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A Half-Century of Stagnation: Labour Productivity in Ontario's Gold Mining Industry

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Abstract

This paper uses mine-level data to study labour productivity in Ontario's gold mining industry from 1920 to 1970. The ounces of gold produced by a mine worker are nearly identical in 1920 and 1970. Thus, the industry appears to experience no productivity gains over this period. In fact, labour productivity in the intervening years was nearly 30% lower than these values, raising concerns about the ability of the industry to remain profitable given a fixed price for gold. Using a unique mine-level data-set for over 75 different mines comprising nearly 90% of the industry in Ontario, we perform a firm-level analysis of productivity. This analysis allows us to determine whether workers are in fact becoming less efficient over time, or whether other factors, such as entry and exit into the industry, declining quality of ore bodies, or changes in capital stock, are the primary drivers of this stagnation. We are also able to determine the impact that events such as a sudden 70% rise in the price of gold in 1934, the Second World War, and the subsidization of the industry in the late 1940s had on productivity.

JEL classification: D22, D24, L72, N52, Q3
Keywords: Productivity, Gold Mining, Ontario.

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1 Introduction

Gold mining formed a substantial portion of the economy of Northern Ontario during the 20th century. Between 1920 and 1970, 46.4 billion 2017 Canadian dollars worth of gold was produced by Ontario gold mines, which directly employed an average of over 10,000 people a year. Additionally, Ontario's gold industry was important to the economy of Canada as whole during this period as it was a major source of foreign reserves.

Despite the importance of the sector, little has been done to examine its operations throughout this period. This is surprising as a few major events occurred during this period which had substantial impacts on the industry. In this paper, we seek to remedy this through a thorough examination of Ontario's gold-mining industry at the height of its output.

The gold mining industry in general is worthy of study for a number of reasons. Firstly, as explained by Knox (1955), during this period, the industry faced a fixed price for its output as the price of gold was set by the US government. Though movements in the exchange rate meant that Canadian mines would receive payments slightly above or slightly below this rate, the price remained nearly fixed over these fifty years (except for a single 70% increase which is discussed below). Additionally, in this gold-standard era, gold played a key role in the Canadian economy as it was used to obtain foreign currencies through the exchange of gold. Finally, the competitive nature of the industry is interesting, as the fixed output price meant that mines did not view each other as competitors[1].

This period of study is worthy of examination for a number of reasons. As mentioned, these years represent the height of the industry's output. The industry grew from 1920 to 1941, where it peaked, before a slow but steady decline until 1970. Though the industry did not cease to exist at this time, our data source does not continue past this point. During these years, the industry faced three significant events which we will examine here. In 1934, the price of gold spiked suddenly and permanently by 70%, causing major disruptions to the sector. The Second World War saw an initial increase in the demand for gold in the early war years, followed by a sharp and sudden contraction in the later war years. Finally, the rising wages of the post-war period saw the industries survival threatened. It was only through substantial government intervention, in the form of a massive subsidy program, that the industry was able to continue operations.

The focus of this study is an examination of labour productivity in the industry. As Figure 1 demonstrates, the aggregate labour productivity of an Ontario gold miner, measured as ounces of gold produced per worker, displayed an unusual pattern. By 1970, despite a half-decade of technological advancements, it appears that the average worker was no more productive than they were fifty years prior. In the 1920s and in 1970, the average worker produced 250 ounces of gold. Even more concerning is that in the intervening years, productivity was substantially lower, with an average output of only 160 ounces of gold per

[1] See Times (1933).

worker. We seek to decompose changes in productivity throughout this period to determine whether there truly was a lack of labour productivity gains in this period, or whether other facts can explain the observations. This will be done by decomposing changes in aggregate labour productivity into the within, between, cross, and net entry components as described in Foster, Haltiwanger, and Krizan (2001). Full details of this approach will be explained below.

This paper contributes to a number of different literatures, including those that are studies of mine-level data. Analyses of labour productivity in the copper mining industry of the US and Chile are conducted by Aydin and Tilton (2000) and Garcia, Knights, and Tilton (2001) respectively. These authors find different results, as the changes in productivity in Chile in the 1990s are driven by both net-entry as well as by technological change, while net-entry in the US play a relatively unsubstantial role during the 1980s. Ellerman, Stoker, and Berndt (2001) find that scale effects lead to large increases in labour productivity in US coal mines in the late 20th century. The widely cited work of Schmitz Jr (2005), undertakes a comprehensive examination of productivity at US and Canadian iron ore mines in the 1980s where the industry was threatened from international competition. The large boost in productivity in these years is attributed to changing labour practices.

A second branch of literature to which we contribute is the examination of resource extraction industries within a certain geographic regions. An example of this is Slade (2015), who determines the factors leading to entry or exit into the US copper mining industry from 1835 to 1986. Her results indicate that the discovery of new deposits and technological developments were the largest drivers of change. A study of the Russian gold mining industry during the Cold War is conducted by Godek (1994). Her goal is to determine why the amount of gold held by Russia at the end of the war was much smaller than had been anticipated. Her conclusion is that it was not a lack of production which led to this result, but rather a sale of the gold on international markets.

Finally, as gold has such an important place within the economy during this period, there exists a literature which examines the role of gold and the economy. Eichengreen and McLean (1994) examine pre-World War I gold production in an attempt to determine the largest determinants of changes in supply. They conclude that rather than price being the primary determinant, it is human settlement patterns which determined when new gold fields were brought into production. Moel and Tufano (2002) look at North American gold mines from 1988 to 1997 to determine what factors led to their decision to begin or end operations. As expected, the most important factors were the price of gold, operational costs, and the amount of reserves. Additionally though, they find that price volatility is particularly important. Finally, Skogstad and Petrunia (2017) examines the impact of Canadian government policies on the Ontario gold mining industry during World War II. Amongst other results, they find that the restrictions put on labour movements at the time led to a loss of nearly $1 billion in present day profits for the industry.

The paper is organized as follows. The next section examines the source of the data and provides some general discussion of the nature of the industry. This is followed by an examination of the trends in aggregate labour productivity at the time. These changes are decomposed in the section that follows. The final section concludes. All figures can be found at the end of the paper.

2 Data

Data for this project comes from the Annual Reports of the Ontario Department of Mines. These reports, produced annually from 1890 until 1970, contained both aggregate statistics for all mining in the province, as well as individual mine-level reports on each mining operation. These mine-level reports combine excerpts from the annual reports produced by the mines themselves and observations and data gathered by the local Department of Mine representative for the region. Because of this, the quality of the data does vary across mines, with some mines providing extensive data over a number of variables, while others provide little to no usable data.

At this stage, for examining trends in aggregate productivity, we make use primarily of the aggregate statistics. These statistics provide the amount of gold produced, the tons of ore milled, and the value of gold at each gold mine in operation in a given year. Data on employment was obtained from the mine-level reports. Very rarely was this labour data unavailable. For only 0.07% of the gold produced in the province during this fifty year period was employment data unavailable. We consider this missing value to be unfortunate, but almost surely to be insignificant to our findings.

During the fifty year span, there are 189 unique gold mines in operation that produce at least one ounce of gold. Summary statistics for these mines can be found in Table 1. Recall that our data are at a yearly frequency. By looking at the statistics for ounces produced, tons milled, and employment, it is clear that there are some large mines which are skewing the distributions. It is indeed the case that the industry is very heterogeneous in regards to the size of firms. To demonstrate this, note that the five largest mines account for over 50% of the total output in the province in this period. In general though, most mines produced in the tens of thousands of ounces a year range, though there is also a significant amount of mines which produce an extremely small amount of gold and only remain in operation for a short period of time.

We consider three different measures of annual average labour productivity in this paper. The first, average ounces of gold produced per worker, is our preferred measure as it is the most intuitive way of thinking of the output of a gold mine. We do also consider two alternative measures. The first is the average tons of ore milled per worker. Since the amount of gold produced in a year is highly dependent on the grade of the ore, that is the ounces of gold per ton of ore, it might be more logical to measure how much ore was milled per year. The problem with this measure is that the amount of ore a mine chooses to mill is not independent from its grade. During the excavating process, miners will avoid ore where the grade is below a certain threshold. Occasionally, mines may find very high-grade pocket of ore, which a manager may try to ration over years in order to smooth year-to-year gold output. Finally, some mines may be designed to process a large amount of low grade ore while others are optimized to process a small amount of high grade ore. Though both may be profitable and efficient mines, they will vary considerably in the tons of ore milled per worker.

The final productivity variable considered is the amount of revenue earned per worker. Given that there is not much overall variation in the price of gold from year to year, the ounces per worker productivity variable captures much of the same information here. Note that we examine nominal revenue per worker here, as the price of gold does not inflate over time as other prices do.

Examining the data for our preferred measure, we see that, on average, miners were producing around 161 ounces of gold per worker. This may seem low in light of the data presented in Figure 1, but recall that the measure there is weighted by the relative size of the mines. Productivity varied significantly between mines, ranging from a high of 649 ounces at Campbell Mine in 1964, to a low of 0.04 ounces at the Telluride mine in 1937, where they only managed to produce 1.09 ounces using 25 employees. It should be noted here that our employment measure is the average number of total employees working at the mine in a given year. Thus, not all employees are directly involved in the production process.

