Centre of Excellence for Sustainable Mining and Exploration (CESME)

Annual Report to the Office of Research Services

June 2017

Executive Summary

In the past year CESME has achieved the following:

- Co-sponsored a talk and two days of workshops The Office of Aboriginal Initiatives at Lakehead University, in partnership with Wilfrid Laurier University's Indigenous Rights and Resource Governance Research Program, Lakehead University's Centre of Excellence for Sustainable Mining and Exploration (CESME) and Matawa First Nations Management brought the United Nations Special Rapporteur on the Rights of Indigenous Peoples, Victoria Tauli-Corpuz, to Thunder Bay.
- Director Hollings was invited to be a witness before the House of Commons' Standing Committee on Natural Resources (RNNR)
- Supported the research of one PDF and one PhD student
- Provided two scholarships to support graduate research
- Hosted two guest speakers
- Established an Advisory Board

CESME goals & objectives

As outlined in the original proposal to the Senate Research Committee the purpose, rationale, mission and goals of the Centre of Excellence in Sustainable Mining and Exploration (CESME) are as follows:

Purpose

CESME will encourage and support research, education and outreach activities regarding the nature and impacts of mineral resource exploration and extraction particularly in Northern Ontario.

Rationale

Northern Ontario's dynamic mining sector is booming, creating challenges regarding how best to undertake sustainable economic development while ensuring environmental protection and respecting constitutionally protected Aboriginal and Treaty rights. CESME will help address these challenges by linking Lakehead University researchers with partners from First Nation, Métis and local communities, government, and industry. This collaborative approach recognizes that Canadian natural resource development requires sophisticated planning, collaboration, assessment, implementation, and remediation strategies that are calculated to minimize negative environmental, socio-economic, and cultural impacts. CESME uses the term "sustainable" to imply reconciliation of the three pillars of environmental, social equity, and economic demands (2005 World Summit on Social Development) that is now widely recognised by the mining industry. To this end, CESME is structured under three pillars: 1) Mining, Exploration and Mineral Processing; 2) Environmental Impacts; and 3) First Nation, Métis and Local Community Engagement.

Through the Centre academic, community, government, and industry partners will carry out cutting-edge research in discovery, advanced exploration, and development, and address the environmental, social and cultural aspects of mineral extraction.

Mission

CESME will:

- Support the development of community-based research and outreach activities in both the Lakehead University community and the region as a whole;
- Generate research projects that facilitate sustainable resource development in Northern Ontario and evaluate the current and future ecological, social, cultural and economic impacts of development; and
- Apply research outcomes from Northern Ontario projects to broader sustainable development issues in other northern Canadian and international jurisdictions and apply the lessons learned in other jurisdictions to Northern Ontario.

Goals

CESME will:

- Increase the capacity for mineral deposit research at Lakehead University and enhance the reputation of the institution in the region, nationally and internationally;
- Increase the capacity for research into the environmental impacts of mining and the sustainability of this activity in Northern Ontario;
- Increase the capacity for research into the social and cultural impacts of mining, especially the involvement of local and First Nation and Métis communities and the recognition of Aboriginal and treaty rights;
- Increase the capacity for research into mining and mineral processing;
- Initiate interdisciplinary research into these fields and develop multidisciplinary research proposals for funding agencies and research partners;
- Bring together a diverse range of researchers at Lakehead University working in fields related to mining exploration, sustainable mining, and environmental and community impacts; and
- Make Lakehead University the hub for sustainable resource extraction research in Northern Ontario.

Progress towards the Centre's goals

In our original proposal to the Senate Research Committee we indicated that we would achieve the goals of the Centre by undertaking a number of activities. This section lists those activities and highlights progress made.

1. *Initiate discussions with the wider community to shape the research activities of the Centre.*

   We have participated in meetings with a number of groups on and off campus in order to address this point. These include meetings with representatives of the mining industry (Goldcorp, Noront, Newgold), with First Nations and Métis communities (Matawa First Nations), politicians (provincial Minister of Northern Development and Mines, Michael Gravelle and Minister of Natural Resources, Bill Mauro) and alumni. On December 19, 2016 we held the first meeting of the Advisory Board to set the future research direction of CESME.

2. *Generate multidisciplinary research proposals and apply for external funding*

   We continue to seek additional funding to support research projects both through philanthropy and research councils. CESME Director, Dr. Pete Hollings is a co-applicant on a CREATE grant (S3I2P Water: Training for Water Stewardship Shared through Science, Indigenous knowledge, Industry and Policy) Notice of Intent that was submitted in 2016.

3. *Invite and fund proposals for research and outreach activities*

   Thanks to an excellent ongoing partnership with staff of the External Relations office, particularly Jennifer Childs and Deb Comuzzi, we have initiated a PhD project supported by SNC Lavalin and continue to award the John R. Craig Memorial CESME Awards intended to support graduate students undertaking research related to First Nations and Métis issues.

4. *Recruit and foster faculty, postdoctoral fellows, postgraduate, graduate, and undergraduate student participation*

   As additional funding becomes available we hope to increase student participation in CESME. We successfully recruited our first PDF, Dr. Karl Skogstad, to investigate the economic impacts of mining. Thanks to funding from Churchill Diamonds and CEMI we are initiating a second PDF to investigate the “Geochronology and mineral chemistry as exploration tools for economic diamond deposits in the Superior Province”. Finally thanks to support from the Provost and Dean of SES we have been able to recruit Dr. Dawn Mills as a Program Development Coordinator to develop a certificate program to train First Nations community members.

5. *Establish working relationships with similar national and international centres (e.g., Mineral Deposit Research Unit (MDRU) at the University of British Columbia, Mineral Exploration Research Centre (MERC) at Laurentian, CODES – ARC Centre of Excellence in Ore Deposits at the University of Tasmania, Centre for Exploration Targeting (CET) at the University of Western Australia)*

   We have established excellent working relationships with CET and CODES with CESME members currently co-supervising students at both institutions. In addition we are building relationships with the Centre for Excellence in Mining Innovation (CEMI) based out of Sudbury and the Pan American Indigenous Rights and Governance Network (PAIR-GN). We are also in the process of initiating a collaboration with Laurentian’s newly funded Metal Earth program.

6. *Develop and maintain a website for the Centre*

We have established a website that highlights CESME activities and acts as a repository for our publications and videos of our guest speakers. This site has finally been migrated to the new system, which will allow us to update it more easily.

Members of CESME

We are thrilled to announce that we have established the first Advisory Board for CESME. The initial membership comprises:

- Mr. John Mason, CEDE - Chair
- Mr. Peter Moses, Matawa
- Mr Glenn Nolan, Noront
- Dr. James Franklin, Consultant
- Dr. Scott Jobin-Bevans, Consultant

The service of these individuals is greatly appreciated and we look forward to working with them to strengthen CESME in the coming years.

The following faculty members have agreed to lead the three research pillars of CESME:

- Dr. Peggy Smith continues as leader of the First Nations Pillar
- Dr. Pedram Fatehi has accepted the role of leader of the Mining, Exploration and Mineral Processing pillar
- Dr. Peter Lee has accepted the role of leader of the Environmental pillar.

The following faculty members have signed up as CESME members:

Dr	Ehsan Rezazadeh	Azar	Civil Engineering
Dr	Amir	Azimi	Civil Engineering
Dr.	Matthew	Boyd	Anthropology
Dr.	Lionel	Catalan	Chemical Engineering
Dr.	Aicheng	Chen	Chemistry
Dr.	Han	Chen	Natural Resources Management
Dr.	Andrew	Conly	Geology
Dr.	Bahram	Dadgostar	Business Administration
Dr.	Jian	Deng	Civil Engineering
Dr.	Amanda	Diochon	Geology
Dr.	Martha	Dowsley	Anthropology
Dr	Karen	Drake	Faculty of Law
Dr.	A. Ernest	Epp	History
Dr.	Pedram	Fatehi	Chemical Engineering
Dr.	Philip	Fralick	Geology
Dr.	Tony	Gillies	Civil Engineering
Dr.	Scott	Hamilton	Anthropology
Dr.	Mary Louise	Hill	Geology
Dr.	Mary Lou	Kelley	Social Work
Dr.	Rhonda	Koster	Outdoor Recreation
Dr.	Thamara	Laredo	Sustainability Sciences
Dr.	Peter	Lee	Biology
Dr.	R. Harvey	Lemelin	Outdoor Recreation

Dr.	Baoqiang	Liao	Chemical Engineering
Dr.	Nancy	Luckai	Natural Resources Management
Dr	Jason	MacLean	Faculty of Law
Dr.	Douglas	Morris	Biology
Dr	Rob	Petrunia	Economics
Dr.	Wensheng	Qin	Biorefining Research Institute
Dr.	Chander	Shahi	Natural Resources Management
Dr	Peggy	Smith	Natural Resources Management
Dr.	Darlene	Steven	Nursing
Dr.	Robert	Stewart	Geography
Dr.	Shannon	Zurevinski	Geology

The following adjunct faculty are also members of CESME:

Dr.	Greg	Ross	NOSM
Dr.	Robert	Mackereth	Centre for Northern Forest Ecosystme Research

In addition there is one Post Doctoral Fellow (Karl Skogstad, Economics) and two PhD students (Jeffrey Ross & Dan Duckert, NRM) affiliated with CESME.

Research Projects & Scholarly Activities

One of the key achievements of CESME in the past year was the publication of the report on "The Mining Industry in Northwestern Ontario: An Analysis of Recent Developments and the Strategy for Success" co-authored by Dr. Karl Skogstad and Dr. Ayman Alahmar, and published by the Northern Policy Institute. The report investigated the fate of a number of mining developments in Northern Ontario in order to identify the key factors that influenced success or failure. The report received extensive coverage by regional media outlets raising CESME's profile considerably. Copies of the report were provided to local, provincial and federal politicians and can be downloaded from http://cesme.lakeheadu.ca. Dr Skogstad presented the results of the report during the Annual Alumni and Friends Breakfast at PDAC

Dr. Skogstad's activities

Dr. Skogstad has resigned from his position to take a new position as the Irving Shipbuilding Chair in the Mulroney School of Government at St. Francis Xavier University. The following is his report on his time at Lakehead University.

The CESME postdoctoral fellowship was designed to develop a better understanding of the economic impact of the mining sector on NW Ontario. This would be accomplished by focusing on issues such as the role of international competition, the impact and importance of infrastructure, and the benefits and costs to the communities in which mines were located. The research projects that were undertaken, and which are outlined below, have certainly contributed to all these areas. On top of this, an in-depth study of the economics of the gold mining sector in the province has been undertaken that will help develop a better understanding of how this sector can remain internationally competitive.

In the policy piece written by Dr. Skogstad, and published through the Northern Policy Institute, “The Mining Industry in Northwestern Ontario,” he examined the factors that led to the failure of a number of mining projects in Northwestern Ontario in the mid-2010s. As proposed, we examined the impact that infrastructure, international competition, and local communities had on these projects. Regarding the issue of infrastructure, they found that a lack of robust roads, rails, and electrical transmission networks resulted in relatively high costs for mine developers. Only where these networks were more established, such as around New Gold’s Rainy River project, was development able to successfully occur. Contrasting this to the complete lack of infrastructure in the Ring of Fire, goes far in explaining why projects in that area are not yet profitable.

This report also examined the impact that international competition, had on these projects. They discussed how the ability of other countries to bring their projects online quicker, led to an increase in global mineral output and ultimately to a fall in resource prices. The inability of Northern Ontario mining projects to develop quickly due to a lack of infrastructure, long environmental review processes, and complicated discussions with local communities prevented the projects from coming online fast enough to benefit from high resource prices.

In an attempt to better understand how competitive Northern Ontario mines were compared to mines in other countries, Skogstad approached local mines in an attempt to obtain financial and production data. Unfortunately, the mines were not interested in providing any data. Fortunately, the Chancellor Paterson library’s collection of mining statistics for the region is outstanding, and Skogstad was able to gather detailed production, financial, and employment data for all of Ontario’s gold mines from 1920 to 1970. This data has allowed me to work on a number of projects that examines the competitiveness of the industry.

The first project which makes use of this data, “The Impact of Labour Policies on Ontario Gold Mines in World War II,” examines how the industry reacted to labour-market restrictions imposed by the government during the war. Skogstad and his co-author found that in the early years of the war, when the mines were supplied with additional labour to boost gold production, the labour was inefficiently assigned to the mines. Instead of labour moving to the mines that could maximize the gold output (which was the goal of the policy), labour instead went to mines which could offer the highest wages. In the later war years, when the need for gold was reduced, and labour was withdrawn from the industry, we find that the government’s policy of preventing mine closures meant that the gold mines were forced to operate at an inefficiently low level of output. Measured in 2017-dollars, the inefficient policy resulted in nearly one billion dollars of forgone profit for the industry. This paper was presented at two large North American conferences: The 2016 Canadian Economic Association annual meeting in Ottawa and the 2016 North American Productivity workshop in Quebec City. We are presently making revisions to the paper as requested by the Canadian Journal of Economics, the leading economics journal in Canada.

They are currently working on another project using this data that analyzes labour productivity in these mines during the period. If one compares the average amount of gold produced by a miner in Ontario in 1930 to the amount of gold produced in 1970, they will find these numbers to be nearly identical, despite forty years of technological and organizational progress. This type of productivity stagnation is undesirable in any industry, and may contribute to the difficulty that current projects in the region are having at competing in an increasingly competitive international market.

The richness of the data-set will allow Skogstad to continue to work on projects over the coming years. One project will be the examination of the impact and effectiveness of the Emergency Gold Mining Assistance Act, which subsidized gold production in Canada between 1948 and 1971. Over three hundred million dollars were paid out to mines over that period in order to prevent their closure, and the prevent the perceived devastating impact that this would have on mining communities such as Kirkland Lake, Timmins, and Red Lake. This project will estimate how many jobs were saved over this period thanks to this program, and weigh this against the cost of the program. This will allow them to comment on the feasibility of such a scheme to encourage the development of present-day projects.

Another project will be the examination of the relative productivity of various mining camps. Kirkland Lake, Timmins, and Red Lake all had a large number of mines concentrated within a small area. By comparing the productivity of mines in these camps to one another we will be able to comment on why some regions were more productive than others. From this they will be able to draw lessons that can apply to present day mines.

Ultimately, Skogstad will be able to build the data-set forward to the present day. The difficulty with this is that the Government of Ontario stopped collecting the statistics in 1970. It would be necessary to go to reports produced by the mines themselves to gather the data. This would present an amazing opportunity though, as it would allow us to track the industry over a one hundred year period.

Mr. Dan Duckert's activities

This project has been funded through support of Dr. Peggy Smith and her Giving Voice SSHRC grant and the Keewaytinook Okimakanak Research Institute. Dan Duckert is the recipient of a SSHRC doctoral fellowship grant and the John R Craig Memorial CESME scholarship. Dan received the John R. Craig Memorial CESME Awards intended to support students undertaking research related to First Nations and Métis issues and is continuing his research.

Other activities

CESME is a partner on the application "S3I2P Water: Training for Water Stewardship Shared through Science, Indigenous knowledge, Industry and Policy" submitted as an NOI for the CREATe program.

CESME is a partner on Lakehead's submission to the AANDC Post-Secondary Partnerships Program. If successful this will provide funding for a coordinator to develop undergraduate programming targeted at increasing First Nations enrolment and retention.

CESME hosted meetings with New Gold and Musslewhite mines to introduce those companies to Lakehead Researchers. These meetings are leading to new research collaborations and the donation of a 3D printer to the Faculty of Natural Resource Management.

Educational Activities

On October 27, 2016 CESME co-sponsored a talk by Victoria Tauli-Corpuzon "Free prior and informed consent: A local and global issue. The talk was attended by >200 people and required the setting up of overflow rooms.

On September 15, 2016, CESME sponsored a talk by Dr. Dawn Mills on "Indian Mining Regulations: A Study to Advance Mining on First Nation Title Lands" which was attended by ~15 people.

On February 8, 2017 CESME sponsored a talk by Dr. Sara Seck on "A Gender Perspective on Business, Human Rights, and Sustainable Mining" which was well attended with ~20 people present.

Videos of these talks and copies of the presentations can be found on the CESME web site.

In November 2016 Hollings was invited to make a presentation to the House of Commons' Standing Committee on Natural Resources (RNNR).

Undergraduate and graduate training

As discussed above we currently have two PhD students undertaking research related to CESME. We have supported two graduate students through the John R. Craig Memorial Scholarship and we have been successful in seeking funding to support CESME-related scholarships that will be used to support undergraduate and graduate research in the coming years.

We are currently in discussions with CESME faculty about the possibility of establishing a 0.5 FCE course with the theme of Aboriginal Engagement.

Financial statement

CESME is in reasonable financial health. The statement provided below covers the 2016-2017 financial year.

