitrate ore in the north may have been of a slightly higher quality, the characteristic was highly localized.

Figure 3. Residuals of workers and capacity (factor 1). Blue symbols represent model over-prediction of works, orange symbols represent under-prediction

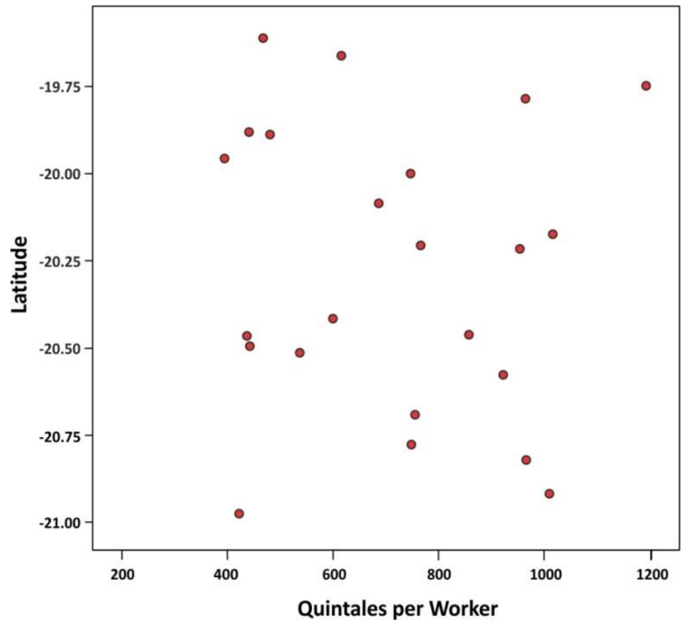

Figure 4. Worker output in 1926 (quintales) and latitude of oficina.

DISCUSSION

The inefficiency of the Shanks system at extracting nitrate from the ore required a large workforce to hand sort the highest grade ores. The variable nature of the caliche ore and the difficulties in the timing of the extraction processes (especially draining off the nitrate saturated liquid) made these jobs highly skilled. Adding more equipment to increase production would have required a proportional increase in the labor force, with many of these jobs requiring specialized skills. In this situation an oficina's ability to increase profits would have been severely constrained since increasing production capacity would have been a zero-sum game. Increasing profits in locations where the nitrate ore quality was inconsistent or consistently low would have been very difficult since operators could only influence labor costs. Substituting mechanization for labor in the northern nitrate fields simply was not a viable option. Even the advent of the Guggenheim process in the mid-1920s was of little help to established oficinas, due in large part to the high startup and fuel costs. Given only one option to increase profits[21]—cut labor costs while maintaining or increasing the size of the labor force—it is not surprising that operators chose to use it. This was especially true of the oficinas in Tarapacá, which were overwhelmingly foreign owned and felt no sense of obligation to Chilean laborers.[22]

Oficinas recruited large number of poor, indigenous Peruvians and Bolivians to work in the nitrate fields, undercutting local wages and dividing the labor force along national/ethnic lines.[23] While Chileans made up the largest group of nitrate workers, the recruitment of Peruvians and Bolivians as contract laborers created internal strife within the labor force. These contract laborers (*enganchados*) were resented by the in-situ Chilean labor force since they were often hired at lower wages, which tended to drive the overall wage down. By 1910 over 40 percent of the nitrate workforce were either Peruvians or Bolivians.[24] Other tactics were used to keep wages low. Oficina operators timed production to coincide with spring planting in Europe and the United States. Nitrate orders for the planting season could be filled within a few months, after which the workers contracts would expire. Recruitment for the next season would then begin at lower wages, which the workers were often willing to take after months of unemployment. To reign in skilled labor wages, particularly among the caliche sorters, workers were paid on a per-piece basis. Sorters tried to circumvent this by hiding lower grade ore pieces in with their cartloads, yet these effort were only marginally successful. Additionally, a series of fiscal missteps by the Chilean government in the early 1900s led to the devaluation of the Chilean peso from 48 ducats per peso in 1879 to a low of 7 ducats per peso in 1906.[25] Nitrate producers resisted any attempts by the Chilean government to strengthen the peso, in part because operators paid their laborers in script and the uneducated laborers were more concerned with the volume of script they received rather than its purchasing power. Since nitrate was sold abroad for gold, the devaluation of the peso was a windfall for nitrate operators.