To get a better understanding of the heterogeneity, Figure 2 graphs a five-year moving average of labour productivity for six mines in the sample[2]. These were six of the largest mines in the sample, that all existed from the 1920s into the 1960s. Clearly, there exists a lot of heterogeneity across the mines, with the difference being as large as 200 ounces per worker in the early 1930s. Even when the values converge in the mid-1950s, the difference is still significant at over 20 ounces per worker.

To get a better understanding of some of the trends in the data, we will be relying on the data obtained through the mine-level excerpts, so a discussion of these data are warranted. This data-set was less complete than the aggregate source, as many small and short-lived mines provided very little data. In general, better data is available for mines which are larger and mines which are older. This source provided data for 76 mines which produced 91.5% of gold in the province between 1920 and 1970. This covers roughly 78% of all mines which produced at least 5,000 ounces of gold in a given year. Comparing aggregate output statistics to those obtained from this mine-level data source indicates that the data-set that we have created represents the Ontario gold mining industry very well. We rely on this source for variables such as milling capacity, quantity of reserves, and production costs.

[2]A moving average was chosen as the value can change sharply from year to year and makes understanding the trend more difficult.

3 Trends in Aggregate Productivity

As we have already seen in Figure 1, between 1920 and 1970, the aggregate labour productivity of an Ontario gold miner, measured as ounces of gold produced per worker, displays a concerning patterns. From 1920 to 1934, the average Ontario gold miner was able to produce an average of 253 ounces of gold a year. Suddenly, in 1934, this figure dropped substantially. Between 1934 and 1949, the average labour productivity was only 162 ounces. It was not until the late 1940s that productivity began to rise, until it once again reaching the 250 ounces per worker level in the mid 1950s, where it remained, largely unchanged, until 1970.

Our goal here is to determine the causes of this peculiar pattern. More specifically, we wish to determine what caused the sudden decline in productivity during the mid-1930s, and understand why it remained so low for the following years. Next, we hope to examine what precipitated the rise in productivity in the early 1950s, and to understand why, despite over three decades of technological process, were workers no more efficient in the 1950s and 1960s than they were in the 1920s.

As mentioned previously, the first consideration will be that our measure of labour productivity is not the most valid measure. When mining gold, much is dependent on the quality of the ore body. The number of ounces of gold found in each ton of ore mined will have a large impact on the amount of gold produced per worker. Though this value is not entirely exogenous, as the mines can target sections of their ore body with higher or lower grade. Nevertheless, it is a valid measure of labour productivity, and Figure 3 presents the movement in this variable over time. We can immediately see that this variable does not have the large drop in productivity in 1934 observed in Figure 1, though the growth in productivity seen during the early 1950s is indeed present. There is also a large increase in productivity in the final five years of the data, which was not present in Figure 1 either.

Another variable with which we can measure productivity is the amount of revenue earned per worker. Figures 4 and 5 present this data. Figure 4 presents the nominal values while Figure 5 presents the real value. Since the price of gold was determined by the US government throughout this period, there is no need to adjust these values to account for inflation in the price of gold over time. As such, our analysis will focus on nominal revenue per worker. However, the real-series do give a better indication of the purchasing power of the output per worker, so the graph is still informative.

Each of these figures presents two different lines. The revenue per worker line merely indicates the average amount of revenue earned per worker. The adjusted revenue per worker line includes the value of a subsidy program that was introduced by the Government of Canada in 1948 and which continued until the early 1970s. Officially, the program, the Emergency Gold Mining Assistance Act (EGMAA), was structured as a cost subsidy, where mines would receive a payment per ounce of gold produced above a certain threshold. The amount of they payment was equal to a fraction of the difference between the average cost of producing an ounce of gold in that year and a specified value. Over the years, the policy changed in terms of the fraction reimbursed per ounce and the specified value. For instance in 1951 the formula was given by the following:

$$S = 0.5\,(C - 22) \tag{1}$$

where S is the subsidy per ounce, and C is the actual average operating cost per ounce of gold. So a mine that produced 10,000 ounces of gold above the designated threshold, at an average cost of $28 per ounce were receive a total subsidy of $30,000. Though structured as a cost subsidy, many mines treated it as a subsidy to the price of gold. This is what the second line in these figures shows, the revenue received per worker, adjusted for this subsidy.

Analyzing Figures 4 and 5, we see that in nominal terms, there does not appear to be much variation in the revenue earned per worker between 1920 and 1948 (except for a large spike in 1934 which we will discuss further below). After 1948, the value shows a continual increase until the end of the data-series. In real terms, revenue per worker has an inverted U-shape between 1920 and 1948. Afterwards it remains relatively constant. Given the negative inflation present in the 1920s and 1930s, it is not surprising to see such a shape in the real data. What is interesting is that it appears that the increasing productivity of labour in 1950 and beyond is nearly exactly offset by the rate of inflation.

Figure 6 combines our four productivity measures, ounces per worker, tons per worker, revenue per worker, and adjusted revenue per worker, into a single image. In order to compare these values, we normalize every series to 100 in 1920. Clearly some similar patterns exist in the data, though some differences appear as well, such as in 1934, where revenue per worker suddenly spikes and ounces per worker suddenly falls. Of course, this divergence is not unexpected given that in 1934 the US government suddenly increased the price of gold by nearly 70% from $US 20.67 to $US 35.00 an ounce. Thus even if nothing else changed in that year, the productivity of labour as measured in dollars per worker would suddenly jump. Figure 7 shows the movement in the price of gold over the 50 years. After the large jump of 1934, the only remaining changes were through movements in the exchange rate. Clearly, these were relatively minimal.

One might ask what else in the industry was changing over this fifty year time span that might have influenced labour productivity. Figure 8 shows the aggregate amount of labour employed in the sector during this period. There is clearly a strong upward trend for the first half of the data, until the Second World War, where employment falls drastically. There is a slight post-war recovery, but ultimately the sector does not recover, and employment falls off quickly in the late 1960s.

Over this period, another major change to the industry was the entrance and exit of mines. Figure 9 shows the number of mines operating in the industry in a given year. Clearly, the increase in the price of gold in 1934 led to a large increase in the number of operating mines. It went from 21 to 69 in only four years. During the war, a large number of mines ceased operations. After a short recovery, there was a near continuous decline in the number of operating mines until the end of the period.

Another factor which might influence the productivity of the mines is the quality of the ore being mined. Figure 10 shows the average grade of the ore milled in a given year. The increase in the price of gold clearly led to a decline in the average quality of ore milled. Whether this was caused by new mines entering with lower grade ore, or whether existing mines began to process lower grade ore from their own reserves, cannot be determined from this graph alone. The average grade remains relatively constant after this, indicating that this is less likely to be a significant contributing factor of any further changes in aggregate productivity.

Economies of scale are another potential contribution to the change. Figure 11 shows how the average amount of gold produced by a mine changed from year to year. We observe an inverted U-shaped pattern in this data. It is of note that an increase in scale in the early 1950s coincides with increases in our labour productivity variables, though the direction of causality here it not immediately clear.

Additionally, differences across mining camps in the province may play an important role. Figure 12 shows the location of the mines from the mine-level data source. The four mining camps of Red Lake, Greenstone, Timmins, and Kirkland Lake, contained the largest concentration of mines within the province with 12, 11, 24, and 14 mines respectively[3]. Figure 13 indicates the average labour productivity for these four mining camps. Kirkland Lake and Timmins in Eastern Ontario were first developed in the 1910s and contained a number of large mines. The Greenstone and Red Lake mining camps were only opened after the rise in the price of gold in the 1930s. Clear differences in labour productivity, in terms of ounces per worker, exist across these four mining camps during this period, with all four being both the most productive and least productive for at least one year in the sample.

One final potential evolution in the industry is the substitution of capital for labour. Figure 14 indicates the average available milling capacity at a mine from 1934 to 1967. Though it remains relatively unchanged throughout the entire period, there is a slight increase in the 1950s, corresponding to the increasing labour productivity seen at that time. Figure 15 displays how much of the capacity was being used in each year throughout this period. Except for the Second World War, capacity usage was, on average, above 90% in the 1930s and in the mid-80% range for the post war years, before dropping substantially in the late-1960s.

All of these figures indicate that during this fifty year period the industry faced a number of sudden events and policy changes which the industry reacted to over the following several years. For the purposes of this study, we have identified four periods where we will examine how aggregate productivity changed in reaction to a specific event or policy change.

The first period is from 1933 to 1938. In January 1934, the industry was revitalized by the sudden increase in the price of gold from $20.67 to $35. The industry responded to this event through a massive increase in the number of mines in operation, as seen in Figure 9.

[3] Recall this is out of the 76 mines for which mine-level data is available. Location data for the other 113 operations has not yet been compiled.

Additionally, the average quality of ore milled by these mines fell as well. As a result, Figure 6 shows that from 1933 to 1938, productivity, in terms of ounces produced per worker fell dramatically, while revenue per worker increased. Note that even though the price of gold increased by 70%, revenue per worker did not, indicating that there was not a complete pass through.