Item	Credit	Debit
Carry Forward	$33,947.40	
Donations	$4,520.00	
Intrafund transfer	$15,000.00	
Travel & Conferences *(PDAC, Roundup)*		$2,839.90
Travel (*Fatehi – PDAC*)		$1,070.98
Travel (*Franklin – Board meeting*)		$715.52
PDAC booth rental		$2,112.08
Telecommunications		$768.60

Sessional coverage for Director		$7,837.00
Guest speaker *(Seck)*		$770.17
Guest speaker *(Tauli-Corpuz)*		$723.38
Sponsorship *(SEG course)*		$108.84
Catering *(Speakers and Board meeting)*		$445.72
Printing		$330.01
Subtotal	*$53,467.40*	*$17,722.20*
Balance	**$35,744.80**	

In addition to the items listed above CESME received a $150,000 donation from Derek and Joan Burney to support a Postdoctoral Fellow for a period of three years.

One-year and five-year plans

The immediate goals of CESME are as follows:

- Work with the Advisory Board to identify additional members and provide guidance for CESME
- We are in discussions to develop a 0.5 FCE undergraduate course on First Nations engagement that would be taught by members of CESME. Dawn Mills will also be working to develop a certificate course for environmental technicians in First Nations communities
- We are seeking funding both from research councils and donors to support graduate and undergraduate research.
- We are considering the possibility of hosting another conference at Lakehead or alternatively providing support to other related events on campus. Specifically we are planning two workshops. One will be for CESME members to share research plans and discuss our strategic vision whereas the second will bring together representatives of the mining industry and local communities with CESME members to discuss research needs and highlight the work of Lakehead faculty.
- We continue to engage with faculty across campus to encourage them to participate in and identify CESME activities.

In the medium term we are seeking to establish three research chairs, one related to each of the CESME pillars (Mining and Exploration, Environmental Impacts and First Nation, Métis and Local Community Engagement). These chairs are critical to the long-term success of CESME as they will provide the core researchers around which Centre activities can be developed. In addition to funding the Chair we are seeking ways to support graduate students and Post-Graduate Fellows who will undertake much of the research. We are investigating a number of mechanisms to fund these chairs, including:

- The NOHFC Industrial Research Chairs program;
- Corporate donations;
- Philanthropy; and
- NSERC Industrial Research Chairs program

We are working closely with the Office of Research Services and External Relations to achieve this goal.

2017-2018 Budget*

Item	Cost
Attend PDAC meeting to promote CESME (2 x$2,000 people)	$4,000
Attend Roundup meeting to promote CESME (2 x$2,000 people)	$4,000
Conferences for CESME members	$4,000
Teaching relief for Director (1 x $7,800)	$7,800
Promotional materials	$1,000
Invited speakers	$3,500

* Scholarships provided by CESME are not included here.

Emerging Trends

CESME activities are more important than ever in the face of changing developments and conditions in the mining sector in northern Ontario. The provincial government has made commitments to develop infrastructure to support the development of the Ring of Fire, but relatively little progress has been made. The mining and exploration industry is picking up in Northern Ontario and we are anticipating increased interest in CESME activities. This has been reflected in meetings we have hosted with local mining companies who are keen to work with CESME researchers.

Appendix

Media reports, posters and publications

CENTRE OF EXCELLENCE FOR
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& EXPLORATION

DONOR IMPACT REPORT

SNC Lavalin CESME Graduate Scholarship

At the 2016 PDAC Alumni & Friends breakfast, Lakehead University and the Centre of Excellence for Sustainable Mining and Exploration (CESME) were proud to announce the establishment of the SNC Lavalin CESME Graduate Scholarship.

Jeffrey Ross, PhD candidate in Forest Sciences and Biology, is investigating the 'Duty to Consult' and what that means to indigenous communities, mining companies and government in the Treaty #3 territory. Jeffrey is currently the Director of Territorial Planning for Grand Council Treaty #3.

Lakehead University is grateful for SNC Lavalin's contribution to CESME.

Dr. Pete Hollings (CESME Director), Stephen Lindley (Vice-President of Aboriginal and Northern Affairs, SNC-Lavalin) and Dr. Brian Stevenson (Lakehead Vice-Chancellor and President)

"In our strong tradition of supporting sustainable mining development and capacity building within the Indigenous community, SNC-Lavalin is proud to be providing 2 years of financial assistance to an Indigenous PhD candidate in Lakehead University's highly regarded CESME program. We wish the candidate and CESME every success in growing the program, and want to thank them for providing us an opportunity to work together by making a small contribution towards strengthening the future of our mining and Indigenous communities."

Stephen Lindley, Vice President, Aboriginal & Northern Affairs, SNC-Lavalin

"Without our donors CESME would not have been able to continue our research into the economic impact of mining in Northern Ontario or support the outstanding students working with our faculty - Thank You"

– Pete Hollings, CESME Director

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Centre of Excellence for Sustainable Mining & Exploration

Lakehead UNIVERSITY

2015-2016 CESME ACCOMPLISHMENTS

- Publication of the report on "The Mining Industry in Northwestern Ontario: An Analysis of Recent Developments and the Strategy for Success" co-authored by Dr. Karl Skogstad and Dr. Ayman Alahmar, and published by the Northern Policy Institute. The report investigated the fate of a number of mining developments in Northern Ontario in order to identify the key factors that influenced success or failure. The report release received extensive coverage by regional media outlets (January 2016)
- Dr. Pedram Fatehi (Mining, Exploration and Mineral Processing pillar leader) leads an NOHFC Industrial Research Chair in Green Chemicals and Processes with industrial partners including FPInnovations, Goldcorp and Resolute Forest Products to produce chemicals from waste forestry biomass that will create greener, more cost-effective pulping, mining and oil processes. (February 2016)
- The John R. Craig Memorial CESME Awards intended to support students undertaking research related to First Nations and Métis issues were awarded to two graduate students. PhD student Dan Duckert (Natural Resource Management) with his project "Going Beyond Values Mapping: Giving voice to communities about their relationships in the land and their well-being needs" and MSc student Kristi Dysievick (Biology)
- CESME was co-sponsor of nine CESME Speakers Series, with over 180 people in attendance at the "Free, Prior and Informed Consent: A Local and Global Issue" presentation with Victoria Tauli-Corpuz, United Nations Special Rapporteur on the Rights of Indigenous Peoples (October 2016)
- A Memorandum of Understanding was signed between Lakehead University and New Gold to explore potential research programs of mutual interest and benefit, identify potential undergraduate and graduate students for educational on-site training, and identify opportunities for knowledge transfer between communities and the existing mining industry workforce (October 2016)
- CESME established an active collaboration with Dr. Dawn Mills from British Columbia to look at the environmental impacts of mining. This has led to a DFO/MITACS funded project that is supporting MSc student Hannah Britton Foster working with Dr. Peter Lee on a study of "Sediment and Water Quality of the Mamxwen Blind Channel, Squamish BC". (October 2016)
- CESME hosted a press conference for the Ministry of Northern Development and Mines where Minister Gravelle and Minister Mauro announced Ontario's Mineral Development Strategy (December 2015)

CESME ADVISORY BOARD

The Advisory Board was established to provide advice and guidance to the Director of the CESME with regards to the overall goals and objectives of the Centre. The service of these individuals is greatly appreciated and we look forward to working with them to strengthen CESME in the coming years.

CHAIR:

John Mason, Project Manager, Thunder Bay Community Economic Development Commission (Honorary Doctorate from Lakehead University)

MEMBERS:

- **Mr. Peter Moses**, Mineral Development Information and Support Officer, Matawa First Nations Management
- **Glenn Nolan,** Vice-President, Aboriginal Affairs, Noront Resources Ltd.
- **Dr. James Franklin,** President, Franklin Geosciences Ltd
- **Dr. Scott Jobin-Bevans,** Chariman and CEO, Caracle Creek International Consulting
- **Dr. Pete Hollings,** CESME Director, Lakehead University

Lakehead UNIVERSITY

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Philanthropy Director
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FREE PUBLIC LECTURE

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A LOCAL AND GLOBAL ISSUE

Victoria Tauli-Corpuz

United Nations Special Rapporteur on the Rights of Indigenous Peoples

Victoria Tauli-Corpuz is an Indigenous leader from the Kankanaey Igorot people of the Cordillera Region in the Philippines. She has served as the United Nations Special Rapporteur on the Rights of Indigenous Peoples since 2014. She is a social development consultant, Indigenous activist, civic leader, human rights expert, public servant, and an advocate of women's rights in the Philippines. She was the former Chair of the UN Permanent Forum on Indigenous Issues (2005-2010). As an Indigenous leader she was actively engaged in the drafting and adoption of the UN Declaration on the Rights of Indigenous Peoples in 2007. She helped build the Indigenous peoples' movement in the Cordillera as a youth activist in the early 1970s. She helped organize Indigenous peoples at the community level to oppose and stop projects such as the Chico River Hydroelectric Dam and establishment of the Cellophil Resources Corporation.

Thursday, October 27th

7:30 pm

ATAC 2021

Lakehead University, Thunder Bay

FOR MORE INFORMATION VISIT OUR WEBSITE
aboriginalinitiatives.lakeheadu.ca

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Social Sciences and Humanities Research Council of Canada
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MATAWA FIRST NATIONS

Lakehead UNIVERSITY

CENTRE OF EXCELLENCE FOR SUSTAINABLE MINING & EXPLORATION

Free Public Lecture

Presents Guest Speaker

DR. SARA SECK

Associate Professor, Faculty of Law, Western University
Senior Fellow, CIGI International Law Research Program

A Gender Perspective on Business, Human Rights, and Sustainable Mining

Guiding Principles on Business and Human Rights were endorsed by the United Nations Human Rights Council in 2011, and are promoted to Canadian mining companies operating internationally as part of Canada's 2014 CSR Strategy. Entitled "Doing Business the Canadian Way", the CSR Strategy promotes several international CSR standards that embed the business responsibility to respect rights with specific attention to the rights of indigenous peoples and local communities. Notably, a gender perspective was introduced for the first time in the 2015 OECD Stakeholder Engagement Guidance for extractive industries.

This presentation will examine why respect for the rights of women and girls, as well as men and boys, is crucial for responsible and sustainable mining, both within and outside of Canada.

BIOGRAPHY:
Dr. Seck researches and teaches in the areas of international corporate social responsibility law, environment and climate law, and transnational legal theory. In 2015, she received the Emerging Scholarship Award from the IUCN's Academy of Environmental Law for her extensive research contributions on home state responsibility for transnational mining. She is a member of the editorial board of the new Business and Human Rights Journal (Cambridge University Press).

FEBRUARY 8, 2017 AT: 1:00 pm IN: AT 5036

Lakehead UNIVERSITY

CENTRE OF EXCELLENCE FOR SUSTAINABLE MINING & EXPLORATION

Free Public Lecture

Presents Guest Speaker

DR. P. DAWN MILLS

Ph D Law
Indigenous Natural Resource Research
Norman B Keevil Institute of Mining Engineering
University of British Columbia

Indian Mining Regulations: A Study to Advance Mining on First Nation Title Lands

Indian Mining Regulations were adopted in 1961 and amended in 1968 as a means to promote mineral resource development on First Nation Reserves that the First Nation held title to the mineral resource. Discussed are the Indian Mining Regulations in light administrative law, and second their deficiencies in relationship to Saskatchewan and Ontario mining law and administration. Lastly it is recommended that a critical review of mineral resource potentials, exploration, mine permitting and environmental monitoring be established prior to a revision process of the existing Indian Mining Regulations, or creation of new regulations that can be developed under the First Nations Commercial and Industrial Development Act for mineral resource development on First Nation Title Lands.

BIOGRAPHY

Dr. Mills holds her PhD from the Faculty of Law at UBC. Her PHD work focused on Gitxsan property law and their management structures as it was spoken during the Delgamuukw trials and the reconciliation period afterwards. Dr. Mills' research is related to administrative law, and legislative reform at the intersection of Aboriginal and Treaty Rights and Mineral Resource Development.

Dr. Mills is currently the inaugural Finning Resident Scholar for Mining and Communities at the Norman B. Keevil Institute of Mining Engineering. The focus of this position is to engage with First Nation, Inuit or Metis communities related to mineral resource development. This position also facilitates the placement of Senior Undergraduate Students in between First Nation communities and at a Mine Site. Her teaching responsibilities include delivering the graduate seminar Mine 585 Canadian Aboriginal People and Mineral Resource Development, and APSC 261/262 & 450.

DATE: September 15, 2016 AT: 11:00 am IN: CB 3031

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

Robert J. Petrunia* Karl Skogstad†

May 24, 2017

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
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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 a brief surge in the years before 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.

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.

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

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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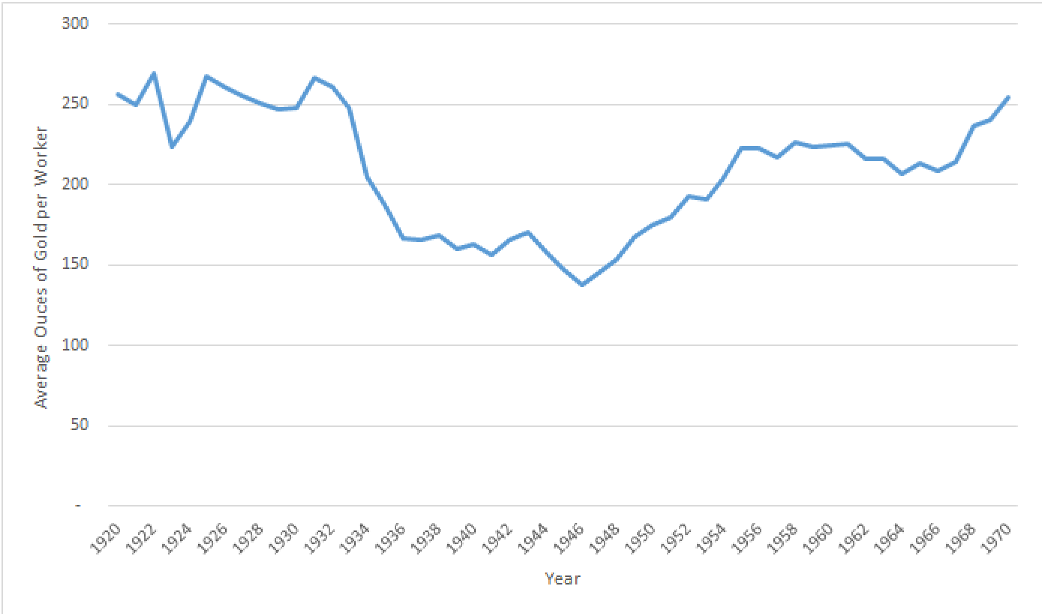
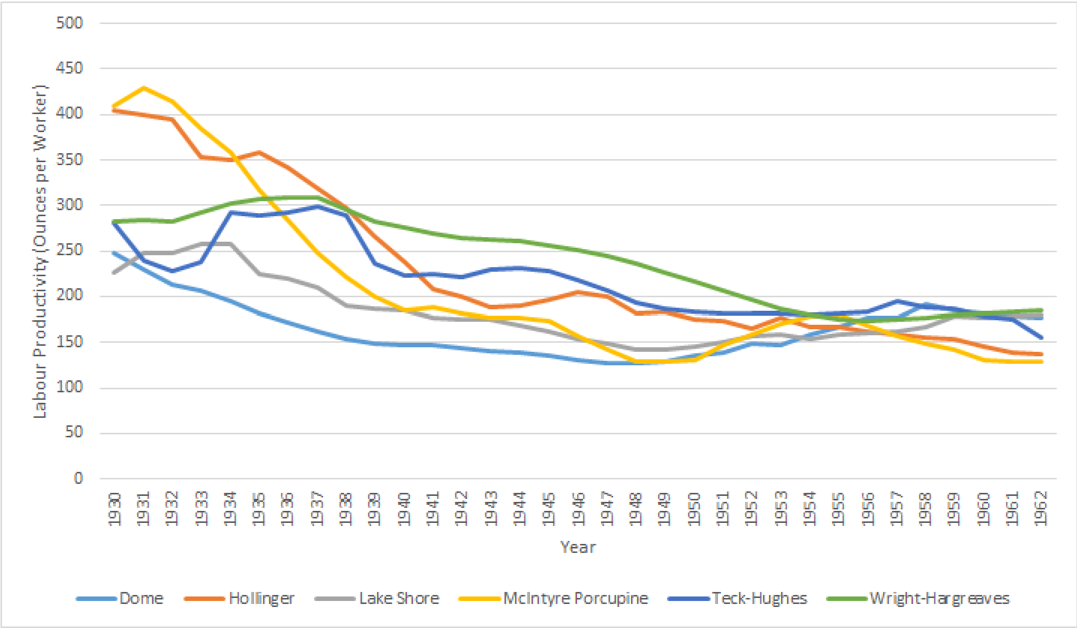
Figure 1: Labour Productivity (Ounces per Worker)



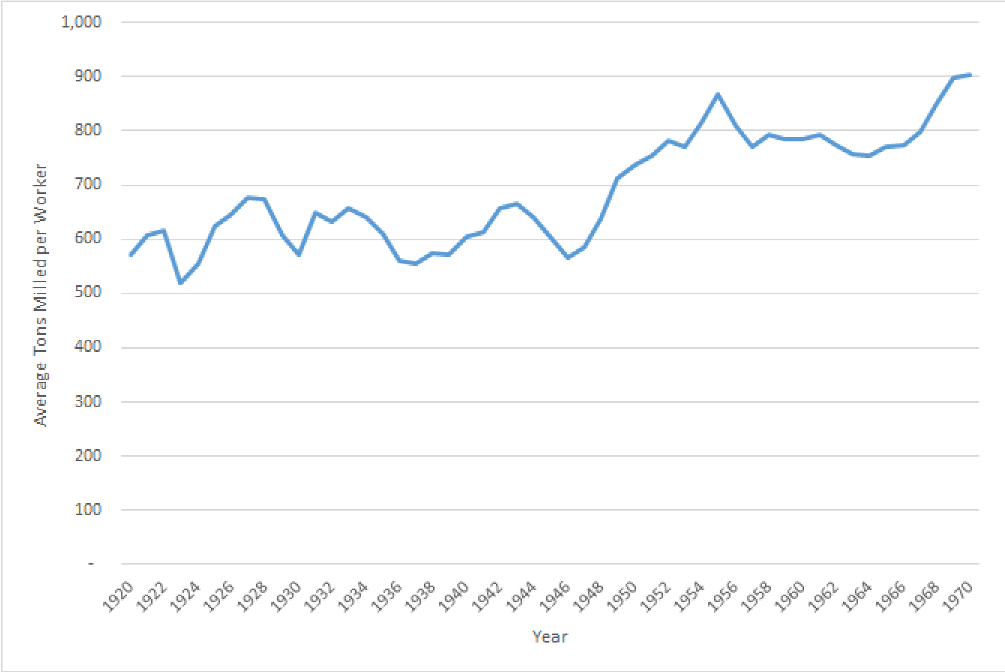
Description: The total ounces of gold produced in Ontario's gold mining industry in a given year divided by the total number of employees in the industry.