The situation of the nitrate oficinas in the Atacama *pampa* (plain) also tended to work against the labor force. The barren nature of the environment, the lack of other opportunities, and the difficulty in transportation all conspired to severely restrict labor mobility. Once workers arrived at an oficina—often with their families—they tended to stay. Although the number of laborers in the northern nitrate fields varied widely from year to year (between 30,000 and 50,000), the inflow of contract workers from outside the region kept the number of unemployed workers high. At any given time there were thousands of laborers, effectively trapped on the pampa, looking for work. By 1909 the situation came to a boiling point and nitrate laborers descended upon Iquique, occupying the main square and demanding better pay. A subsequent clash with the Chilean military led to the deaths of some 200 workers but little else.[26]

Declining demand for Chilean nitrate, a global depression, and the development of synthetic nitrates shook the industry to its core and nitrate producers felt little inclination to meet the worker's pay demands, especially since there was a seemingly inexhaustible supply of ever-cheaper labor. Sensing an imminent collapse of the industry and subsequent loss of revenue, the Chilean government tried to shore-up nitrate prices through a system of combinations (cartels) and quotas.[27] However, the quotas were based on current production, so operators increased production in an effort to receive larger quotas, resulting in a nitrate surplus and falling prices. Within a few years following the global financial crisis of 1929 over 90 percent of Tarapacá's nitrate oficinas had closed and the pampa was all but abandoned.

CONCLUSIONS

This research suggests that the grade of the nitrate ore was the single most important determinant of an oficina's profit making ability. The use of the Shanks system would effectively lock an oficina into fairly narrow profit range, meaning that subsequent increases in capacity (profit making ability) would be offset by the need to increase labor, unless the grade of the nitrate ore changed as mining continued or the cost of labor costs could be driven down. The labor intensive nature of the Shanks system may have also limited the development of scale economies in favor of multiple small operations. This is clearly seen in the proliferation of oficinas in Tarapacá, where over 100 production plants were constructed, yet nearly 70 percent of these oficinas produced less than half as much nitrate as the largest facilities.[28] These smaller operations were even more restricted in their ability to increase capacity, making them eager participants in undercutting wages. Under such constraints on profitmaking, oficinas put continual downward pressure on labor costs, further impoverishing the nitrate workers. This set the stage for worker unrest and eventual rebellion, hastening the demise of an already weak industry. The government's over-reliance on nitrate profits meant that the spectacularly rapid demise of the industry would be felt through Chilean economy for decades.

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[1] Grinnell Jones, Nitrogen: Its fixation, its uses in peace and war, *The Quarterly Journal of Economics*, 34:3 (1920), 391-431.

[2] R. H. Whitbeck, Chilean nitrate and the nitrogen revolution, *Economic Geography*, 7:3 (1931), 273-283, especially Figure 4.

[3] Robert E. McConnell, The production of nitrogenous compounds synthetically in the United States and Germany, *The Journal of Industrial and Engineering Chemistry*, 11:9 (1919), 837-841.

[4] Fritz Haber and Carl Bosch developed the Haber process for producing ammonium nitrate from atmospheric nitrogen, winning the 1918 Nobel Prize in Chemistry. See *The Nobel Prize in Chemistry 1918*. Nobelprize.org. 10 Dec 2012 http://www.nobelprize.org/nobel_prizes/chemistry/laureates/1918/.

[5] Whitbeck, Chilean nitrate and the nitrogen revolution, Figure 7.

[6] The average cost to export a ton of nitrate (with profit) was approximately $50US in 1924, 25% of this cost was the nitrate export tax, U.S. Department of Commerce, Nitrogen survey: Part L- The cost of Chilean nitrate, H.F. Bain and H.S. Mulliken, in *Trade Information Bulletin No. 170*, (1924), p. 3. The governmental revenues from nitrate averaged between $25-30 million US or about 60% of the total governmental revenues (author's calcuations), see Whitbeck, Chilean nitrate and the nitrogen revolution, p. 278.

[7] Rolf Lüders and Gert Wagner, Nitrate export collapse and the Great Depression: Trigger or chance?, *Cuadernos de Economica*, 40:121 (2003), 796-802.