For this period we decompose this change in aggregate productivity to determine which factors were the primary drivers of the substantial fall. One possibility was that a large amount of new, inefficient mines, entered the industry which caused the decrease in aggregate labour productivity in this period. The second possibility is that existing mines were now able to profitably mine lower grade portions of their ore bodies thanks to the increased price of gold, and that the decreased efficiency of these mines caused the fall in aggregate efficiency. Of course it is possible that both of these contributed in equal amounts to the change. Studying this particular period is quite helpful as the price of gold varied very little over the rest of the period of study. This event best captures how the industry responds to a substantial changes in output price.

The second period of study is from 1938 to 1946 and encompasses the Second World War. Skogstad and Petrunia (2017) examines the impact of the war on the industry in detail, though the focus in that paper is on the impact of government policy on the average operating cost of mines rather than on their labour productivity. The war was characterized by two distinct periods. From 1939 to 1941 the need for foreign reserves to purchase American weapons caused the Canadian government to designate the gold mining industry a vital war industry. This gave it priority access to labour. As Figure 8 shows, employment in the industry increased in these early years. In the end this policy was relatively ineffective as total output of gold did not substantially increase despite the increase in labour.

From the end of 1941 onwards, the industry lost this priority status and began to shed substantial amounts of labour. Worse still, labour market regulations prevented labour from moving from one firm to another. Additionally, the larger mines were required to continue operating, even if it meant operating at an inefficiently low level of output. The result of these policies is that operating costs rose substantially. The impact of this policy can be seen in Figure 6, where all three measures of productivity decline sharply during the late-war years.

Although there was some exit at this time, those mines that did exit were relatively small producers and are thus not expected to have much impact on the aggregate productivity measure. At the same time, labour was unable to move between mines. Thus, it is expected that the main driver of the falling efficiency in this period will be the decrease in productivity at individual mines.

The next period we consider is the immediate post-war years from 1946 to 1955. In the post-war years, the costs that mines faced began to grow rapidly, as can be seen in Figure 16. Since wages had been frozen during the war, there was pent-up demand for wages to adjust to reflect market realities. Additionally, Canadian industries were booming in the post-war years, draining labour away from mines. The result is that between 1946 and 1955, average nominal wages increased by 65%, while the price of gold fell by 5.6%. The industry was facing a crisis, and asked for government assistance which came in 1948 through the Emergency Gold Mining Assistance Act.

This was a period of substantial adjustment for the industry. Figure 9 shows that though there was a small post-war bump in the number of operating mines, this was quickly reversed and the industry contracted in the face of these higher operating costs. The appreciation of the Canadian dollar in this period also led to the price of gold being relatively low, slightly under $CAN 35 an ounce, compared to the war years where it was set at $CAN 38.5 an ounce thanks to a freeze in the Canada-US exchange rate. Figure 6 shows that the result of all these changes was that there was in increase in productivity across our three measures during this period. We believe that this will be caused by both the exit of inefficient firms and by the increased productivity of individual firms. During the war, the need to devote all capital production in the economy towards the war effort meant that the capital at mines would have degraded during the 1940s. It is likely that a post-war re-investment in capital at these mines would have contributed to increased productivity at these mines.

Even though the EGMAA subsidy lasted until 1973, there appears to be a break in many of the productivity series in the mid-1950s. Figure 6 shows that ounces per worker flattens out after 1955, as too does tons per worker. Revenue per worker and adjusted revenue per worker also flatten out here for a few years as well, but then continue to grow until the end 1970. This was likely due to a favourable shift in the exchange rate, which caused the price of gold to increase in the late 1950s. Regardless, the data suggests that the post-war adjustment ended in 1955 and a new period emerged in the following years.

The final period is thus 1955 to 1970. Over this fifteen year span, most productivity measures remain stable until a sudden increase in all four in the final few years. It appears that this sudden increase in productivity was caused by a large number of high-output mines closing simultaneously. Three of these mines: the Hollinger mine, the Lake Shore mine, and the Teck-Hughes mine were among the top 10 gold producing mines in the province during this 50-year span, and were relatively inefficient producers in their final years. This is not unexpected as the costs of mining must surely increase as mines age. As the size of the underground mining activities grow, ore must be transported a further distance, more shafts are required, and even the time required by miners to reach the areas where they work will increase. All of these will lead to less production. Another possible factor, as Figure 16 indicates, may have been a sudden steep rise in costs for the industry as a whole.

Thus, these four time periods are unique periods in the history of Ontario's gold mining industry. Each involve a sudden and substantial change to the industry followed by a prolonged period of adjustment. The following section will examine how precisely the industry as a whole and individual mines reacted to these events.

4 Decomposition

Using the decomposition method from Foster, Haltiwanger, and Krizan (2001) we use the following formula to break down the changes in labour productivity between the beginning year and end year for each of our four time periods.

$$\begin{aligned}\Delta P_t = & \sum_{e \in C} s_{et-1} \Delta p_{et} + \sum_{e \in C} (p_{et-1} - P_{t-1}) \Delta s_{et} + \sum_{e \in C} \Delta p_{et} \Delta s_{et} \\ & + \sum_{e \in N} s_{et} (p_{et} - P_{t-1}) - \sum_{e \in X} s_{et-1} (p_{et-1} - P_{t-1})\end{aligned} \quad (2)$$

where N denotes mines that enter, X denotes mines that exit, and C denotes mines that continue to operate. s_{et} denotes mine e's share of aggregate labour in period t, p_{et} denotes mine e's productivity in period t, and P_t denotes aggregate productivity in the industry in period t. Δ represents the change from period t and $t-1$.

The interpretation of each of these five components is fairly intuitive. The first term represents the "within" component of the decomposition, it captures the change in aggregate productivity caused by the change in productivity at an individual mine, weighted by the mine's share of total employment in the industry. The second term is the "between" component, which captures how the relative share of a mine's employment within the industry changes, weighted by their deviation from aggregate productivity. The third term is a cross-term, which captures the interaction between these two previous components. The fourth term captures the impact on aggregate productivity of newly entering mines, while the fifth term captures this change for exiting mines.

In a typical industry one would expect to see certain patterns in a decomposition. First, it would be expected that exiting firms were relatively less productive, as an efficient firm is more likely to be profitable. In the case of mining however, a productive mine may close simply because it runs out of ore. Thus, it is quite possible that exiting firms could cause aggregate productivity to either rise or fall. Second, it would also be typically expected that the within component would be non-negative, especially during this time period. The advances in technology in this period meant that most firms would be expected to become more productive. Again, for the mining sector this is not necessarily going to be the case, as productivity is likely to fall as the depth of the mine increases.

In a well-functioning market, the between component should be positive. If increased productivity is correlated with higher profit margins, as it would most likely be, then the more productive mines would be better able to attract the more productive workers through higher wages. Even in the mining sector, this should hold, so we expect this component to be largely positive. The entry component could be either positive or negative in the mining sector. As mentioned earlier, these mines do not compete on output price, so it is not necessary for entrants to be relatively efficient, so long as they can produce gold at a cost lower than the fixed price of gold. Thus, entrants can effect aggregate productivity in either direction.

Finally, the cross component may be influenced by factors such as returns to scale. If there are increasing returns to scale then it is likely that the two terms comprising this component will move in the same direction. From Skogstad and Petrunia (2017) there is some indication that this is the case in the mining sector, so it is likely that this component will be positive.

As mentioned, we decompose the change in aggregate productivity during these four time periods. Table 2 displays the decomposition between 1933 and 1938. Recall that in January 1934 the price of gold was increased by nearly 70%, and thus this decomposition indicates how the industry adapted to this change. With a net entry of 47 mines in this short time frame, it was expected that this would have a significant impact on the change in productivity, and this is indeed the case. Focusing at first on the measure of ounces per worker, there was a reduction in productivity of 79 ounces per worker between these two years, of which 52% can be accounted for by the entry of new, relatively unproductive, firms. Offsetting this is a productivity gain caused by the exit of six relatively unproductive mines. Note that in this table and those that follow, the exit component has the negative value from equation 2 already factored-in. Thus a positive value here indicates that relatively unproductive mines were exiting. Despite its importance though, the impact of new entrants is much less significant than the declining efficiency of continuing mines, which accounts for 83% of change. Despite an increase in labour at these continuing mines of over 2,500 workers (an increase of 31.2%), their gold output fell by 3.5%. Offsetting these negative changes slightly is a positive value in the cross term, indicating that, in this case, those firms which were losing share were also becoming less productive, indicating the presence of increasing returns to scale in the industry.

The alternate measure of productivity of tons of ore milled per worker largely demonstrates the same patterns. However the net-entry component and within component are of a more similar magnitude. The between component is also of more significance here, indicating that labour is moving away from the most productive mines.