Figure 2: Labour Productivity at Select Mines



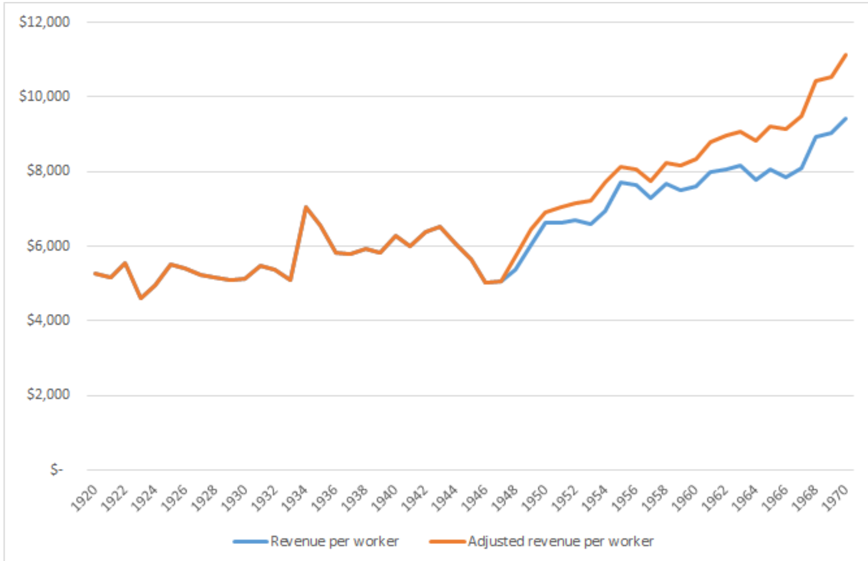
Description: The average ounces of gold produced per worker at six of Ontario's largest mines that operated between 1930 and 1962.

Figure 3: Labour Productivity (Tons Milled per Worker)



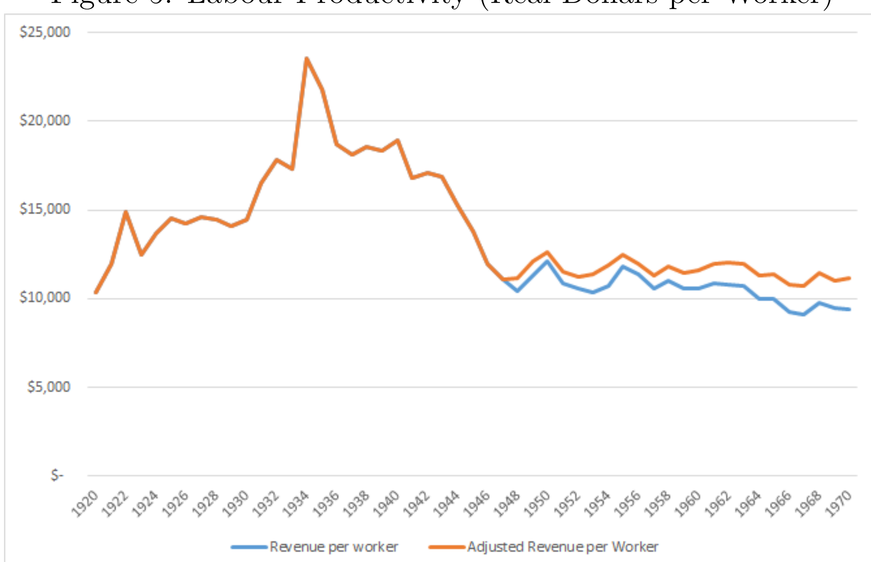
Description: The total tons of ore milled in Ontario's gold mining industry in a given year divided by the total number of employees in the industry.

Figure 4: Labour Productivity (Nominal Dollars per Worker)



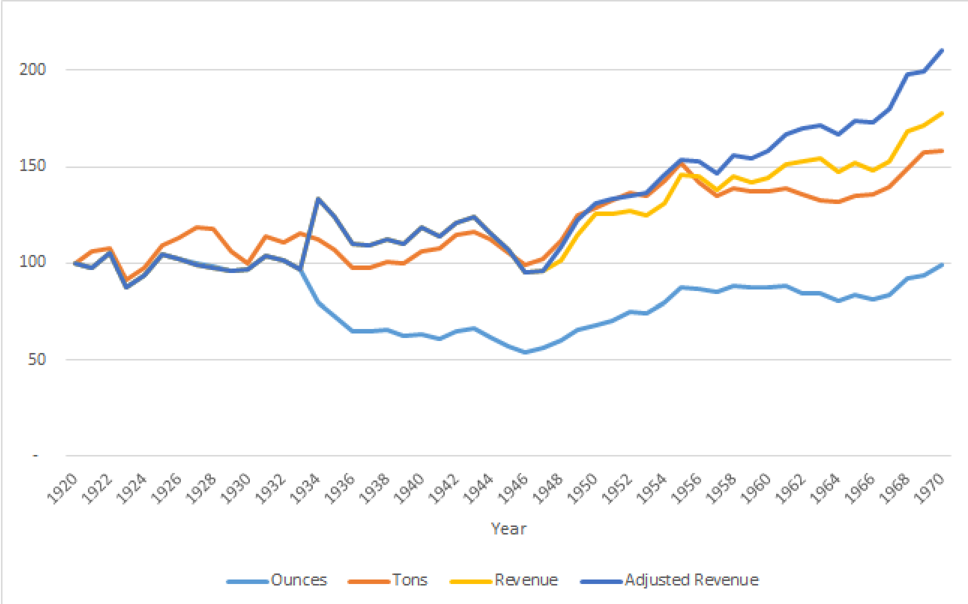
Description: The 'Revenue per worker' line is the total revenue from the sale of bullion earned in Ontario's gold mining industry in a given year divided by the total number of employees in the industry. The 'Adjusted revenue per worker' line is the total revenue earned from the sale of bullion plus 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)



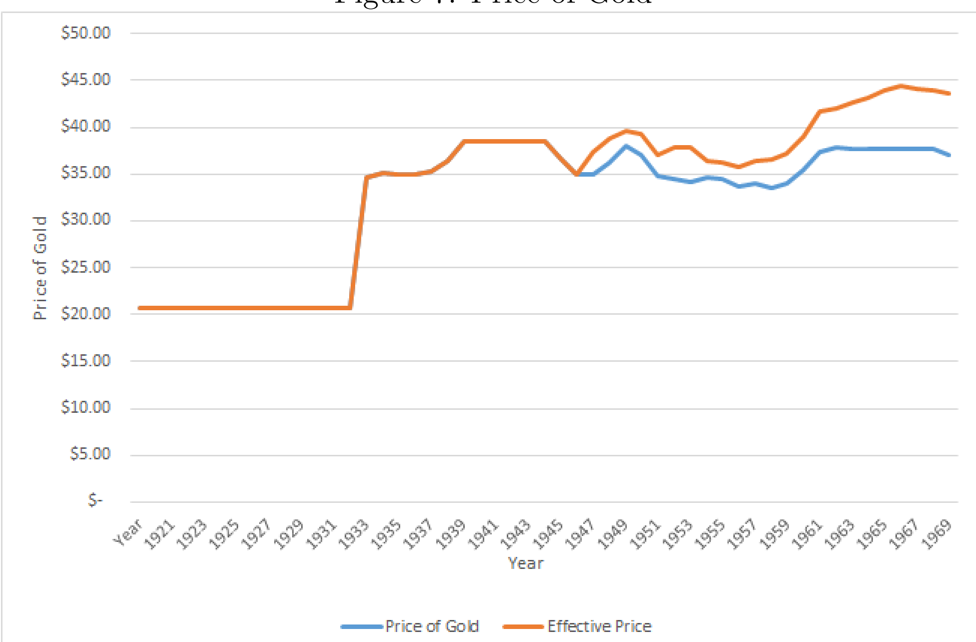
Description: The 'Revenue per worker' line is the total revenue from the sale of bullion earned in Ontario's gold mining industry in a given year divided by the total number of employees in the industry. The 'Adjusted Revenue per Worker' line is the total revenue earned from the sale of bullion plus 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



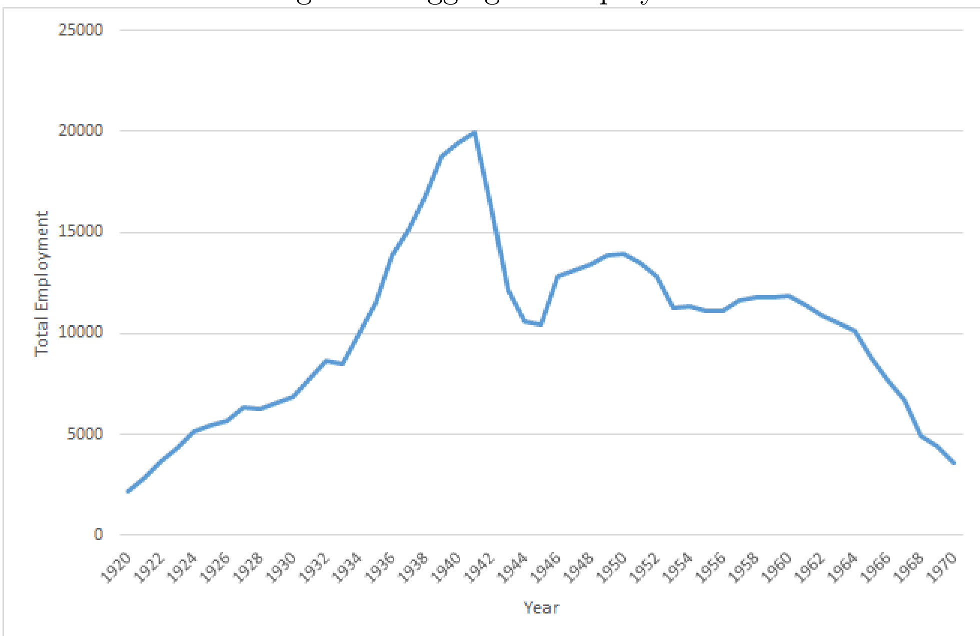
Description: These are indexes of the four labour productivity variables introduced in Figures 1, 3, and 4. They are each normalized to 100 in 1920.

Figure 7: Price of Gold



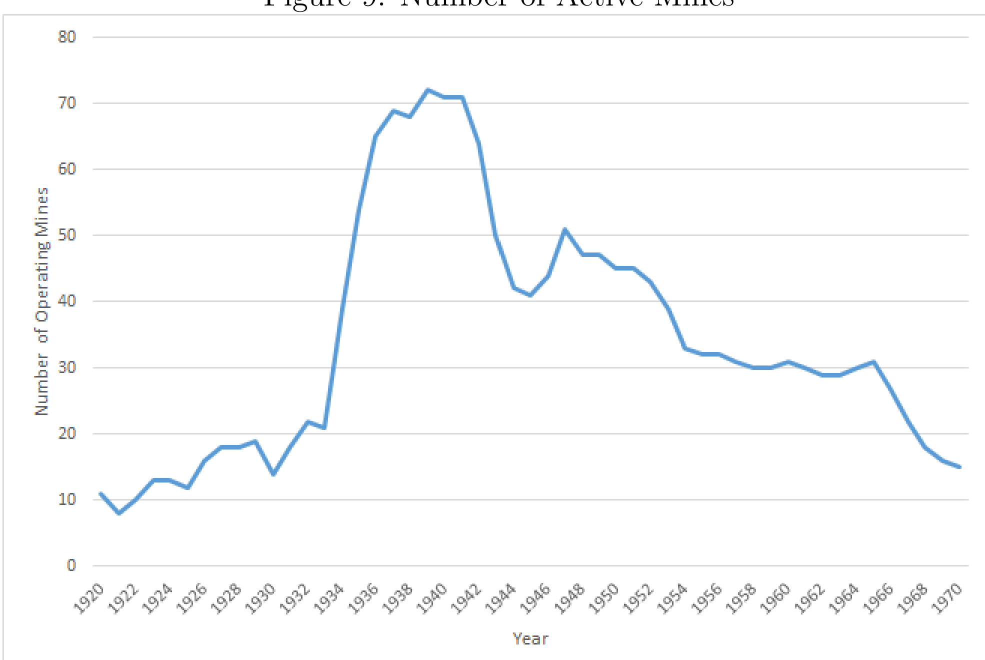
Description: The 'Price of Gold' line is the average yearly price of gold received by Ontario's gold mines. It is found by dividing total revenue from the sale of gold by total ounces of gold produced in a given year. The 'Effective Price' is found by dividing the total revenue from the sale of gold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



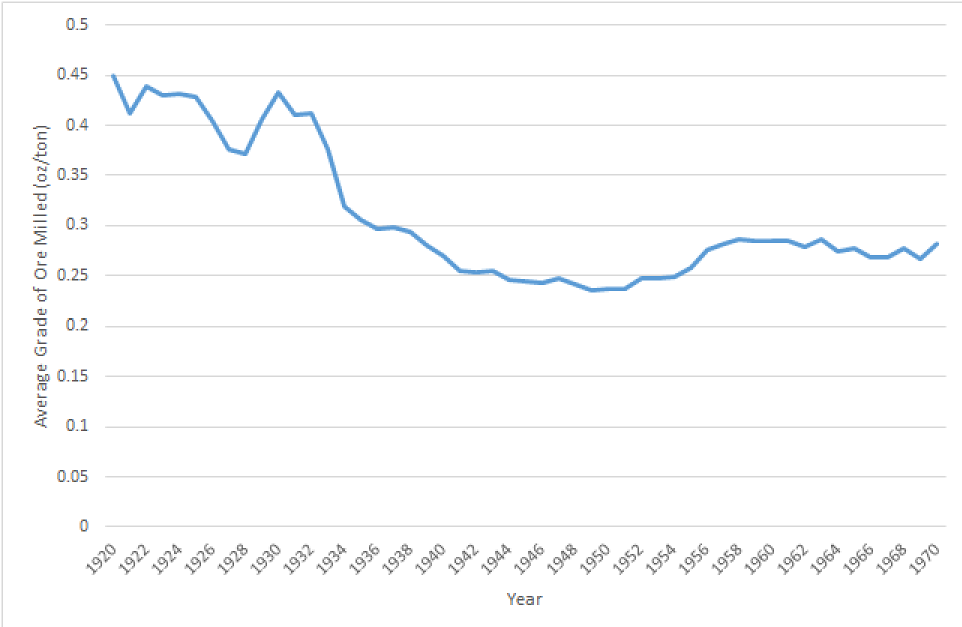
Description: The average total number of people employed in Ontario's gold mining industry in a given year.