[8] Mirko Lamar, *The World Fertilizer Economy*, Stanford University Press (1957), especially tables on pgs. 134 and 157.
[9] The total number of unemployed in northern Chile reached 50,000, with about one-third being heads of households. See Clarence F. Jones, Chilean commerce, *Economic Geography*, 3:2 (1927), 139-166.
[10] For example, J.R. Brown, Nitrate crisis, combinations, and the Chilean government in the nitrate age, *The Hispanic American Historical Review*, 43:2 (1963), 230-246; Jonathan R. Barton, Struggle against decline: British business in Chile, 1919-1933, *Journal of Latin American Studies*, 32:1 (2000), 235-264; Rolf Lüders and Gert Wagner, Nitrate export collapse and the Great Depression: Trigger or chance?
[11] This system was developed by James Shanks to produce carbonate of soda and was first applied toward the recovery of nitrate by James Humberstone in the 1870s. See Michael Monteón, The British in the Atacama Desert: The cultural bases of economic imperialism, *The Journal of Economic History*, 35:1 (1975), 117-133.
[12] The other nitrate mining technique—the Guggenheim process—required much more capitalization for machinery, but could treat ore grades as low as 8% versus the minimum grade of 15% for the Shanks system. See Harry A. Curtis, Technology of the Chilean nitrate industry, *Industrial and Engineering Chemistry*, 23:5 (1931), 456-452.
[13] The Guggenheim process was invented by Guggenheim chief metallurgist Cappelen Smith in 1922, but was not used in Chile until the Maria-Elena oficina was upgraded in 1926. See Elisabeth Glaser-Smith, The Guggenheims and the coming of the Great Depression in Chile: 1923-1934, *Business and Economic History*, 24:1 (1995), 176-185.
[14] The most important modification was the addition of a leaching stage. Earlier nitrate operations used a single-tank extraction method where the Shanks system boils and leaches the nitrate ore in multiple stages. See A. W. Allen, *The Recovery of Nitrate from Chilean Caliche*, (1921) London: Charles Griffin and Company.
[15] 'High grading' refers to the selective extraction of the highest grade ores. This is often done at the expense of lower grade ores, rendering them worthless.
[16] See M. B. Donald, History of the Chile nitrate industry, *Annals of Science*, 1:2 (1936), 193-216, especially the 'Summary of Production' table on pages 214-5.
[17] Juvenal Valenzuela O., *Album Zona Norte de Chile, Informaciones Salitreras*…, Santiago, 192? The actual publication date is not stated on the frontispiece, however publication was likely between 1926 and 1929 based on the data presented in the text.
[18] Much of the data listed in *Album Zona Norte* were in units not commonly used at present (e.g. quintals, sacos, cuadras). These data were converted to standard metric units for analysis. The conversions for these obsolete units can be found at http://www.unc.edu/~rowlett/units/.
[19] In total 114 nitrate oficinas operated in Tarapacá. Not all of these production facilities operated concurrently, and several started and stopped operation many times, depending on the price of nitrate. On average it is thought that between 60 and 70 oficinas were operating at any given time.
[20] Oficinas Felisia and San Remigo were located within a few hundred meters of each other, shared worker housing and grocery store, and were operated by the same company. These two oficinas were combined for the study.
[21] After the global financial crisis of 1929 and the subsequent decline in the nitrate market, operators shifted their focus from increasing to maintaining profits.
[22] See Michael Monteon, The enganche in the Chilean nitrate sector, *Latin American Perspectives*, 6:3 (1979), 66-79.
[23] Ibid, pg. 67-8, Table 1.
[24] Ibid, pg. 69-70, especially Table 2.
[25] J. Laurence Laughlin, The strike at Iquique, *The Journal of Political Economy*, 17:9 (1909), 641-643. One ducat of gold weighted 0.1107 troy ounces.
[26] Ibid, pg. 643.
[27] J. R. Brown, Nitrate crises, combinations, and the Chilean government in the nitrate age, The Hispanic American Historical Review, 43:2 (1963), 230-246.
[28] Of the 54 oficinas for which production data were available, 37 oficinas (69%) produced less than 320,000 quintales of nitrate per year, or half the output of the 650,000+ quintales produced by the 3 largest facilities.