Looking at the third measure of labour productivity, revenue earned per worker, we see a considerable rise in productivity, as expected, since the price of gold increased substantially. Although the price of gold increased by 70%, revenue per worker did not increase by the same margin, indicating that there was not complete pass-through here. The decomposition shows that the change in productivity is overwhelmingly driven by the increased revenue per worker at continuing mines, with the entry of new mines causes a fall in this productivity measure.

Overall, despite the entry of a large number of small and relatively inefficient mines, it was the decreasing productivity of existing firms which largely drove the fall in productivity. Existing mines began to mine portions of their ore bodies that were previously uneconomical, resulting in a large decline in the average grade of ore mined in the province and an accompanying fall in productivity. The negative result for the between component indicates that the labour market was not assigning labour efficiently in the period, though the impact of this was relatively minor. The positive value for exit indicates that unproductive mines were exiting the industry. This is somewhat unexpected given that the increased price of gold would have likely kept these mines profitable. It is possible that they simply depleted their ore body and could not continue operations.

Table 3 displays the results of the decomposition for the World War II time interval. The result of the war was a substantial decline in both the ounces produced by each worker and in the revenue generated by each worker. No substantial change in the tons of ore milled per worker were seen, though this decomposition is presented here for sake of completeness. Since the price of gold was fixed during this period except for the first and last year, the results for ounces per worker and revenue per worker are largely identical. Comparing the magnitudes of the decomposition components, we see that it was overwhelmingly the reduction in efficiency within the mines themselves which drove this change. As Skogstad and Petrunia (2017) indicate, the inefficient labour policies of the war meant that mines were forced to become less efficient. This is further reflected by the negative value for the between component, indicating that labour was not allowed to flow to more productive mines in this period. Offsetting these results are positive components for the cross variable, again indicating increasing returns to scale, and the exit of 34 relatively unproductive mines. Though this is a large number of mines that exited, their impact is relatively small due to their small share of employment prior to exit.

Table 4 has the results for the decomposition for the period 1946 to 1955. With the introduction of the Emergency Gold Mining Assistance Act, we can now look at both revenue per worker and adjusted revenue per worker, which includes the subsidy. We see that for all four measures of productivity, there was increasing productivity during these years. In all four cases, the within component was driving the results. Individual mines were becoming more efficient. This is likely a result of the ability of the mines to re-capitalize as well as their ability to hire workers to work at a more efficient level of output. The between component is also significant, indicating that labour was flowing to the more productive mines in this period. This stands in contrast to the previous time period where government labour policies prevented this from occurring. Finally, the entrance of six relatively efficient mines and the exit of eighteen inefficient mines further pushed these productivity measures higher. If we use this to evaluate the success failure of the EGMAA, we can say that the introduction of the policy coincided with a period of increased labour productivity in the industry.

Table 5 displays the decomposition results for the final period, 1955 to 1970. As the decomposition shows, this period saw massive increases in the revenue and adjusted revenue earned per worker, though increases in productivity in the other two measures were much more modest. Focusing on the revenue measures for this period, we see that without adjusting for the impact of the EGMAA, individual mines were becoming less efficient. The productivity gains were driven mainly by the between component and the exit component. As mentioned already, there was a substantial exit of a large number of large, old mines, which were dragging down productivity. Their closure certainly helps explain the large increase in productivity. Labour was also flowing out of these unproductive mines in general in this period, as seen by the importance of the between component. If you factor in the additional revenue earned through the EGMAA, then there is some indication that individual mines were becoming more efficient. Looking to the ounces per worker measure for further evidence, we see here that the exit story is again salient, and that labour was indeed flowing to the more efficient firms.

Taking all of these results together, the within component is often the primary driver of aggregate productivity change in this industry, and is especially so in the first three time periods. In general, the firms seemed to become less efficient as the years progressed, with the exception of the post-war period where they made substantial productivity gains. As expected, the between component is positive during most of the period of study. This indicates that the labour market was operating well to move labour to the more productive mines. The major exception to this was during the war, where restrictive labour policies prevented this from occurring. The cross term is consistently positive, indicating the likely presence of increasing returns to scale in the industry.

The entry term displays both positive and negative values. In the first period it is strongly negative as the sudden rise in price allowed even the most marginal mines to enter operations profitably. During the later-two periods, new entrants were more productive than average. This may be caused due to the fact that many of these new entrants were in the Red Lake gold camp which enjoyed relatively high-grade ore bodies. Finally, the exit component was consistently positive, indicating that relatively unproductive mines were existing the industry. As stated above, this was not necessarily going to be the case for this particular industry.

5 Conclusion

This paper undertook a decomposition of the aggregate labour productivity of Ontario's gold mining industry during four distinct time periods between 1920 and 1970. The objective was to explain why the industry appeared to make no labour productivity gains over this fifty year span in terms of ounces produced per worker, and why throughout the 1930s and 1940s, productivity was persistently low.

The cause of the sudden decline in productivity is now very clear. A sudden, 70% rise in the price of gold led to existing mines exploiting lower-grade portions of their ore bodies that were previously unprofitable. Additionally, a large number of small, relatively unproductive mines entered the industry, further bringing down aggregate productivity. Thus aggregate productivity fell because the mines were using lower quality inputs (lower grade ore) and because the scale of production of the entering mines was small.

It might very well have been the case that without the Second World War, productivity would have rebounded quicker as the real price of gold fell with inflation, forcing low productivity mines out of the industry. However, the six-year long war kept labour productivity low as poor labour policies forced individual mines to operate at an inefficiently low level of output, exit of the larger mines was forbidden, and replacement capital was unavailable. Thus, productivity gains in the industry were pushed back until the post-war period. These gains came from individual firms becoming more efficient, labour moving to the more efficient firms, firms being able to take advantage of increasing returns to scale, the entry of highly productive mines, and the exit of relatively unproductive mines. All these gains were only possible however thanks to the subsidization of the industry through the EGMAA which kept the industry viable. Finally, some aggregate productivity gains were made in the 1960s thanks to fortuitous exchange rate premiums and the simultaneous exit of some old, large, and relatively inefficient mines.

Thus, it is not the case that the average worker in 1970 is not any more productive than that in the 1920s. For one, workers in 1970 are processing ore of a much lower quality. They are also potentially handicapped by an inefficient use of the capital stock which is operating far below its designed capacity in 1970. Finally, the scale of the average mining operation in 1970 is smaller than in the 1920s. Our next steps will be to analyze how these factors influence the labour productivity of an average mine to determine if they explain the difference entirely, or if other, unseen, factors, such as technological advancements, are contributing to the change.

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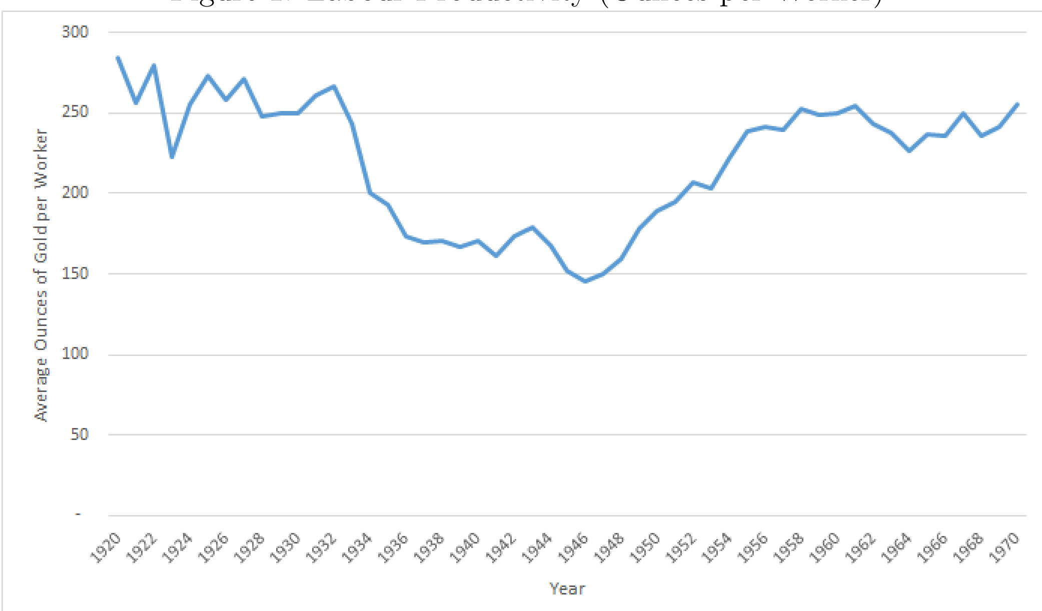
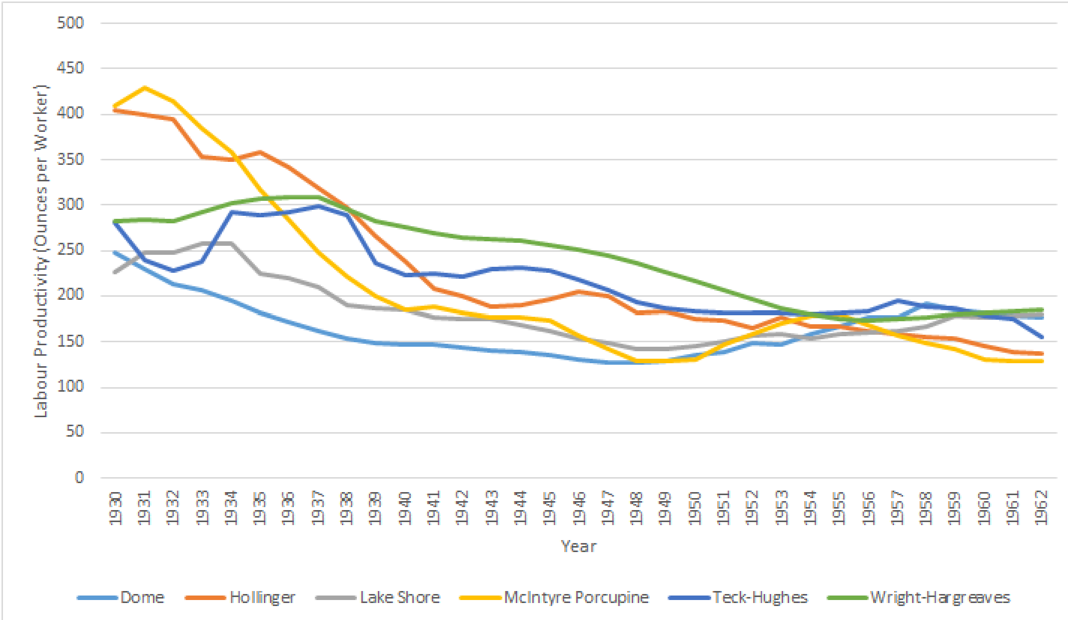
Figure 1: Labour Productivity (Ounces per Worker)