Figure 9: Number of Active Mines



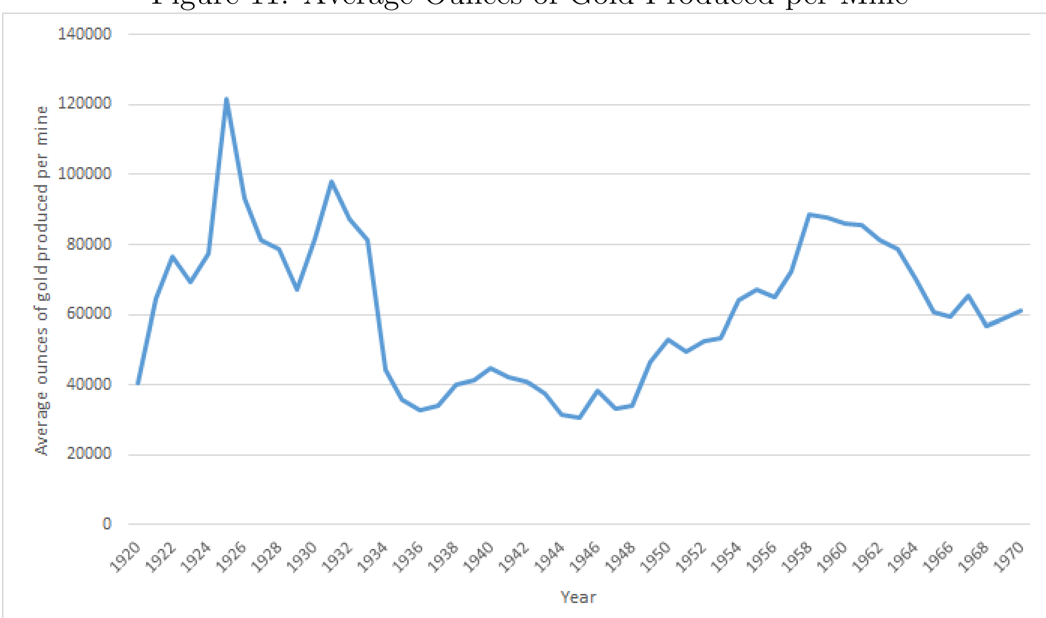
Description: The total number of gold mines that produced at least one ounce of gold in the province of Ontario in a given year.

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

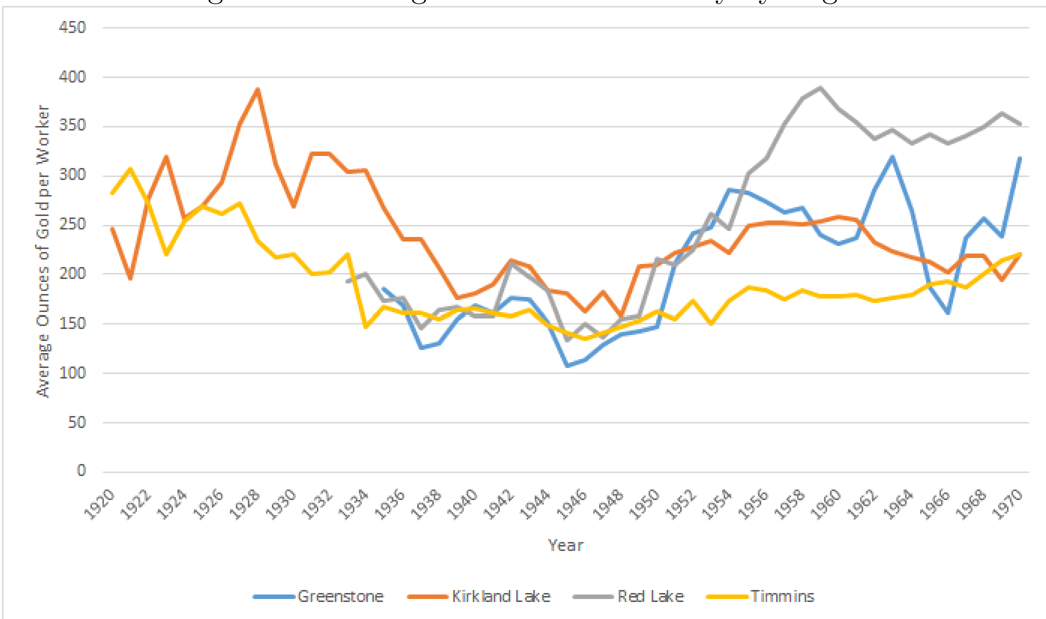


Description: The average ounces of gold produced per mine is calculated by dividing the total number of ounces of gold produced by gold mines by the total number of gold mines that produced at least one ounce of gold in the province of Ontario in a given year.

Figure 12: Location of Mines

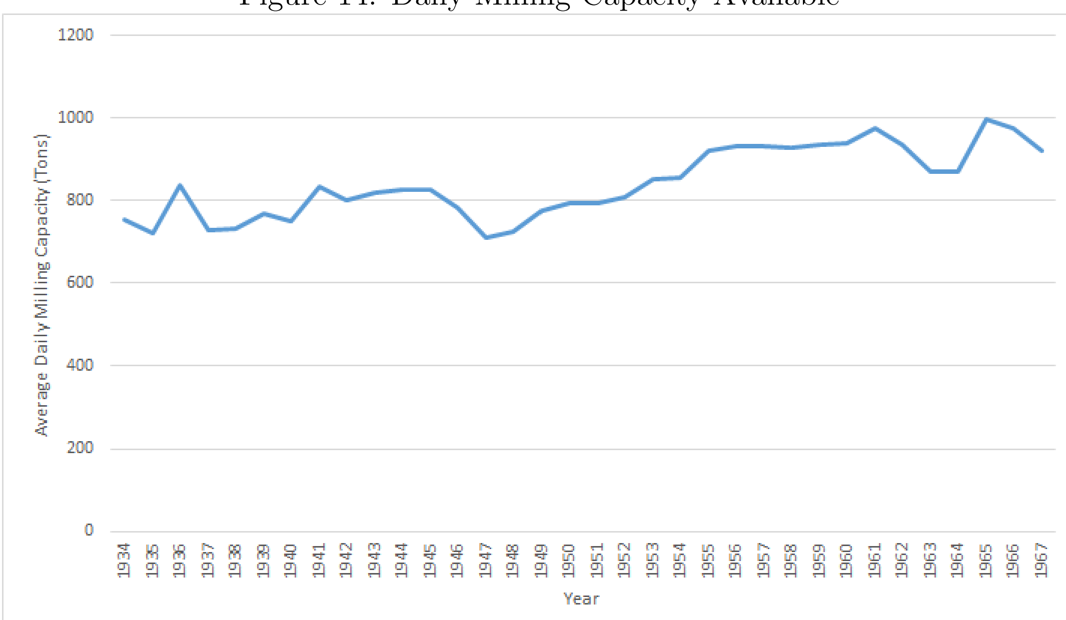
Description: Each pin is the location of a mine where mine-level data is available. Note that Red Lake has 12 pins, Greenstone has 11 pins, Timmins has 24 pins and Kirkland Lake has 14 pins.

Figure 13: Average Labour Productivity by Region



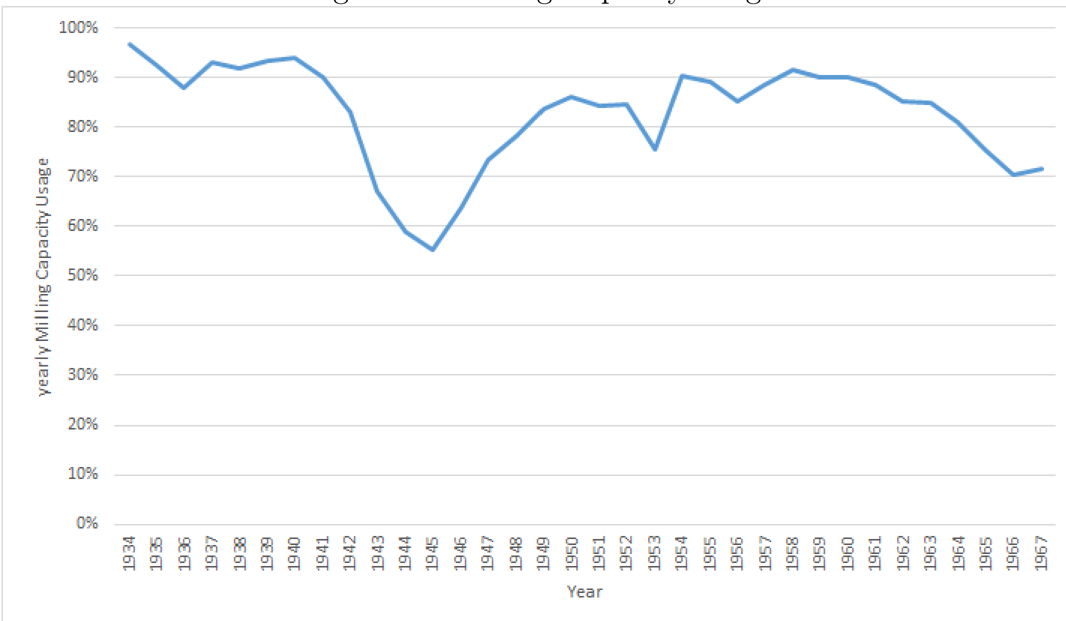
Description: For each of the four mining camps, the total ounces of gold produced therein in a given year is divided by the average total number of employees working at the mines in these locations.

Figure 14: Daily Milling Capacity Available



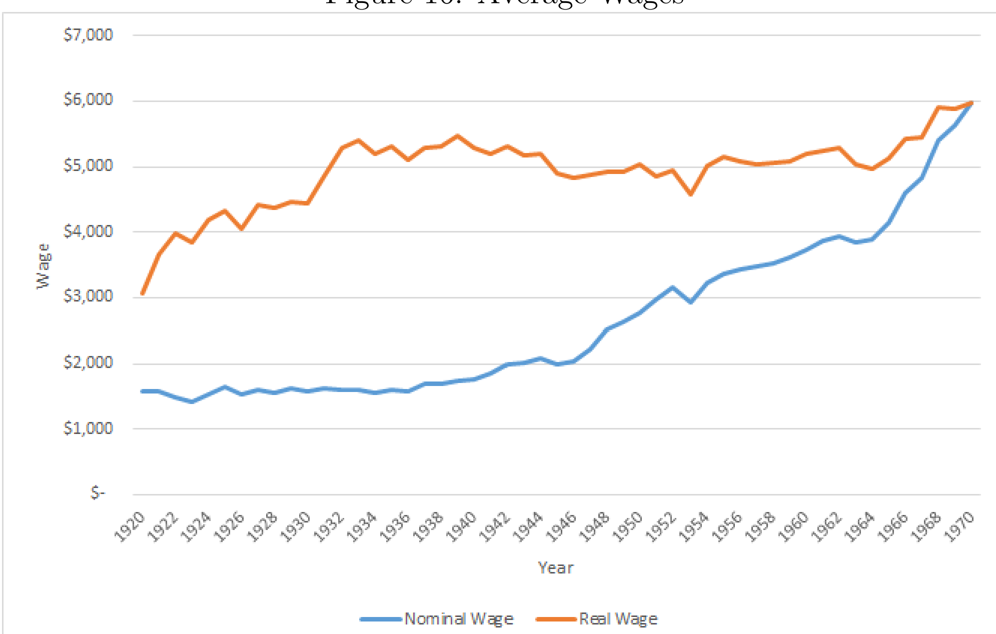
Description: The processing facilities at each mine are rated to process a certain amount of ore per day. This line indicates the average amount of processing capacity at an individual gold mine in a given year.

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.

The Impact of Labour Policies on Ontario Gold Mines in World War II*

Karl Skogstad† Robert J. Petrunia‡

January 30, 2017

Abstract

This paper uses a financial and operational data set of Ontario gold mines between 1939 and 1945 to analyze the response of the industry to two government labour policies enacted during the Second World War. The early war policy designated the gold mining industry as vital for the war effort to boost gold output in order to purchase foreign reserves. The late war policy resulted in restrictions that prevented labour movement into and between the mines. We find that the first policy is largely ineffective in its goal. Although the market allocated labour to the lowest cost producers, the policy caused only a modest increase in gold output. To evaluate the second policy, we estimate the cost curves of the individual mines. The results indicate an inefficient allocation of labour across mines. The gold mining industry experiences operating costs 22 percent higher than with efficient labour allocation during this late war period. The estimated efficiency loss to the industry is nearly $58.4 million 1940 Canadian dollars.

JEL classification: N52, L72, Q3
Keywords: Gold Mining, Ontario, World War II

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1 Introduction

Prior to the Second World War, the gold mining industry in Ontario was a relatively large and important sector of the economy. In 1939, it employed 18,032 people, producing 3,086,060 ounces of gold, valued at over $112 million[1]. This output represented 7.8 percent of the world's total output of gold for that year. Canadian gold mines experienced two distinct policies during World War II. The first policy, enacted between 1939 and 1941, attempted to boost gold production by classifying the gold sector as a vital war industry. The second policy, occurring between 1942 and 1945, prevented gold mines from hiring new workers and prevented workers from moving between mines. Using historical data, this paper examines the impact and effectiveness of these two labour policies on Ontario gold mines. We show that the both policies led to poor outcomes: (i) the first policy does not significantly increase gold production; and (ii) the second policy introduces an inefficiency into the industry that results in a net loss of $58.4 million.

Due to a lack of capital build-up in the interwar years, a lot of investment was needed for the development of Canada's war defense industries[2]. This investment project required the import of capital from the US, which would cause Canada's trade deficit with the US to worsen further. Prior to the war, a trade surplus with the UK provided the US dollars for Canada to fund this trade deficit with the US. The war caused an expected reduction in trade with the UK, which further restricted Canada's access to US Dollars. To overcome this problem, a fixed exchange rate was implemented and very restrictive capital controls were put in place to ration foreign reserves. Additional gold production was thought to help alleviate the problem, as the US was willing to exchange Canadian gold for American Dollars. As a result, Canadian gold mining was classified as an essential industry during the first three years of the war. This classification gave gold mines priority access to labour and capital.

We first examine the effectiveness of this policy to increase production at Ontario gold mines. Our results indicate that labour did not flow to the mines that were capable of producing the most gold, but instead to the lowest cost producers. Given the objective to maximize the amount of gold production, a better policy would have been to direct labour to high producing mines. Rather, the policy meant lower cost mines acquired additional labour through increased compensation.

The second policy is in fact a collection of different labour policies that impacted the entire Canadian economy. The 1941 US entry into World War II led to the removal of essential status designation for the gold mining industry. With the removal of its priority status, gold mines became subject to the price controls and labour market restrictions that regulated all

[1]Note that all dollar amounts are 1940 Canadian dollars unless otherwise noted.

[2]Skogstad (2016)

other non-vital sectors of the economy. As we outline below, policies were put in place that led to prices and wages being fixed during the war[3]. Furthermore, these labour policies put restrictions on the movement of labour between firms and between industries, and became more severe as the war progressed. These policies meant that: (i) initially, mines could not offer workers higher wages in order to induce mine-to-mine movement; and (ii) if a worker did separate from a job then they had to find employment outside the gold mining industry, since gold mining was no longer an essential industry after 1941.

As a result of these late war labour market policies, we find that the inability of labour to reallocate itself between mines lead to higher operating costs at all mines. We show that it would have been more efficient to temporarily close down the least efficient mines and redirect the labour to the most efficient mines. This would result in a reduction of operating costs by 22.21 percent for the years 1942 through 1945, and an increased profit to the industry of $58.4 million. This redistribution of labour could have been done in such a way to as keep gold mines operating in all gold-mining communities of Ontario.

This paper contributes to a number of different literatures. The first relates to studies of mine-level data. Papers in this area include Aydin and Tilton (2000) and Garcia, Knights, and Tilton (2001) who examine labour productivity gains in the copper mining industries in the US and Chile respectively. The latter find that productivity gains in the 1990s are driven by both the opening of new mines and technological change, while the former finds that the opening and closing of new mines play a relatively unsubstantial role during the 1980s. Ellerman, Stoker, and Berndt (2001) investigate labour productivity in the late 20th century for US coal mines. They find that scale effects lead to large increases in labour productivity in this period. Finally, Schmitz Jr (2005), examines productivity at US and Canadian iron ore mines in the 1980s. He attributes their large and sudden boost in productivity to changes in labour practices.

Another branch of literature to which this paper contributes is the examination of a resource extraction industry within a country or region. Slade (2015) examines the US copper mining industry in detail from 1835 to 1986 in order to determine which factors lead to the entry and exit of firms in this sector. She finds entry is strongly related to technological developments and the discovery of new deposits. Godek (1994) looks at the Russian gold mining industry during the Cold War to determine why government reserves are smaller following the war than anticipated in the West. She attributes the low levels not to lack of production, but rather to the international sale of the gold during times of economic need.

Finally, this paper contributes to the literature on the general role of gold production in an economy. Eichengreen and McLean (1994) examine pre-World War I gold production to

[3] Green (1984)

determine what led to changes in its supply. They find that price is not the best indicator of new production, but rather human settlement patterns determine when new sources of gold would come into production. Moel and Tufano (2002) look at North American gold mines from 1988 to 1997 to determine what factors lead to their decision to commence or cease operations. Besides the expected factors such as the price of gold, operational costs, and the amount of reserves, they find that price volatility is particularly important.