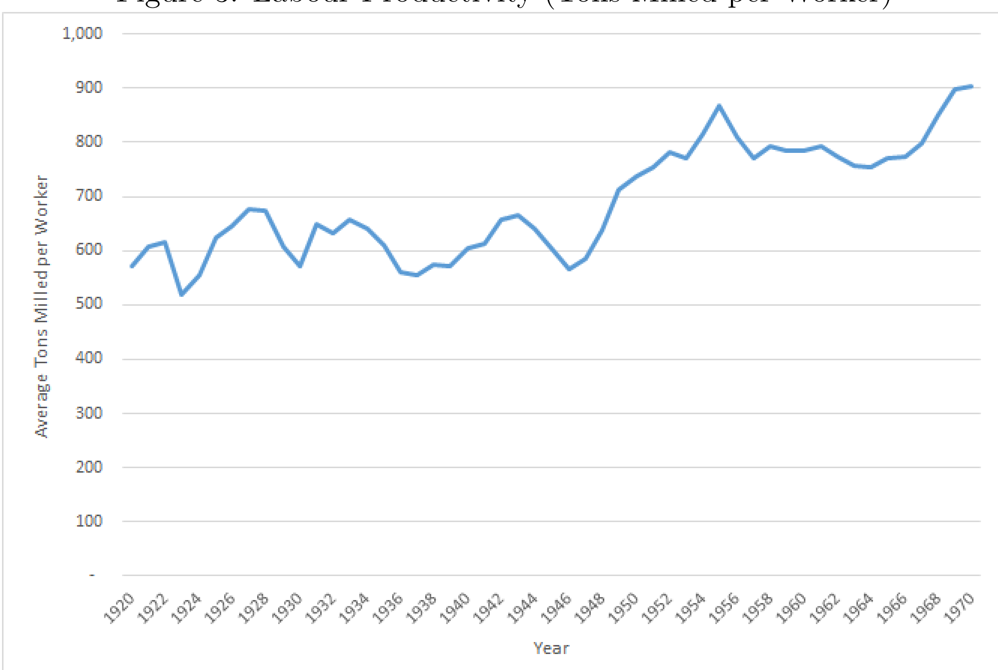
Description: The total ounces of gold produced in Ontario's gold mining industry in a given year divided by the total number of employees in the industry.

Figure 2: Labour Productivity at Select Mines



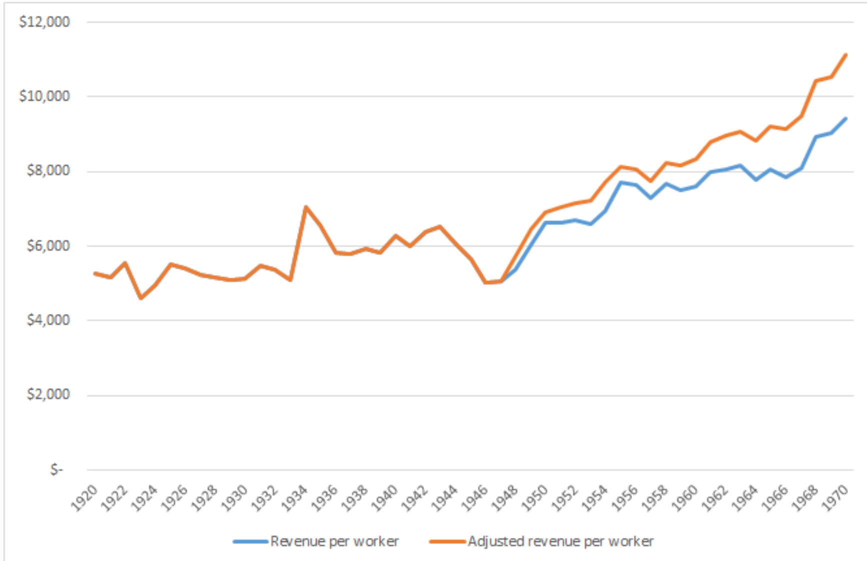
Description: The average ounces of gold produced per worker at six of Ontario's largest mines that operated between 1930 and 1962.

Figure 3: Labour Productivity (Tons Milled per Worker)



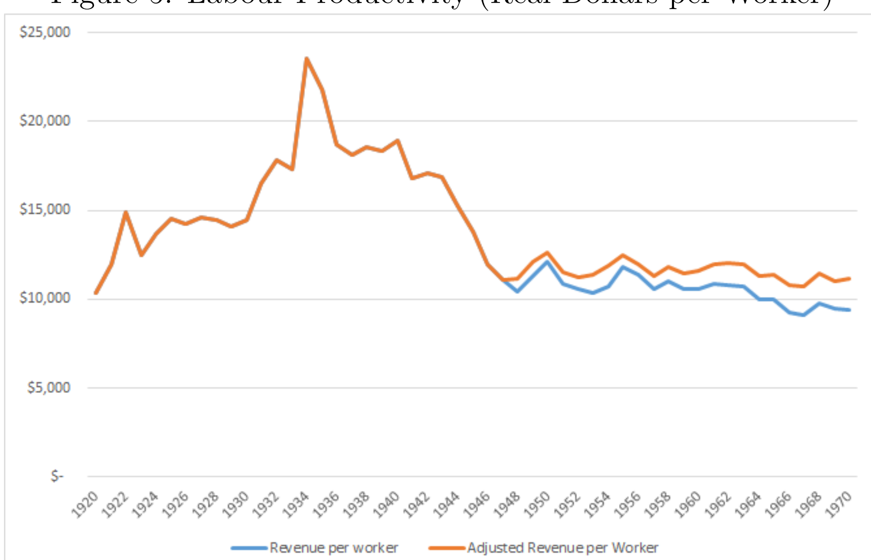
Description: The total tons of ore milled in Ontario's gold mining industry in a given year divided by the total number of employees in the industry.

Figure 4: Labour Productivity (Nominal Dollars per Worker)



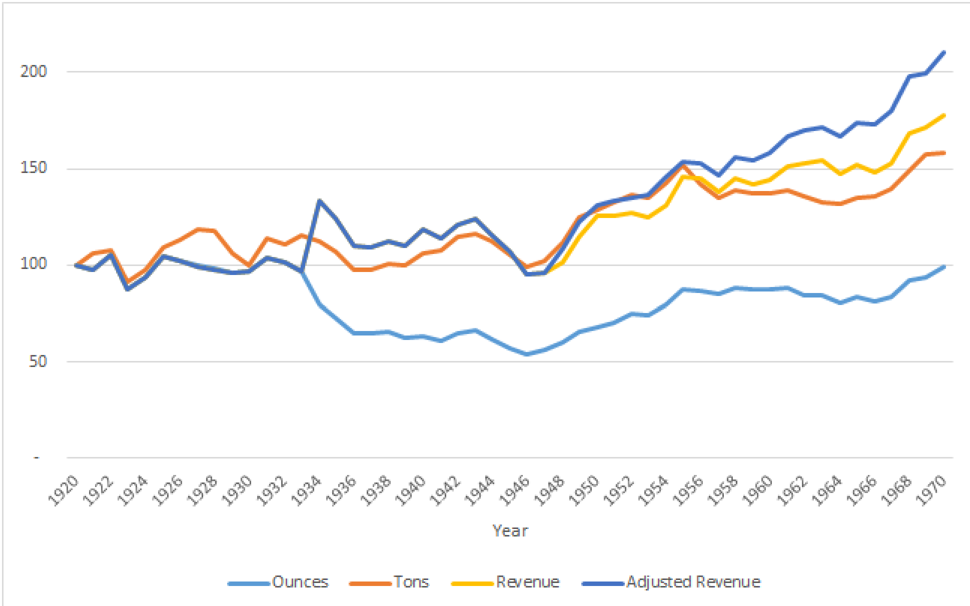
Description: The 'Revenue per worker' line is the total revenue from the sale of bullion earned in Ontario's gold mining industry in a given year divided by the total number of employees in the industry. The 'Adjusted revenue per worker' line is the total revenue earned from the sale of bullion plus the total amount of subsidy provided through the EGMAA in Ontario's gold mining industry in a given year divided by the total number of employees in the industry. These values are not inflation adjusted.

Figure 5: Labour Productivity (Real Dollars per Worker)



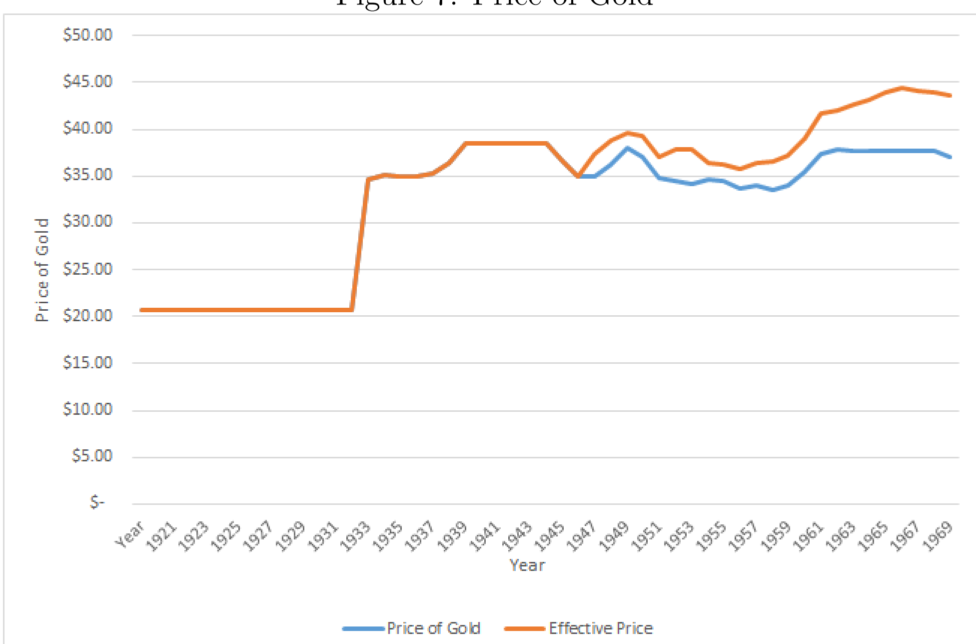
Description: The 'Revenue per worker' line is the total revenue from the sale of bullion earned in Ontario's gold mining industry in a given year divided by the total number of employees in the industry. The 'Adjusted Revenue per Worker' line is the total revenue earned from the sale of bullion plus the total amount of subsidy provided through the EGMAA in Ontario's gold mining industry in a given year divided by the total number of employees in the industry. These values are adjusted for inflation (1970 dollars).

Figure 6: Labour Productivity Indexes



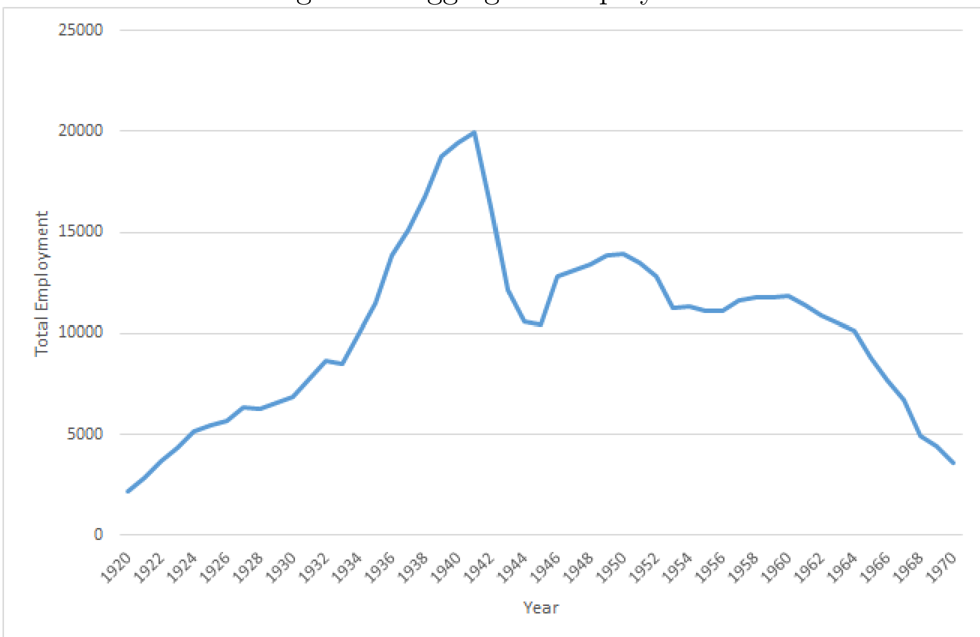
Description: These are indexes of the four labour productivity variables introduced in Figures 1, 3, and 4. They are each normalized to 100 in 1920.

Figure 7: Price of Gold



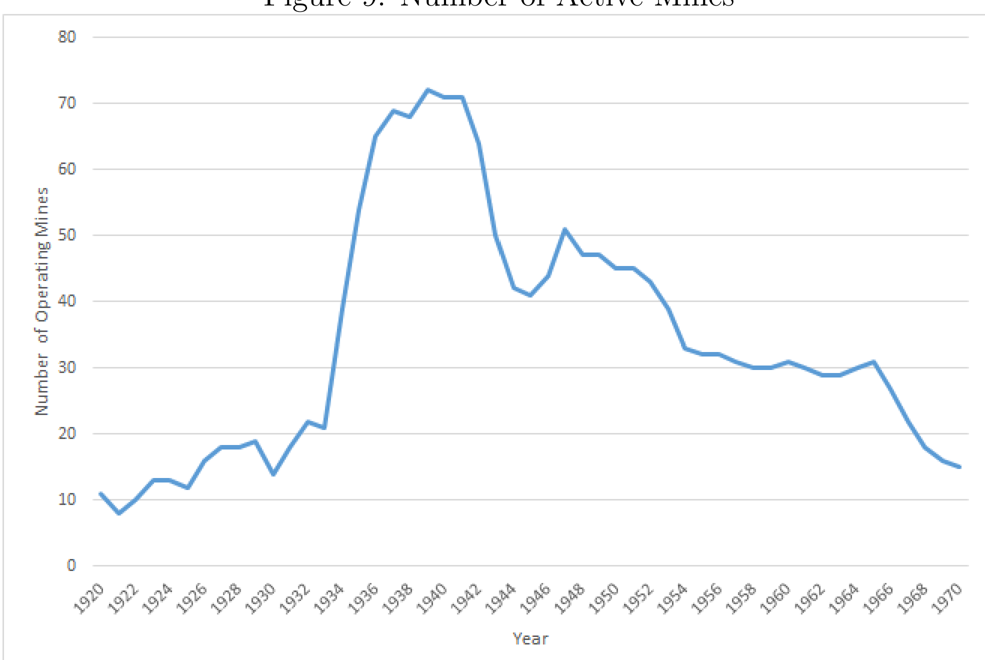
Description: The 'Price of Gold' line is the average yearly price of gold received by Ontario's gold mines. It is found by dividing total revenue from the sale of gold by total ounces of gold produced in a given year. The 'Effective Price' is found by dividing the total revenue from the sale of gold plus the total subsidy through the EGMAA by the total ounces of gold produced by the industry in a given year.

Figure 8: Aggregate Employment



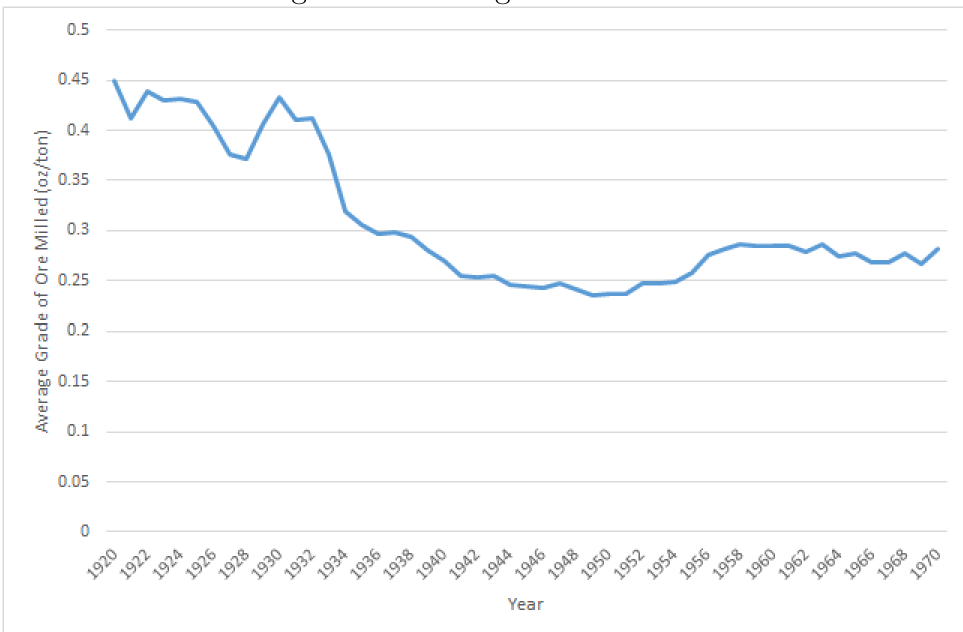
Description: The average total number of people employed in Ontario's gold mining industry in a given year.