The rest of the paper is organized as follows. The next section looks at the gold mining industry in Canada during World War II. Section 3 discusses the data source and provides some general data analysis of the industry. Section 4 briefly discusses the predicted theoretical outcome of the policies. Section 5 examines how labour was allocated within the industry during the war. Section 6 estimates cost curves for the mines and provides a counterfactual scenario. Section 7 concludes.

2 Canada's Gold Mining Industry during World War II

Gold mining was essential for Canada's war efforts in the first three years of the war. Bryce (2005) reports that prior to the war Canada ran trade deficits with the US, and relied on a trade surplus from the UK to provide the American Dollars necessary to continue to run this deficit. With the commencement of the war, the expectation was that the development of the war industries in Canada required a significant amount of capital purchases[4]. As a result, Canada's trade balance with the US further worsened since the US was the major supplier of this equipment.

After the Hyde Park Declaration of 1941, and the entrance of the US into the war, the need to exchange gold for foreign reserves was reduced. At the time, a debate occurred on whether gold production was necessary in Canada, and whether there were more effective uses for labour elsewhere. The US decided that gold mining was not a priority, and diverted labour away from gold mines and the production of gold mining machinery. Bryce (2005) notes that nation-wide labour shortages force US gold mines to cease operations between October 1942 and March 1944. In November 1941, the Canadian government largely followed the lead of the Americans and put gold mines at the bottom of the priority list. However, the government was concerned that the outright closure of the gold mines would be too detrimental to their local communities. The mines continued to operate with labour diverted to them if levels fell so low to jeopardize continued operations; however, their output was expected to shrink.

[4]Skogstad (2016)

These policies directly impacted mining operations. The statistics indicate that employment in Ontario gold mines rose from 18,032 in 1939 to 19,362 in 1941, only to fall to 15,561 in 1942 and bottom-out at 9,996 in 1944. Additionally, Knox (1955) indicates that capital investment in Ontario gold mines fell throughout the war from a 1939 value of $7,205,166 to $596,159 in 1943. Demand from high-priority sectors of the economy meant that equipment replacement was not an easy task at gold mines. Thus, some mines were expected to close[5]. Despite the government's policy of maintaining all mines in operation, some smaller mines did close during the war due to unprofitability and the depletion of their reserves.

There was no doubt amongst policy makers that a complete mobilization of the Canadian economy was necessary to support the war effort. At the beginning of the war few restrictions on labour were needed as there was a large number of unemployed people available to work in the war industries. However, as the war progressed, labour shortages became very serious. As Stacey (1970) notes, by the spring of 1941, the military reported facing a shortage of 116,000 recruits.

This labour shortage lead to higher wages and, in turn, higher prices. To combat this rising rate of inflation, the government instituted wage and price stabilization policies[6]. As Whitton (1941) indicates, prices on goods sold in retail stores were limited to the highest price set between September 15th and October 11th, 1941. Additionally, rents and utility rates were fixed. King (1941) reports that wages were also fixed and controlled by the government, though some flexibility existed in the system. Thus, mines could not offer to pay higher wages to attract new employees, or to induce current employees to stay. For the purpose of this study, we can conclude that the cost of inputs remained constant during the later years of the war.

To deal with the labour shortage, the government began to impose restrictions on the labour market, ultimately leading to a policy of directing individual workers to specific positions. This decision to enforce direct movement of people from one job/industry into another came about very slowly and reluctantly. The goal of the government was to be the least intrusive as possible into the life of the workers. As the war grew in scale and labour shortages became more acute, more drastic steps were necessary. A series of policies that began simply with preventing workers from entering certain industries, expanded into requiring permission to make any sort of change to employment, and then, ultimately, requiring labour to move to fit the needs of the government.

The National Resources Mobilization Act of June 1940 instituted rigorous labour controls in an effort to divert more of the domestic economy towards war production. Provisions of the

[5]Huebert (2001)
[6]Stacey (1970)

act include: (i) requiring employers to report the identity of their employees; and (ii) requiring a worker to obtain a permit before beginning work at a new firm. After September 1942, the National Selective Service Regulation imposed further restrictions such as forbidding any worker from seeking a new job without possessing a permit to do so, forbidding employers from advertising for workers without permission, and making it illegal for a worker to be out of work for more than seven days by forcing them to apply for and accept jobs in high priority industries. On top of these regulations, employment in non-essential industries was curtailed to minimum levels. Finally, in 1943 a set of seven compulsory transfers forced men out of certain industries and jobs, such as working as barbers, ice parlours, and brewing. According to Stacey (1970), over 15,000 workers ended up moving to new jobs by these orders.

The labour shortages experienced by the Canadian military and the Canadian war industries meant that these steps were not surprising. In the summer of 1942 the Minister of National Defence reported that, in his estimation, meeting army's manpower needs required the curtailment of non-essential industries, such as gold mining. The army required an additional 154,000 men for overseas service. On top of this, the Minister of Munitions reported that the war industry required an additional 100,000 to meet their total need of 910,000 men. At this time, he too believed that the curtailment of non-essential industries was the only way to provide the necessary manpower[7].

There are a few unique aspects to the gold mining industry in this era that must be understood prior to undertaking the analysis. First, the price of gold was fixed by the government. As Knox (1955) indicates, the US Government stood ready to buy and sell gold at a price of $US 20.67 prior to the great depression. In addition, after the events of the early 1930s where a number of countries abandoned the Gold Standard, the US government began restricting individuals from accessing gold for monetary and speculative purposes, as described in Cassel (1936). Green (1984) explains the impact of these policies and others on the Canadian mining industry. The terms of the 1932 Gold Export Act obliged Canadian mines to sell their output to Canadian government at the US price. If there was an exchange rate difference between the Canadian and American dollars, the mines themselves would benefit or lose depending on the direction of the difference.

On January 1st, 1934, President Roosevelt increased the price of gold to $US 35 an ounce. This price remained in effect until the end of the Gold Standard in the early 1970s; Canadian mines received this price for their output during this period. According to Powell (2005), during the war, Canada's exchange rate was fixed to the US dollar at a rate of $Can 1.1 for every US dollar. Thus, during the period of study, all Canadian mines received $38.50 for each ounce of gold produced.

[7]Stacey (1970)

The second unique factor about this industry stems from the nature of the demand for its output. Individual mines face a horizontal demand curve for their output, which implies a constant marginal revenue for all levels of output. Times (1933) reports that the unique nature of this demand results in mines not seeing each other as competition. This competitive feature allowed for high levels of sharing of technology and techniques between mines, which kept most mines operating efficiently.

To sum up, in the first three yeas of the war, there was a great need for gold for foreign exchange, so gold mines received priority access to labour. By the end of 1941 this need no longer existed, which curtailed the movement of labour into gold mines. However, the restrictions placed on the labour market meant that labour could not be distributed optimally within the gold mining industry. Labour could not move between mines due to wages being fixed and the fact that separation meant that employees had to get a job in an essential industry, rather than at another gold mine.

3 Data

The source of our data is the Annual Reports of the Ontario Department of Mines. These reports, available as far back as 1890, contain aggregated statistical information on all mining operations in the province. They also include individual reports about the operations of each mine in the province. These individual reports are a combination of data provided by the mines to the ministry as well as excerpts from the annual reports the mines produced for their owners. In order to provide a clear picture of the state of Ontario's gold mining industry during the war, we present a series of graphs that indicate how the industry changed in the years leading up to the war, during the war, and following the war.

Figure 1 shows the output of gold in Ontario from 1930 to 1955. The first thing to note is the rapid rise in gold output following the 1934 increase in price. Gold output in Ontario increases from 2.15 million ounces in 1933 to 3.09 million ounces in 1939. Gold output continues to increase during the early war years. Output grows by 5.7 percent to 3.26 million ounces in 1940 and remains high in 1941 at 3.19 million ounces. Beginning in 1942, gold production falls drastically and reaches pre-1930 levels by the end of the war. A minimum level of output is reached in 1945 with a production of only 1.63 million ounces, less than half of its peak-1940 level.

Figure 2 displays the number of employees in the Ontario gold mining industry during this same time period. Employment growth occurs in the first two years of the war. Employment peaks in 1941 with 19,362 miners working in Ontario gold mines. The impact of the loss of the industry's priority status causes employment to drop dramatically for the rest of the war. Employment reaches a minimum in 1944 at 9,996 employees, just over 50 percent of its maximum level in only 3 years. These two figures give an impression of the inefficiencies introduced into the industry. For example, total output of gold is significantly lower in the later year despite having more workers in 1945 than in 1934.

Figure 3 is a count of the number of operating mines in the province. Again, the pattern is similar. The number of operating mines in the early 1930s is relatively constant at around 25 operating mines. After the price increase of 1934, the number of operating mines jumps very quickly to over 70 and remains at that level during the early war years, until some of the smaller mines began to close down. By 1945 the number of operating mines falls to 50, down from the 1941 peak of 74. We note that the closing mines are mostly small operations with fewer than 30 employees on average.

The main concern of this paper is the efficiency and operations of individual mines; thus, we turn our attention to the data on individual mines. The amount of data available for mines varies between mines and over time. In general, larger mines operate for longer periods and provide more data than smaller mines operating over shorter periods. Ultimately, data are available for 33 of the gold mines operating in the province from 1939 to 1945. 105 unique mine operate at some point during the war, but many of these are extremely small scale mines. Our 33 mines account for 87.3 percent of the 17.2 million ounces of gold produced during the war. The average yearly gold output for mines in the sample is 65,176 ounces, while the average output for mines outside the sample is 4,365 ounces.

Within the sample, there is a great deal of heterogeneity between the mines. Table 1 lists the mines in our sample and provides data on the average value of output, workforce size, grade of ore, milling capacity, and operating costs during the war. As this table shows, the mines differ on their location and their size. Though mines are spread across all of northern Ontario, they are largely concentrated at one of six locations indicated in Figure 4. Mine locations include: (i) three mines in Red Lake; (ii) two mines in Pickle Lake; (iii) four mines in Greenstone; (iv) 11 mines near Timmins; (v) 11 mines near Kirkland Lake; and (vi) two mines near Matachewan.

The mines in Kirkland Lake and Timmins are, on average, slightly older than the other mines in the sample. Gold mines in these areas began operating in the early 1910s in the case of Timmins and the mid-1910s in the case of Kirkland Lake[8]. By 1939, for these two regions, the average age of the mines in the sample is 11 years. The mines in the other four communities are relatively new and commence operations after 1934. By 1939, the average age of mines in these communities is only 3 years.

Table 1 shows that the Timmins and Kirkland Lake mining camps are both large and

[8]Barnes (1995)

extremely productive, with their average gold output being larger than mines from the other regions. The Hollinger mine produces nearly 14 percent of the gold output of the province during the war, by far the largest producer of gold in Ontario at the time. The seven largest mines are responsible for just over half of the province's gold output during the war. These seven mines are also responsible for 47 percent of employment in gold mining during these years.

One important difference between mines is grade or the concentration of gold found in the ore. On average, the mines in the sample have access to ore with a grade of 0.30 ounces of gold per ton. The grade varies across the mines, reaching levels as low as 0.10 ounces per ton and as high as 0.78 ounces per ton. All else equal, the expectation is that locations with access to higher grade ore have relatively lower operating costs, and thus, relatively higher profit.

There are clear differences in the operating costs across the mines. Operating costs are measured as the average cost of extracting, refining, and bringing an ounce of gold to market. These range from a low of $14.80 at the Dome mine to a high of $36.50 at the Bidgood mine, with the average being $23.22.

We next examine some correlations in the mine-level data to get a better sense of its nature. The first thing to note is the strong correlation between ounces of gold produced and employment at these mines. Figure 5 displays the strong positive log-linear relationship between the value of employment and the ounces of gold produced in that year at a same mine. Further, the correlation coefficient between these variables is 0.95.

Figure 6 shows the relationship between the logged yearly ounces of gold produced and the logged yearly total operating costs. Again, a clear positive relationship is visible, as would be expected. Figure 7, on the other hand, shows the same information, except costs are now expressed as the logged value of the yearly operating costs divided by total number of ounces of gold produced in a year, in other words the log of the average cost. Here there appears to be a U-shaped relationship in the data.

We use data about the milling capacity of the facilities at the mine sites to look at the relationship between a mine's size and efficiency. The mills are designed to process a certain tonnage of ore each day, but mines are able to operate at levels both above and below this designated value. As Table 2 indicates, there is not much change in the size of the milling facility during the time period of interest, though twenty of the mines did increase their milling capacity in 1940 or 1941 while enjoying essential status. Table 3 indicates the percentage of this designed milling capacity that these mines use each year. As indicated, most mines operate above capacity in 1939 and 1940, which makes the expansions of 1940 and 1941 understandable. However, by the later war years, all mines operate below capacity.

The average usage went from 99 percent in 1939 and 100 percent in 1940 to 55 percent by 1945.

Figure 8 shows the relationship between logged milling capacity and logged average operating costs, while Figure 9 shows the relationship between the percent of milling capacity used and logged average operating costs. In both cases there is a slight negative relationship indicating the possibility of returns to scale. A U-shaped relationship is expected for Figure 9. The apparent absence of this relationship may be due to the relatively small number of observations above the 100 percent value.

We note that the capacity of a mill is not directly proportional to the mine's amount of gold production, but rather the amount of ore processed. The grade of the ore body determines how much gold can be recovered from every ton milled. Figure 10 shows the relationship between the logged average grade of the ore milled and the logged average operating cost. A clear negative relationship can be seen.

4 Theoretical Considerations

Before beginning the statistical analysis, it is helpful to examine the predicted outcomes from a standard economic model. The devaluation of the Canadian Dollar (CAD) vis-à-vis the US Dollar (USD) occurs at the start of the war from a rate of one CAD per USD to a rate of 1.1 CAD per USD. Given the nature of gold mining, a mine's marginal revenue is constant and equal to price. Thus, output and employment at gold mines should increase as their marginal revenue increases by ten percent as a result of the Canadian Dollar's devaluation.

For the cost side of these firms, the status as a vital industry meant that labour moved more easily into gold mining than compared to other non-vital industries. Wages experience upward pressure in the early war period. For the industry as a whole, average wages increase by 1.4 percent between 1939 and 1940, 5.8 percent between 1940 and 1941 and 6.6 percent between 1941 and 1942. There is a clear upward trend in the early war years, so that average and marginal costs increase as a result of these rising labour costs. These rising costs put pressure on mines to reduce output contrary to the effect resulting from rising marginal revenues.

Overall, Ontario gold production increases during this period, which indicates the rise in the marginal revenue outpaces the increasing marginal costs in most cases. Only 17 of the 33 mines in our sample see an output increase between 1939 and 1941. Thus, some clear differences occur between mines during this period. Half of the mines expand their output to meet the call for more gold. One possible explanation is that the more efficient mines acquire labour from the less efficient mines. Employment fell at 15 of the mines during these years and only grew at 18, which supports this explanation. Restriction free movement of labour between mines in the early war years allows lower operating cost mines the ability to offer higher wages and draw labour way from higher cost mines. Thus the policy, as designed, does not necessarily allocate labour to the larger mines with greater potential gold output, but instead to the mines able to offer workers the highest wage.

We next turn to theoretical predictions for the later war years, 1942 to 1945. Marginal revenue remains constant during the period, but we now expect the mines to face higher average and marginal costs. Restrictions to the labour force limits the amount of mining done. Thus, mines may no longer operate at the profit maximizing level of output. The existence of increasing returns to scale implies that mines move up their average cost curve. Underutilization of capital may lead to higher average costs.

We expect an inefficient allocation of labour in the industry, which leads to rising average costs. Given that the movement of miners from one mine to another is not possible, the industry, as a whole, likely operates inefficiently. The least efficient mines were almost certain to close without the government taking action to ensure all larger mines remain in operation during this period. Mine closures would have meant labour would likely move to the remaining gold mines if no labour market restrictions were in place. However as a result of late war policies, labour could only relocate to a vital war industry, which gold mining was no longer considered.

The data support this assertion at both the aggregate and mine-level. For the industry as a whole, operating cost per ounce of gold rose on average 5 percent a year during the war, from $17.6 per ounce in 1939 to $24.4 per ounce by 1945. Since prices are fixed for the majority of this period, these rising operating costs are almost certainly the result of inefficiencies from mines operating at below optimal levels of labour. When examining individual mines, average operating costs steadily rose in nearly every mine in the sample.

If the market did operate efficiently, we expect to see the closure of the least efficient mines as the more efficient mines poach away their labour force. Instead, we find that a reduction in labour and output occurs at all mines, and a high level of inefficiency.

5 Changes in Labour Force

Total gold output in Ontario decreases by over 67,000 ounces, or a fall of 2.1 percent, between 1940 and 1941 despite an employment increase of 750 workers or 4.0 percent, which illustrates the failure of the early war policy to increase gold production. We examine the failure of this policy by looking at the allocation of the additional workers across gold mines. There are two, non-mutual exclusive, possibilities to consider as a result of the early war policy: (i) workers move to more productive mines; and (ii) workers move to mines with more output. Between 1939 and 1941, there is a fall between 5 and 603 workers at the 15 mines which experienced reduced employment, while employment rises between 2 and 265 at the other 18 mines in our sample. The mines losing the most workers actually produce more gold on average. In 1939, the average output of the mines losing labour is over 81,000 ounces, while the average output of mines gaining labour is only 79,300 ounces. A more revealing fact is that the labour reducing mines have an average production cost of \$20.77 in 1939, while the labour gaining mines have an average production cost of \$18.29 in the same year. These comparisons indicate that labour likely flows during this period to the mines with the lowest production costs.

The following regression provides a conditional analysis of the factors leading to employment changes at mines:

$$\%\Delta L_{i,t} = \beta_1 \text{AOC}_{i,t-1} + \beta_2 \text{OZ}_{i,t-1} + X_{i,t-1}\beta_k + \upsilon_i + \epsilon_{i,t} \tag{1}$$

where $\%\Delta L_{i,t}$ is the percentage change in employment at mine i from year t and year $t-1$, $\text{AOC}_{i,t-1}$ is the logged average operating cost of mine i in year $t-1$, $\text{OZ}_{i,t-1}$ is the logged ounces of gold produced at mine i in the year $t-1$, and υ_i is a fixed effect for each mine. $X_{i,t-1}$ is a set of control variables unique to the mine including the number of employees, the size of the gold reserves, the milling capacity of the mine and the grade. All of these variables are logged and lagged one period. We use lagged values of variables to examine their impact on the change in employment moving into the following year.

Table 4 shows the results of fixed effect panel regressions for the years 1939 to 1941, when gold mining is an essential industry. The table presents seven different specifications. The coefficient estimate on lagged logged average operating cost is negative in all specifications. This conditional negative relationship between average operating cost and employment growth supports the notion that more efficient mines are acquiring additional labour.

The next variable of interest is a mines gold production. The goal of declaring gold mining essential is to increase the amount of gold produced. A possible result of the policy is that labour moves to the mines capable of producing more gold due to their already established production size and the size of their ore body. The results provide weak evidence that the relationship between mine size and employment growth is negative. The coefficient on mine gold production is negative and statistically insignificant across most specifications. There is no evidence to support the notion that labour flows to mines with the largest output.

For the other variables, the coefficients on the size of the labour force and the grade of the ore body are not statistically significant. The coefficient on the size of the milling facilities is positive, which indicates mines processing more raw ore increase their labour force by a larger amount. As would be expected, the size of the gold reserves shows a positive relationship, which indicates larger employment growth at mines with more proven gold reserves. We note that the quality of the data for this variable is somewhat low for two reasons. First, not all mines report their reserve level, so the inclusion of this variable significantly reduces the number of observations. Second, mines may not measure reserves in the same way. Some mines only report if they have enough gold for the immediate future, while others try to estimate the entire size of their remaining ore body.

Overall, these results indicate that the market works as expected by allocating the additional labour to the mines with the lowest production costs. The policy may not achieve the goal of increasing gold output as the mines producing the most gold tend to lose labour, rather than gain it.

Next, we turn to the analysis of the late war years, 1942 to 1945. Recall that during these years labour market policies did not encourage allocation of workers to the industry. Table 5 displays regression estimates for equation 1 using mining data from the late war years. Changes in employment are negatively related to both lagged average operating cost and the amount of gold produced. The coefficient on these variables is always statistically significant except for specification one. During this period nearly all mines are losing employees. Thus, negative coefficients on these variables indicate that firms with higher operating costs and firms producing more gold have greater reductions in their employment.

Given that wages are fixed in this time period, the first result is somewhat unexpected. All mines, even at the most efficient, could not offer higher wages to retain or attract labour. Mines may have offered non-wage benefits to workers in place of wage increases. Larger mines shedding more workers is not a surprising result. Most mines were able to maintain operations at very low levels of employment. Larger mines had the ability to lose more employees while still staying in operation when compared to smaller mines.

The estimated mine fixed effects are also of interest. The fixed effects for all mines in Timmins are positive except for one, while the fixed effects for most mines outside the Timmins area are negative. These fixed effects estimates indicate that labour force reductions for mines in Timmins are less severe than compared to mines in other locations. This result shows up unconditionally as well. Between 1942 and 1945, the total labour force of Timmins mines fell by 34 percent, compared to an average of 44 percent at mines in the other five communities.

The data set is rich enough to allow us to delve deeper into how different mines responded to the war. In general, the average operating costs of the mines are broken down into four categories: (i) Development/exploration; (ii) mining; (iii) milling; and (iv) general costs. Each of these costs trend upwards during the war, except for the development and exploration component. On average, in 1939, the development and exploration component comprises 20 percent of the mines' operating costs at \$3.9 per ounce of gold produced. By 1943, this value falls to 14 percent at \$3.3 per ounce of gold produced. Mining and milling costs rise consistently year to year. General costs see the largest rise by more than doubling from \$2.0 per ounce in 1939 to \$4.2 per ounce by 1945. The increasing importance of these general costs is not surprising as they represent fixed costs not varying with output, such as non-productive office staff and heating costs.

By examining non-financial values we see that in 1939, 1940, and 1941 the mines are very active in development and exploration. Both development and exploration are measured in feet. The average yearly development across all the mines is equal to 430,000 feet in the first three years of the war. This value fell to 300,000 feet in 1942 and then to less than 190,000 feet for the remaining three years of the war. Exploration, as measured by the feet of diamond drilling, also fell. In both 1940 and 1941, the total amount of diamond drilling at these mines was over 1,200,000 feet. For each of the last three years of the war, this value was less than 870,000. As these exploration and development costs are often incurred to gain future revenues, it would be illuminating to examine the post-war impact of these cuts. We hypothesize that those mines making the highest cuts in these areas likely see lower future profits.

The results indicate that the most cost effective mines appear to acquire and hold onto labour more effectively than less efficient mines throughout the entire war. The results further suggest that the government does not achieve the goal of maximizing gold output in the early years of war, as largest producing mines tend to have smaller increases to their labour supply. So, even though the market was acting efficiently in terms of devoting labour to lower cost producers, this was not serving the policy's intended purpose as gold output was not being maximized.

6 Measuring the Inefficiencies

This next section quantifies the impacts that the government's restrictive labour policies have on the overall efficiency of the Ontario gold mining industry. Specifically, we want to quantify the rise in average cost of producing an ounce of gold in this period compared to the theoretically optimal level.

To answer this question, we first identify the most efficient mines. Given that technology and techniques are being freely shared between mines at the time, these mines likely faced very similar cost functions. Our task here is to estimate the average cost curve for the various mines during the period to determine the potentially most efficient mines. To do this task, we estimate the following total operating cost regression specification:

$$\begin{aligned}\text{TC}_{i,t} = \beta_1 + \beta_2 \left(\text{OZ}_{i,t}\right) + \beta_3 \left(\text{OZ}_{i,t}\right)^2 + \beta_4 \left(\text{Grade}_{i,t}\right) \left(\text{OZ}_{i,t}\right) + \beta_4 \left(\text{Grade}_{i,t}\right)^2 \left(\text{OZ}_{i,t}\right) \\ + \beta_5 \left(\text{Mill}_{i,t}\right) + \upsilon_i + \epsilon_{i,t}\end{aligned} \quad (2)$$

$\text{TC}_{i,t}$ is the logged total operating cost of mine i in year t. $\text{OZ}_{i,t}$ is the logged output of gold, measured in ounces, at mine i in year t. $\text{Grade}_{i,t}$ is the log of the grade of the ore body measured in ounces of gold per ton of ore at mine i in year t. $\text{Mill}_{i,t}$ is the log of the measured daily milling capacity of the facilities at mine i in year t. The βs are coefficients to be estimated and υ_i are mine fixed effects. Our approach is to estimate the total cost curves for the mines, and use these to derive the associated average cost and marginal cost curves. We have also estimated the average cost curves directly, and the results are nearly identical to those we obtain here[9].

Table 6 presents the regression results using the above specification. The estimated coefficients for ounces of gold and squared ounces of gold indicate that the average cost curves take on a U-shaped appearance as predicted earlier. Average cost falls very quickly when output is relatively low, but the curve remains relatively flat once reaching a sufficiently high level of output. Average costs only appear to begin to increase once output reaches a relatively high level. In fact no mine in the sample produces beyond the minimum of their respective average cost curve.

For the effect of grade on average costs, the estimated coefficients show that higher grades lead to downward shifts of the average cost curve. This shift becomes larger as the grade increases. This finding is not at all unexpected given the process of milling ore. Before the gold can be extracted, all ore must be pulverized. For a given quantity of gold extracted, the pulverizing machines run less time with higher grades of ore. The only other additional milling cost is additional cyanide to extract the gold from the rock, but the cost of cyanide is relatively insignificant.

Finally, we examine the size of the mill to estimate the effect of capital. The regression results show that, all else equal, larger mills translate into higher average costs, as indicated by an upward shift in the average cost curve. This result is intuitive as smaller mills require less energy, amongst other inputs. The size of the mill is likely to be closely related to the grade of the ore. As a result, we alternatively examine the impact of capital utilization or the percentage use of a mill's maximum operating capacity. The results show that costs increase with the percentage of mill time use. We explore the possibility of non-linearities with this

[9]Results available upon request.

variable, but the coefficient estimates on the quadratic term are insignificant.[10]

Our preferred specification is from column three as the results best match the observed average costs. Figure 11 displays some sample average cost curves based on this specification. As is easily seen, higher grades lead to downward shifts in average cost curves, and large milling capacity leads to upward shifts in the curves. The grade values and mill capacities represent values near to the first and third quartiles from the data.

There is clearly a sharp drop-off in costs after reaching a critical output level. Regardless of other factors, operating at low levels of output is very inefficient for mines. For our sample of 33 mines and in the years 1939 to 1942, on average only 9 mines operate below the 30,000 ounces a year level. This number grows to 14, 18, and 21 in 1943, 1944, and 1945, respectively. The labour market restrictions limits the ability of the industry to allocate labour in the most cost effective way, which results in large inefficiencies.

We now examine a counterfactual scenario using specification three to measure these inefficiencies. We begin by estimating the average cost curve for each mine during the period. Figures 12 and 13 display two of these average cost curves for the Macassa and Hollinger Mines, respectively. The points indicate the observed output and costs for these mines in the given years. As can be seen, the estimates match the observed data very well. In both cases, output increases at these mines in 1940 and 1941 and falls in the remaining war years. The average cost is also increasing for these years. Focusing on these two mines, a transfer of the labour from Macassa to Hollinger would cause the average costs of Hollinger to fall. As total output of gold does not fall, this transfer results in a more efficient outcome for the industry.

Our task is to identify the possible level of output and cost per ounce for the industry with efficient re-allocation of labour across mines. To do this, we first measure how much gold an individual miner can produce. Returning to Figure 5, there appears to be a strong linear relationship between the logged level of employment and the logged ounces of gold produced. Table 7 investigates this relationship further through a series of regressions of ounces of gold produced at a mine and the number of employees. Using level values of variables, specifications 1 and 2 indicate the relationship is linear with each employee producing an estimated 173 ounces of gold. Using the logged values of variables, specifications 3 and 4 suggests a log-linear relationship. Figure 14 graphs specifications 1 and 3. Since few mines have a large number of employees, the results are similar for the level and logged specifications. Thus, we use specification 1, where each additional employee produces 173 extra ounces of gold. Estimation is done to see if this value differs across mines in a systematic way. With only seven observations per mine, there is not enough data to get a statistically significant relationship, though evidence suggests differences exist.

[10]These results are available on request.

In the later war years, the mines are all operating below the capacity determined by the size of their mills. For this reason, an additional miner produces 173 ounces of gold regardless of where they work. In our earlier analysis for the early war years, shifting labour between mines has the potential to increase gold output as some mines were operating near capacity. The marginal product of labour is smaller at these locations than at mines operating below capacity.

Shifting labour between mines does not lead to substantial changes in output. Additional labour at more efficient mines allow them to move down their average cost curves, while the less efficient mines shut down with fewer workers. For this counterfactual exercise, the following steps and assumptions are made. First, we assume an upper limit on the number of employees a mine employs effectively. This limit is the maximum employment between 1939 and 1941. Limiting to this amount ensures we are not projecting beyond a mine's employment range. The result of this assumption is that our estimated efficiency loss is smaller than the true value, as none of the mines reach the minimum of their average cost curve at these observed maximum employment values.

With these maximum labour values in hand, we use our estimated relationship from specification 1 in Table 7 to calculate the predicted level of gold output at each mine at this maximum value of labour. This output level can be thought of as the maximum level of gold output possible for a mine. Then, we input this output level, the grade of the ore body, and the size of the mill into total cost curve specification 3 from Table 6 to calculate an estimated average cost in each year (1942-1945) at a mine's maximum employment level. Using these values, we rank mines from lowest to highest average costs for a given year. Thus, we identify the most and least efficient mines for every year given the unique characteristics of each mine.

The re-allocation of labour across mines is done in the following manner. For each year, we identify a mine's maximum additional workers as the difference between mine's maximum employment from earlier minus current employment. We assume that the least efficient mine closes and allocate the closing mine's workers to the most efficient mine up to maximum additional workers. Any remaining workers are then allocated to the next most efficient mine up to maximum additional workers, and so on. Next, we close the second least efficient mine and redistribute labour in a similar manner. This re-allocation process continues until it is no longer possible to close a mine for redistribute labour to other mines. Thus, the counterfactual scenario moves labour to the most efficient mines up to their maximum employment level.

With this optimal labour distribution within the gold mining industry, we determine the counterfactual level of industry wide gold output and the total cost of producing this output. As a result of this exercise, the 12 least efficient mines close in 1942, an additional mine closes in 1943 and 3 more mines close in 1944. Table 8 summarizes the results. With labour allocated efficiently, industry costs fall by a total of 22.21 percent during the last four years of the war. This figure represents an additional profit of over $58.4 million to the industry or just under one billion dollars in current 2016 dollars.

This approach assumes fully mobile workers. This re-optimization within the industry involves the movement of labour between the six different mining communities. Although mining in each of the six communities continues under this re-allocation of labour, some miners must relocate. Specifically, around 2,500 miners would need to be relocated to Kirkland Lake and Pickle Lake from the other four communities. These two communities benefit from having much lower average costs due to higher grade ore and smaller average mill sizes.

As a comparison, we redo the counterfactual but restrict labour from moving between communities. Thus, the least efficient mines within each community are now closed down, and their labour is redistributed to the most efficient mines within the same community. Table 9 presents the results of this exercise. The added restriction leads to higher average costs than the previous scenario, though they are still much lower than actual costs. Estimated cost savings is 15.37 percent instead of 22.21 percent, which leads to an additional profit of $41.9 million to the industry.

7 Conclusion

This paper shows that the Government of Canada's plan to significantly increase the output of gold in the early years of World War II fails despite diverting scarce labour into the industry. Labour flowed to firms with the highest profit margin, rather than the mines producing the most gold. If the government directed labour more effectively then gold output may have increased to a larger extent in these early years.

In the late war years, when gold was no longer necessary for the war effort, the presence of too many government imposed labour market restrictions limited the movement of labour to the more efficient firms. These restrictions lead to inefficiencies within the industry, which cause extractions costs to increase by 22.21 percent or a loss of profit of nearly $58.4 million in 1940 dollar terms for the industry.

The key conclusion from these findings is that government policy needs to be flexible to avoid these types of inefficiencies. For instance, in the early years of the war, if the need for gold was so dire then the government should not have relied on the labour market to direct labour as to maximize output. The labour market acted as expected by moving labour to the mines offering the most compensation. In the later years of the war, the restrictions on labour did not need to be so severe as to not allow labour to reallocate optimally within the industry.

If gold mining was an important industry and necessary to keep operational during the war, the government should have allowed for labour movement between mines. With the concentration of gold mines around Timmins and Kirkland Lake, this labour movement would not have involved much disruption to these communities. If gold mining was not an important industry then a better policy would temporarily suspend all gold mining operations in the province to free up labour for other, more important industries, or for service in the armed forces, as was done in the US. Perhaps the most effective use would be the transfer of this labour, already skilled in mining, into the mining for base metals or coal, which both faced severe labour shortages. Although generally accepted that World War II meant labour restrictions, imposing these restrictions involves designing policies to minimize unnecessary inefficiencies.