Figure 9: Number of Active Mines



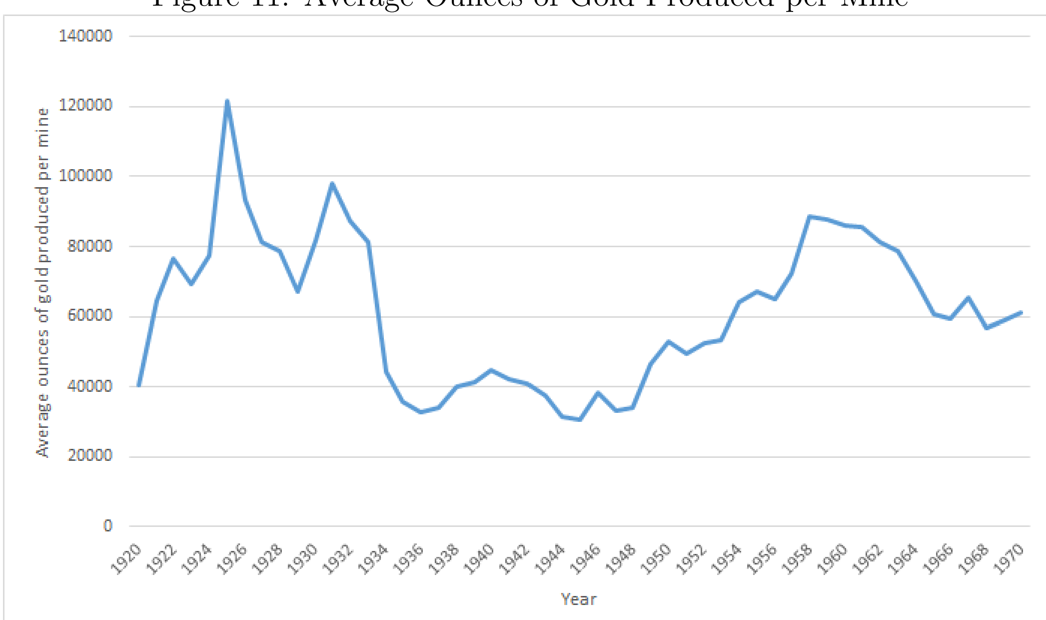
Description: The total number of gold mines that produced at least one ounce of gold in the province of Ontario in a given year.

Figure 10: Average Grade of Ore



Description: The average grade of the ore milled in Ontario's gold mines in a given year. This is calculated as the number of ounces of gold produced in a given year divided by the total tons of ore milled in the same year.

Figure 11: Average Ounces of Gold Produced per Mine

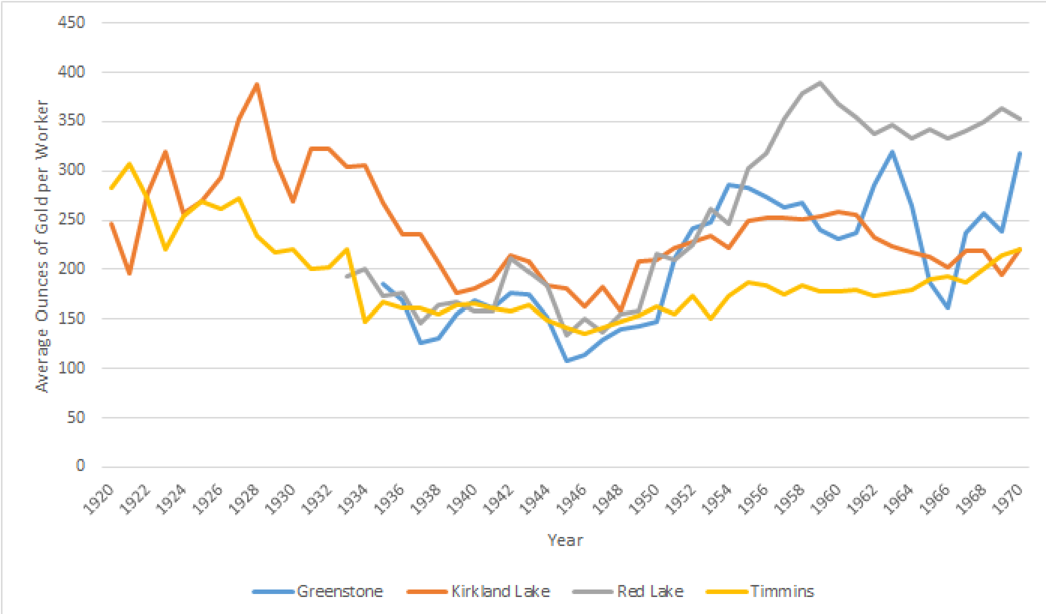


Description: The average ounces of gold produced per mine is calculated by dividing the total number of ounces of gold produced by gold mines by the total number of gold mines that produced at least one ounce of gold in the province of Ontario in a given year.

Figure 12: Location of Mines

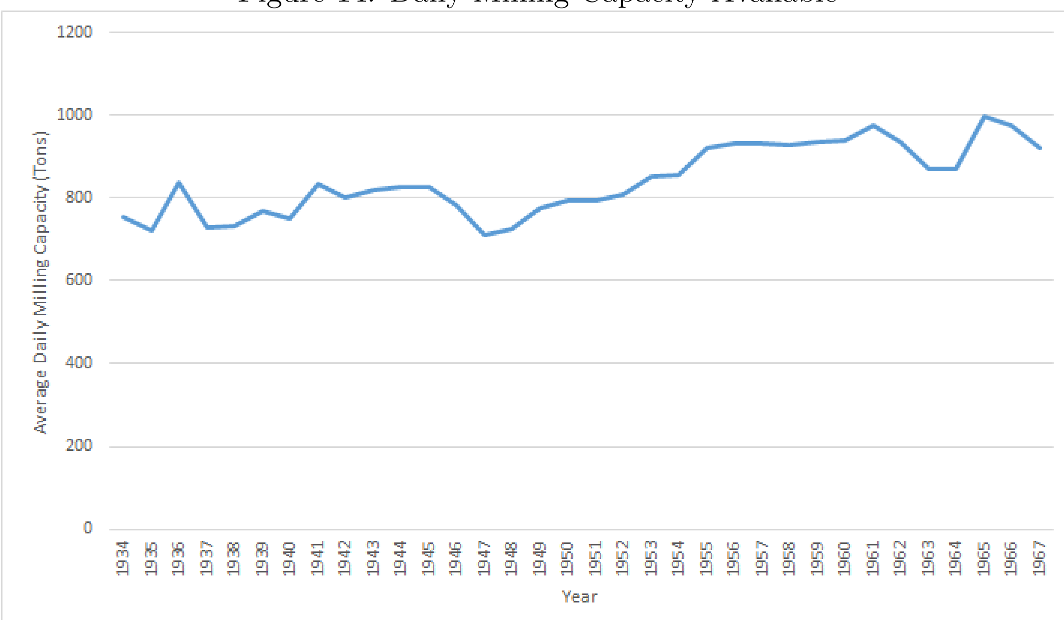
Description: Each pin is the location of a mine where mine-level data is available. Note that Red Lake has 12 pins, Greenstone has 11 pins, Timmins has 24 pins and Kirkland Lake has 14 pins.

Figure 13: Average Labour Productivity by Region



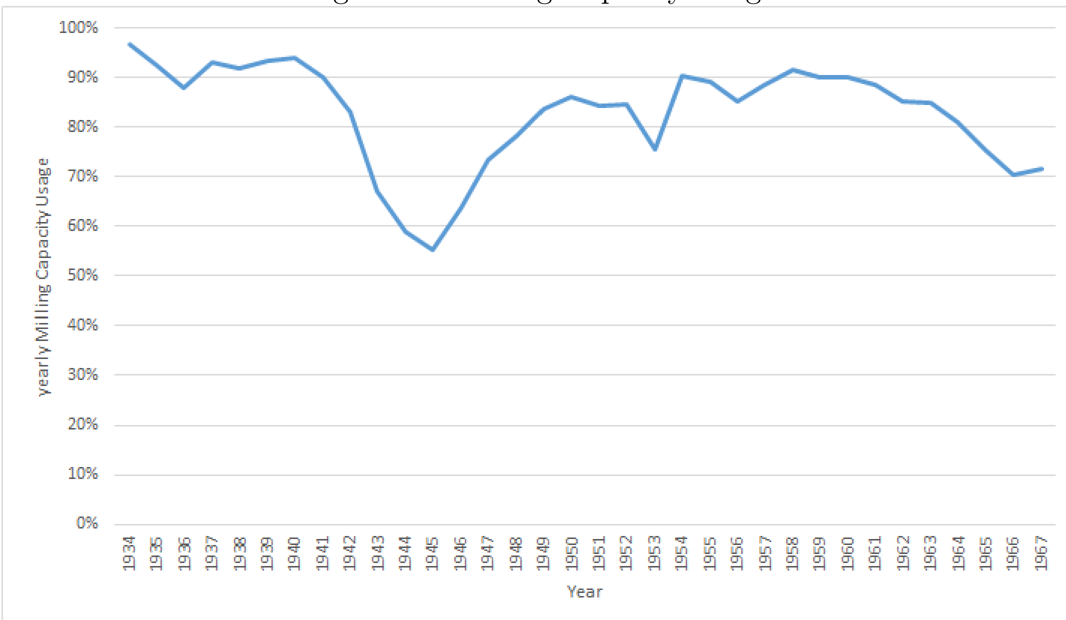
Description: For each of the four mining camps, the total ounces of gold produced therein in a given year is divided by the average total number of employees working at the mines in these locations.

Figure 14: Daily Milling Capacity Available



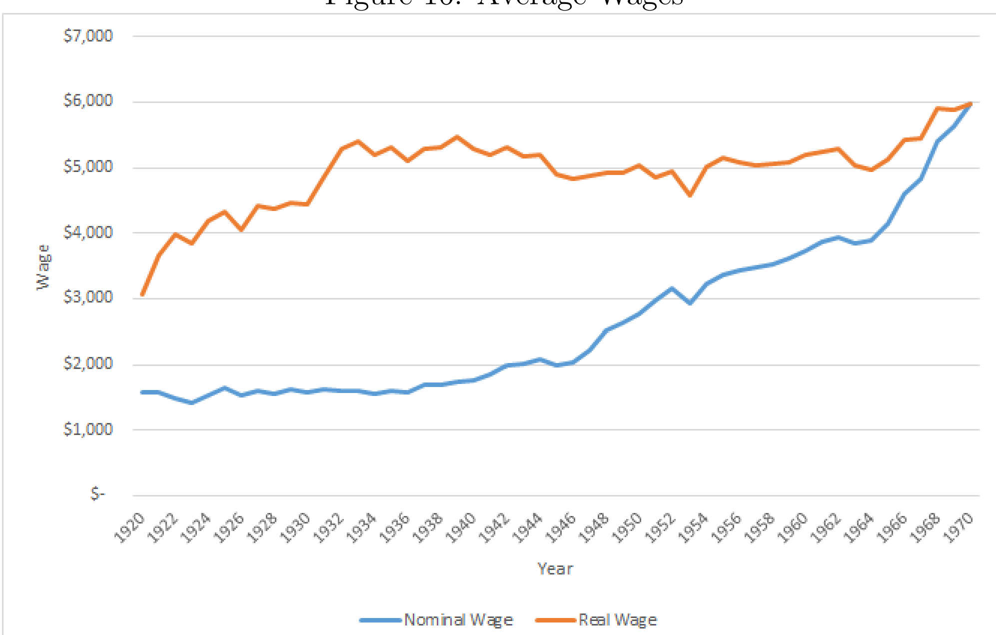
Description: The processing facilities at each mine are rated to process a certain amount of ore per day. This line indicates the average amount of processing capacity at an individual gold mine in a given year.

Figure 15: Milling Capacity Usage



Description: The percentage of total processing capacity at Ontario's gold mines that is being used in a given year.

Figure 16: Average Wages



Description: The average nominal wage and average real wage (1970 dollars) of workers at Ontario gold mines in a given year.

Table 1: Summary Statistics

Variable	Mean	Median	St. Dev	Max	Min
Ounces Produced	58,448	28,763	91,536	757,306	1
Tons Milled	203,605	108,947	298,890	2,178,329	0
Employment	298	179	409	3,124	2
Ounces/Worker	161.16	156.07	96.54	648.98	0.04
Tons/Worker	613.09	541.12	449.84	4,089.13	0.00
Revenue/Worker	$5,508.89	$5,413.16	$3,327.41	$24,502.23	$1.53

Description: Summary statistics for the ounces of gold produced, tons of ore milled, and average employment at Ontario's gold mines for a given year between 1920 and 1970. Summary statistics for our three productivity measures are also presented here.

Table 2: 1933 to 1938 Decomposition

Values	Total	Within	Between	Cross	Entry	Exit
Ounces	-79.18	-65.87	-2.48	22.58	-41.55	8.15
Tons	-84.64	-38.41	-24.56	8.91	-53.12	22.55
Revenue	$808.04	$1,210.51	-$51.36	-$367.31	-$152.19	$168.38
Shares						
Ounces	1.00	0.83	0.03	-0.29	0.52	-0.10
Tons	1.00	0.45	0.29	-0.11	0.63	-0.27
Revenue	1.00	1.50	-0.06	-0.45	-0.19	0.21

Description: A breakdown of the contributions to the changes in aggregate labour productivity between 1933 and 1938 as described in Equation 2. Three different labour productivity measures are considered: ounces per worker, tons milled per worker, and revenue per worker. The upper half represents the values of this decomposition while the lower half calculates what share each variable contributes to the total change. Note that the Exit component presented here has already factored in its negative coefficient.

Table 3: 1938 to 1946 Decomposition

Values	Total	Within	Between	Cross	Entry	Exit
Ounces	-30.86	-31.46	-11.49	7.30	-4.30	9.09
Tons	-5.97	-29.53	-26.83	40.15	-0.70	10.93
Revenue	-$888.11	-$931.73	-$404.25	$262.97	-$134.91	$319.80
Shares						
Ounces	1.00	1.02	0.37	-0.24	0.14	-0.29
Tons	1.00	4.94	4.49	-6.72	0.12	-1.83
Revenue	1.00	1.05	0.46	-0.30	0.15	-0.36

Description: A breakdown of the contributions to the changes in aggregate labour productivity between 1938 and 1946 as described in Equation 2. Three different labour productivity measures are considered: ounces per worker, tons milled per worker, and revenue per worker. The upper half represents the values of this decomposition while the lower half calculates what share each variable contributes to the total change. Note that the Exit component presented here has already factored in its negative coefficient.

Table 4: 1946 to 1955 Decomposition

Values	Total	Within	Between	Cross	Entry	Exit
Ounces	85.58	41.06	12.59	8.39	14.67	8.87
Tons	300.29	192.76	66.60	7.43	29.83	3.67
Revenue	$2,674.86	$1,176.12	$461.59	$229.01	$483.69	$324.46
Adj. Revenue	$3,083.23	$1,523.90	$461.59	$261.96	$511.32	$324.46
Shares						
Ounces	1.00	0.48	0.15	0.10	0.17	0.10
Tons	1.00	0.64	0.22	0.02	0.10	0.01
Revenue	1.00	0.44	0.17	0.09	0.18	0.12
Adj. Revenue	1.00	0.49	0.15	0.08	0.17	0.11

Description: A breakdown of the contributions to the changes in aggregate labour productivity between 1946 and 1955 as described in Equation 2. Four different labour productivity measures are considered: ounces per worker, tons milled per worker, revenue per worker, and adjusted revenue per worker, which takes into account the subsidy under the (Emergency Gold Mining Assistance Act). The upper half represents the values of this decomposition while the lower half calculates what share each variable contributes to the total change. Note that the Exit component presented here has already factored in its negative coefficient.

Table 5: 1955 to 1970 Decomposition

Values	Total	Within	Between	Cross	Entry	Exit
Ounces	31.55	-13.50	17.34	2.35	5.38	19.98
Tons	35.16	-74.82	51.26	-31.71	25.55	64.88
Revenue	$1,704.88	-$248.84	$599.84	$399.49	$263.99	$690.40
Adj. Revenue	$3,000.10	$287.50	$565.67	$1,057.17	$449.52	$640.24
Shares						
Ounces	1.00	-0.43	0.55	0.07	0.17	0.63
Tons	1.00	-2.13	1.46	-0.90	0.73	1.85
Revenue	1.00	-0.15	0.35	0.23	0.15	0.40
Adj. Revenue	1.00	0.10	0.19	0.35	0.15	0.21

Description: A breakdown of the contributions to the changes in aggregate labour productivity between 1955 and 1970 as described in Equation 2. Four different labour productivity measures are considered: ounces per worker, tons milled per worker, revenue per worker, and adjusted revenue per worker, which takes into account the subsidy under the (Emergency Gold Mining Assistance Act). The upper half represents the values of this decomposition while the lower half calculates what share each variable contributes to the total change. Note that the Exit component presented here has already factored in its negative coefficient.