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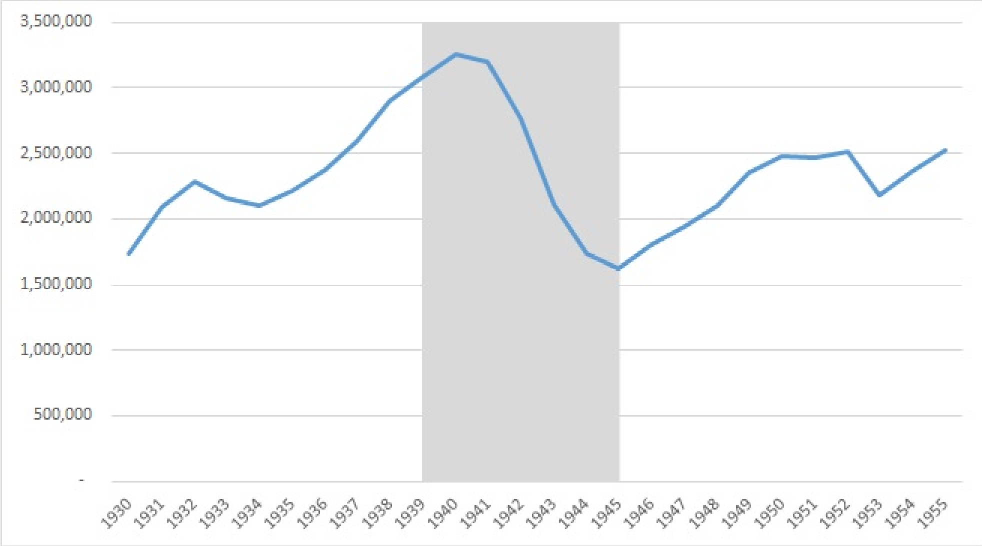
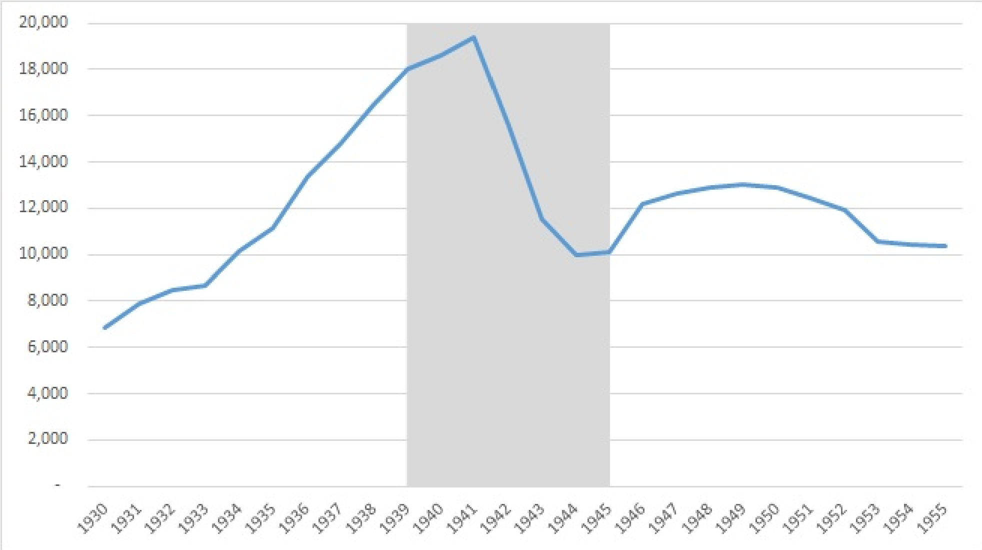
8 Figures

Figure 1: Gold Output



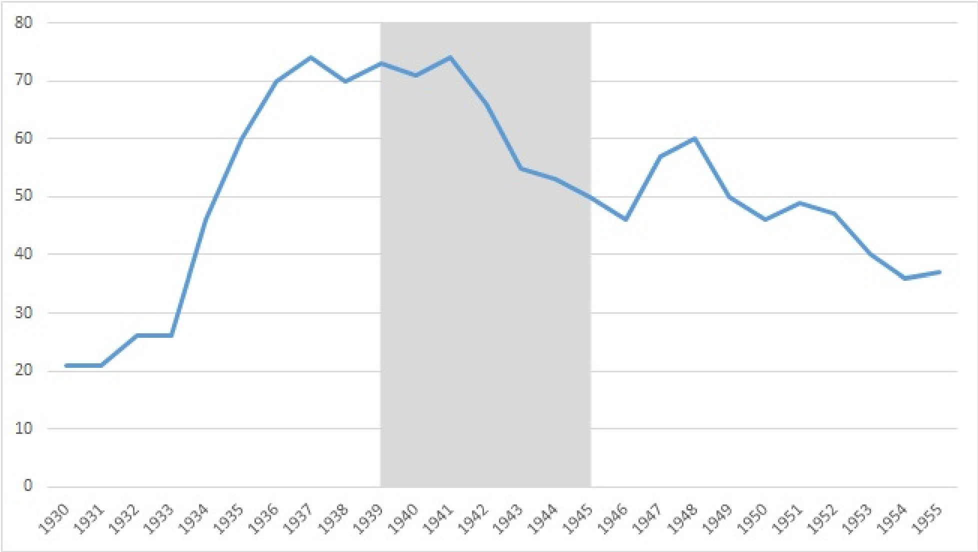
Description: The amount of gold, measured in troy ounces, produced in Ontario by year. The shaded area represents World War II.

Figure 2: Employment in Gold Mines



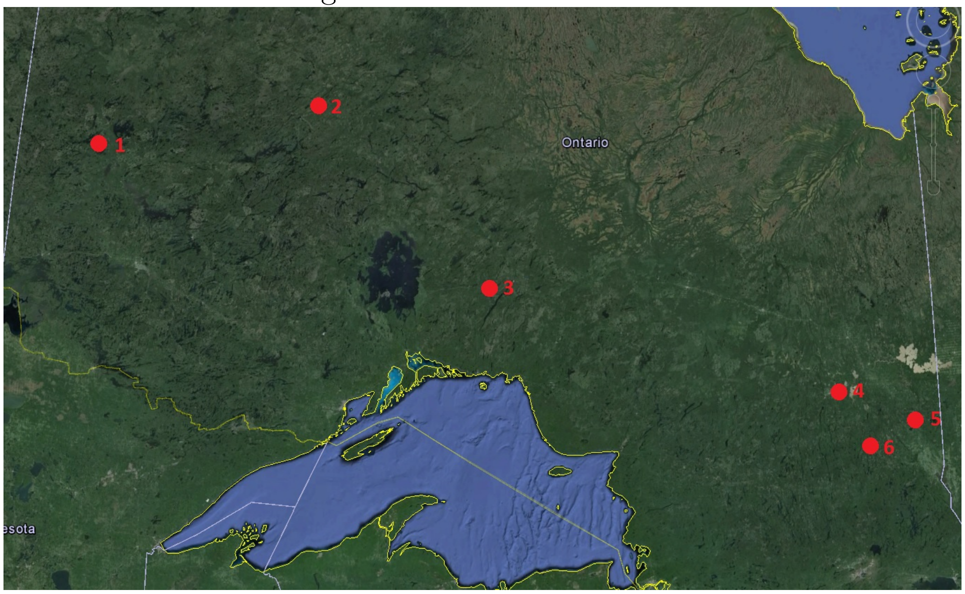
Description: The number of employees working in Ontario gold mines. The shaded area represents World War II.

Figure 3: Number of Operating Gold Mines



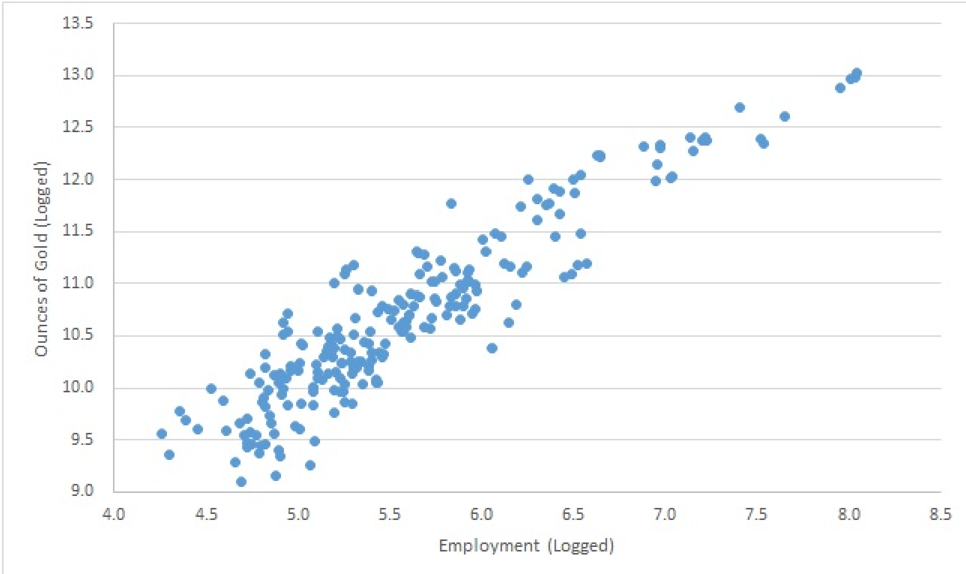
Description: The number of operating gold mines in the province for a given year. The shaded area represents World War II.

Figure 4: Sites of the Mines



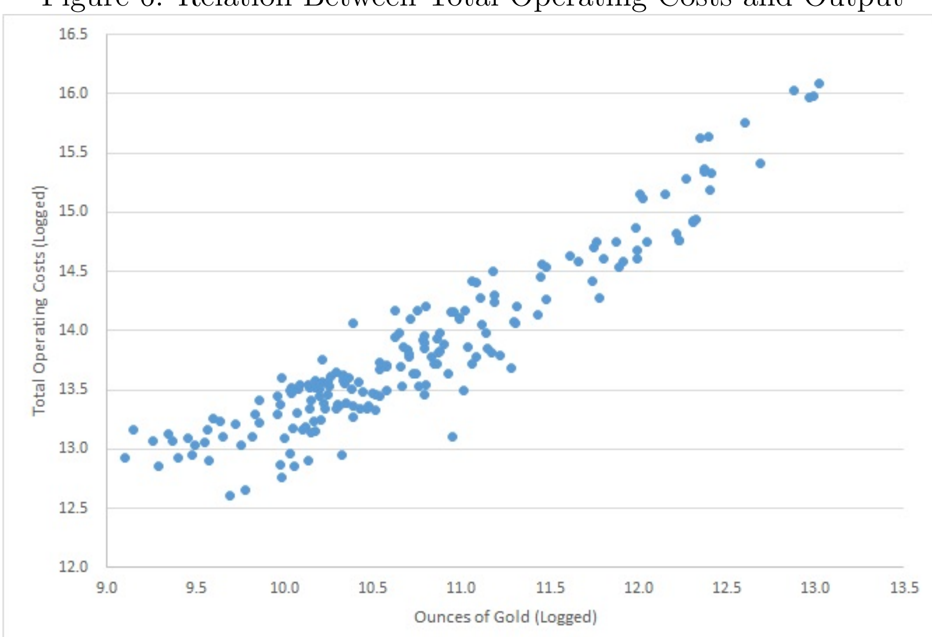
Description: The general location of the 33 mines in the sample. Three mines were located near Red Lake (Point 1). Two mines were located near Pickle Lake (Point 2). Four mines were located near Greenstone (Point 3). Eleven mines were located near Timmins (Point 4). Eleven mines were located near Kirkland Laked (Point 5). Two mines were located near Matachewan (Point 6).

Figure 5: Relation Between Employment and Output



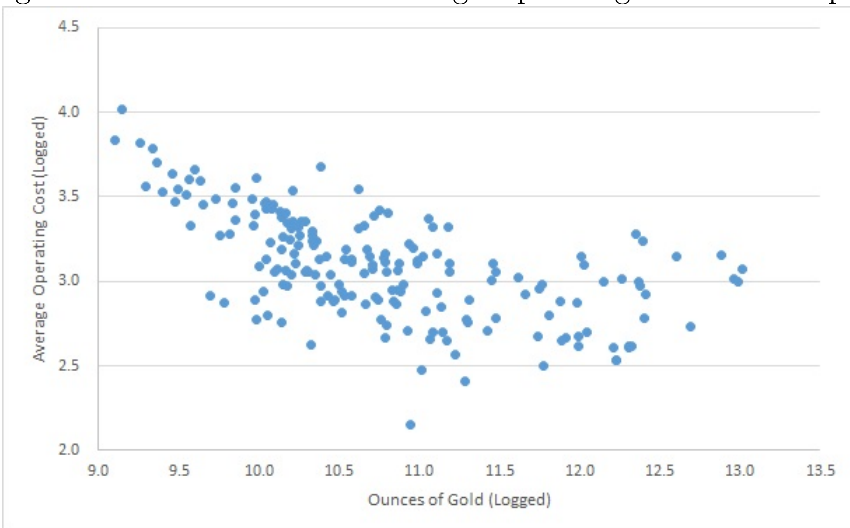
Description: The relationship between the logged employment value and the logged ounces of gold produced value from 1939-1945 for each of the 33 mines in the sample.

Figure 6: Relation Between Total Operating Costs and Output



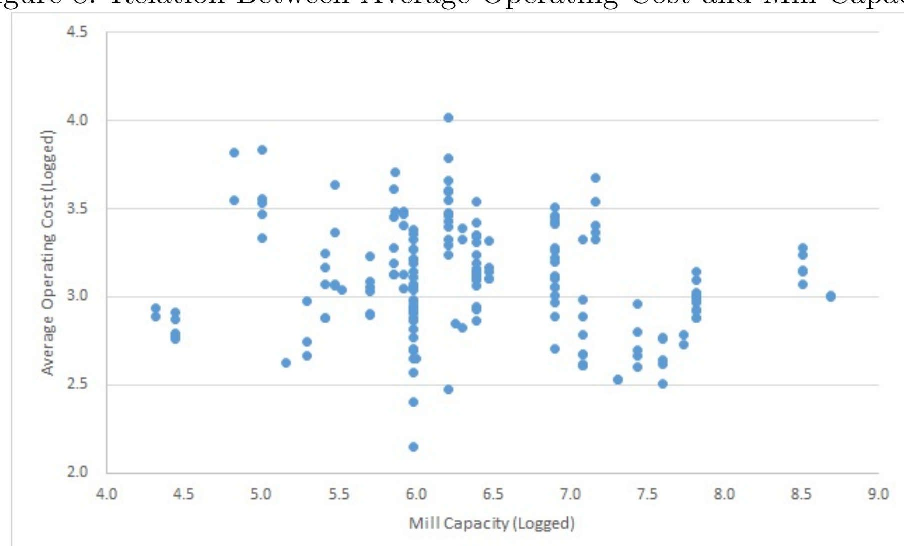
Description: The relationship between the logged total operating cost and the logged ounces of gold produced value from 1939-1945 for each of the 33 mines in the sample.

Figure 7: Relation Between Average Operating Cost and Output



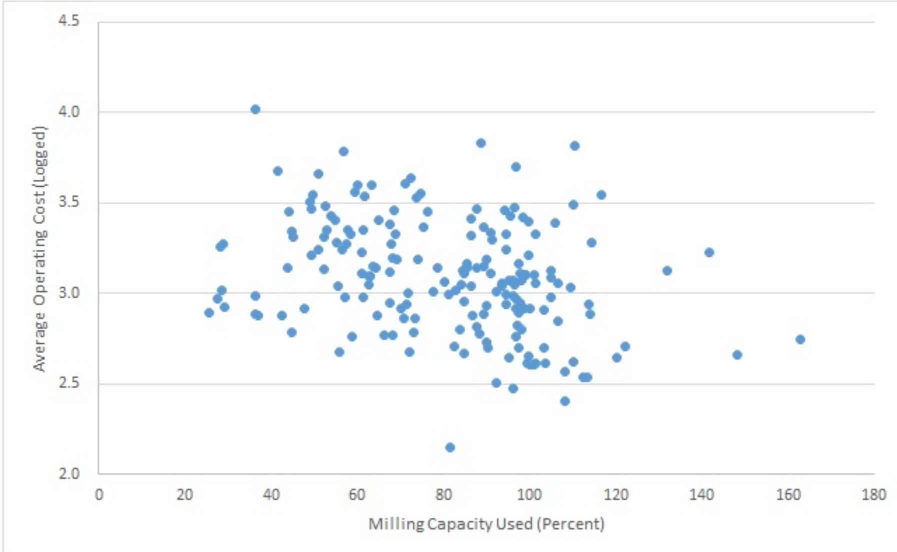
Description: The relationship between the logged average operating cost and the logged ounces of gold produced value from 1939-1945 for each of the 33 mines in the sample.

Figure 8: Relation Between Average Operating Cost and Mill Capacity



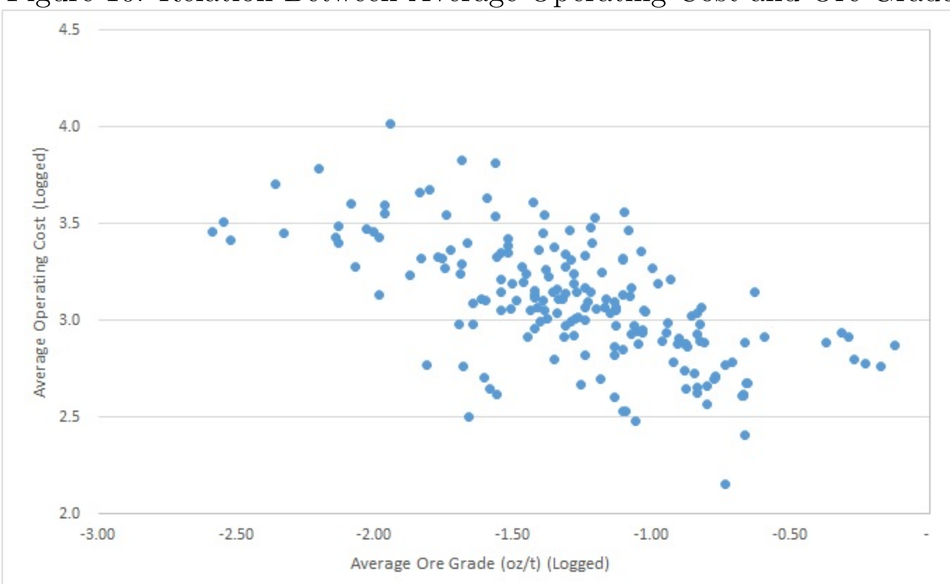
Description: The relationship between the operating cost per ounce of gold produced and the milling capacity from 1939-1945 for each of the 33 mines in the sample.

Figure 9: Relation Between Average Operating Cost and Mill Capacity Used



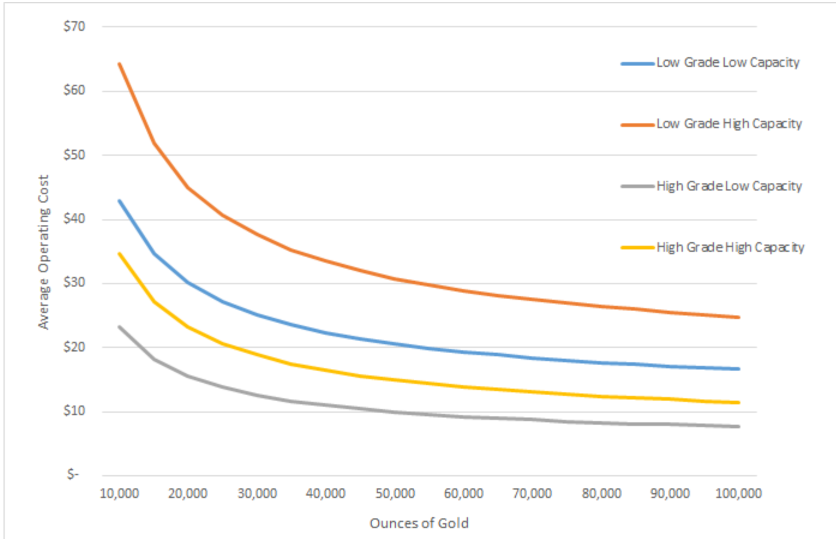
Description: The relationship between the operating cost per ounce of gold produced and the milling capacity used from 1939-1945 for each of the 33 mines in the sample.

Figure 10: Relation Between Average Operating Cost and Ore Grade



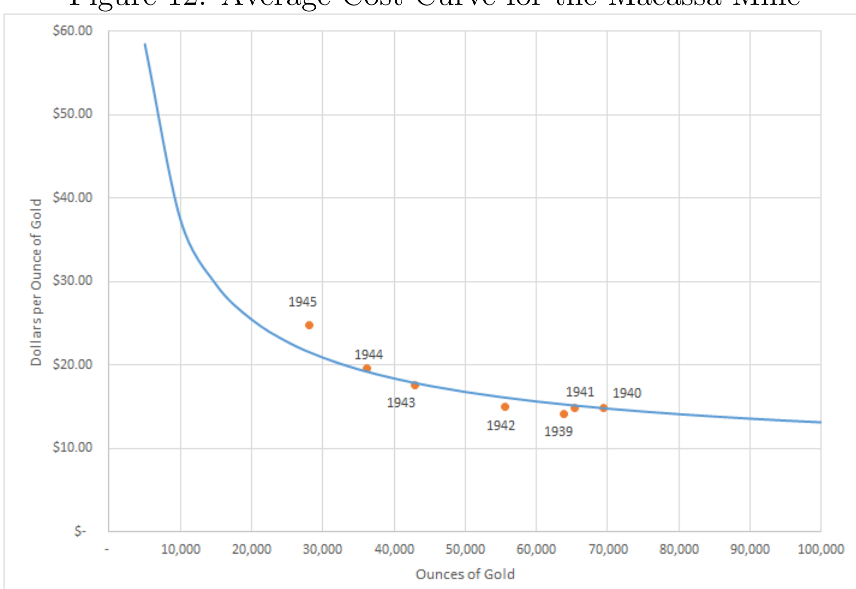
Description: The relationship between the operating cost per ounce of gold produced and the average ore grade from 1939-1945 for each of the 33 mines in the sample.

Figure 11: Average Cost Curves from Specification 3 of Table 6



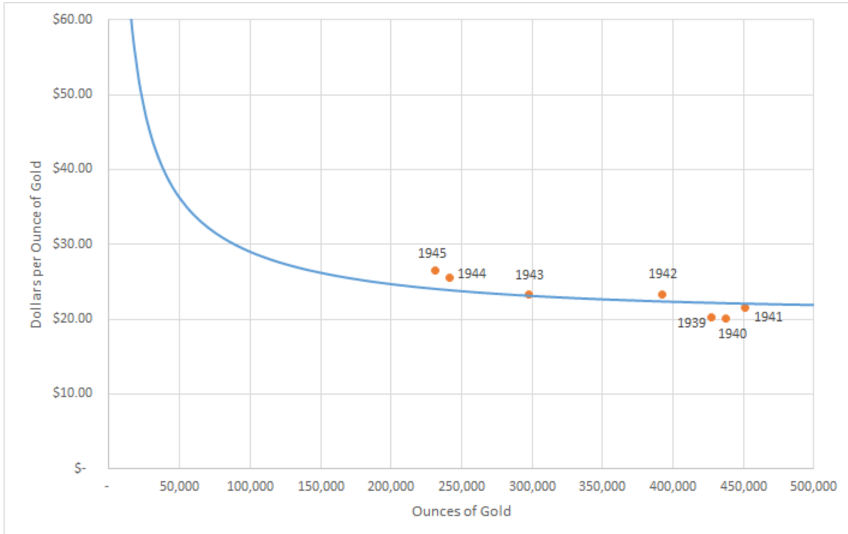
Description: Estimated average cost curves for mines with both low and high grades (0.2 and 0.6 ounces per ton) and small and large mills (250 and 1500 tons per day) based on regression specification 3 of Table 6.

Figure 12: Average Cost Curve for the Macassa Mine



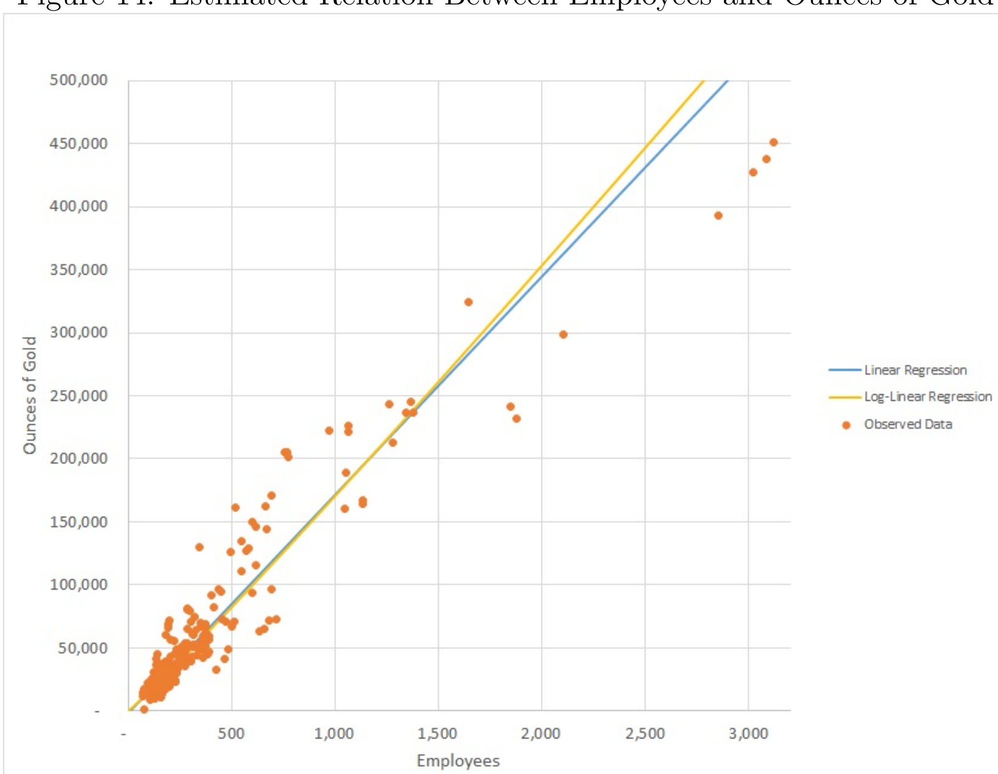
Description: The estimated average cost curve for the Macassa mine using average grade from 1939 to 1945 and average mill size. The points indicate actual output and costs per ounce for the given years.

Figure 13: Average Cost Curve for the Hollinger Mine



Description: The estimated average cost curve for the Hollinger mine using average grade from 1939 to 1945 and average mill size. The points indicate actual output and costs per ounce for the given years.

Figure 14: Estimated Relation Between Employees and Ounces of Gold



Description: The graphed relationship of specifications 1 and 3 from Table 7. The points represent observed employment-output pairs for every mine in the sample for every year.

9 Tables

Table 1: Mines in the Dataset

Mine	Map	Output (troy oz.)	Employ. (workers)	Grade (oz./ton)	Mill Capacity (Tons/Day)	Operating Cost (Dollars/Ounce)
Hollinger	4	340,941	2561	0.24	5286	22.93
McIntyre-Porcupine	4	209,459	1242	0.28	2500	20.56
Lake Shore	5	194,533	911	0.40	2443	18.00
Dome	4	170,519	673	0.30	1643	14.80
Wright-Hargreaves	5	155,798	732	0.51	1200	14.86
Kerr-Addison	5	106,568	402	0.19	1743	15.21
Preston East Dome	4	60,767	353	0.30	779	18.66
Pamour	4	57,565	383	0.11	1500	N/A
Buffalo Ankerite	4	56,476	583	0.18	1243	30.11
Sylvanite	5	55,940	320	0.33	589	19.85
Hallnor	4	55,664	170	0.47	379	N/A
Pickle Crow	2	54,603	245	0.47	400	16.94
Teck-Hughes	5	53,614	356	0.29	1000	21.96
Macassa	5	51,654	252	0.44	401	17.28
MacLeod-Cockshutt	3	47,486	307	0.27	643	23.57
Central Patricia	2	41,026	236	0.36	343	18.99
Kirkland Lake Gold	5	39,076	234	0.38	400	23.29
Coniaurum	4	38,918	285	0.27	600	24.94
Paymaster Consolidated	4	37,723	307	0.21	586	28.95
Little Long Lac	3	34,887	227	0.35	354	24.94
Madsen Red Lake	1	31,796	169	0.24	400	21.24
Young-Davidson	6	28,855	197	0.10	1000	N/A
Upper Canada	5	28,366	163	0.39	218	21.32
McKenzie Red Lake	1	23,695	132	0.31	226	23.42
Hard Rock	3	23,277	150	0.23	336	26.28
Toburn	5	22,241	168	0.44	182	N/A
Delnite	4	21,821	174	0.17	457	31.89
Leitch	3	21,219	102	0.78	82	17.31
Matachewan Consolidated	6	20,266	164	0.10	829	30.41
Omega	5	19,024	182	0.13	500	35.24
Hasaga (J.E. Hammell)	1	17,835	125	0.15	308	30.67
Ross (Hollinger)	4	17,312	122	0.21	279	N/A
Bidgood	5	11,875	128	0.26	143	36.50

Description: Data on the 33 mines in the study for the years 1939 to 1945. Map is the location of the mine on the map in Figure 3. Output is the average yearly output of gold in troy ounces. Employ. is the average number of employees at the mine. Grade is the average ounces of gold per ton of rock. Mill capacity is the average daily milling capacity for the mine in tons of ore per day. Operating Cost is the average cost to produce one ounce of gold.

Table 2: Milling Capacity

Mine	1939	1940	1941	1942	1943	1944	1945
Bidgood	125	125	150	150	150	150	150
Kirkland Lake Gold	400	400	400	400	400	400	400
Lake Shore	2300	2300	2500	2500	2500	2500	2500
Macassa	406	400	400	400	400	400	400
Sylvanite	525	600	600	600	600	600	600
Teck-Hughes	1000	1000	1000	1000	1000	1000	1000
Toburn	150	150	195	195	195	195	195
Upper Canada	175	225	225	225	225	225	225
Wright-Hargreaves	1200	1200	1200	1200	1200	1200	1200
Kerr-Addison	1200	1000	2000	2000	2000	2000	2000
Omega	500	500	500	500	500	500	500
Matachewan Consolidated	300	500	1000	1000	1000	1000	1000
Young-Davidson	1000	1000	1000	1000	1000	1000	1000
Central Patricia	200	200	400	400	400	400	400
Hasaga (J.E. Hammell)	125	275	350	350	350	353	353
Madsen Red Lake	400	400	400	400	400	400	400
McKenzie Red Lake	175	200	240	240	240	240	240
Pickle Crow	400	400	400	400	400	400	400
Buffalo Ankerite	1000	1200	1300	1300	1300	1300	1300
Coniaurum	600	600	600	600	600	600	600
Delnite	300	400	500	500	500	500	500
Dome	1500	1500	1700	1700	1700	1700	1700
Hallnor	400	400	370	370	370	370	370
Hollinger	6000	6000	5000	5000	5000	5000	5000
McIntyre-Porcupine	2500	2500	2500	2500	2500	2500	2500
Pamour	1500	1500	1500	1500	1500	1500	1500
Paymaster Consolidated	550	550	600	600	600	600	600
Preston East Dome	400	500	550	1000	1000	1000	1000
Ross (Hollinger)	225	225	300	300	300	300	300
Hard Rock	300	300	350	350	350	350	350
Leitch	75	75	85	85	85	85	85
Little Long Lac	300	300	375	375	375	375	375
MacLeod-Cockshutt	600	650	650	650	650	650	650

Description: Milling capacity of the mines by year expressed as tons of ore milled per day.

Table 3: Milling Intensity

Mine	1939	1940	1941	1942	1943	1944	1945
Bidgood	117	111	74	88	91	89	60
Kirkland Lake Gold	68	95	94	69	58	53	58
Lake Shore	90	73	43	37	29	29	36
Macassa	100	103	97	82	71	57	49
Sylvanite	107	73	90	80	68	63	52
Teck-Hughes	107	92	98	26	28	28	29
Toburn	101	109	85	61	57	56	59
Upper Canada	74	81	89				
Wright-Hargreaves	100	101	100	72	56	45	36
Kerr-Addison	61	122	95	104	92	66	59
Omega	96	97	94	75	60	63	57
Matachewan Consolidated	142	100	54	86	68	49	44
Young-Davidson	103	101	95	81	53	44	57
Central Patricia	148	163	98	95	72	63	61
Hasaga (J.E. Hammell)	128	88	106	132	114	110	97
Madsen Red Lake	96	97	100	100	99	88	67
McKenzie Red Lake	110	105	96	98	98	89	72
Pickle Crow	108	108	120	87	56	48	44
Buffalo Ankerite	99	86	95	76	55	50	42
Coniaurum	86	85	85	74	51	45	45
Delnite	105	68	91	95	69	51	36
Dome	112	114	101	90	85	84	85
Hallnor	84	96	98	96	78	76	71
Hollinger	78	81	96	89	64	57	55
McIntyre-Porcupine	97	97	95	83	72	63	64
Pamour	107	105	102	105	96	86	76
Paymaster Consolidated	101	106	99	79	61	58	62
Preston East Dome	81	96	97	84	68	68	61
Ross (Hollinger)	68	115	92	93	78	71	67
Hard Rock	101	110	90	105	76	71	5
Leitch	114	114	98	97	88	70	65
Little Long Lac	98	103	86	85	65	49	53
MacLeod-Cockshutt	91	99	101	97	88	52	27

Description: The yearly percentage use of the designed milling capacity.

Table 4: Panel Yearly Percentage Change in Employment Regressions (1939-1941)

Yearly %Δ Total Employment	1	2	3	4	5	6	7
AOC_{t-1}(Logged)	-44.126*		-49.420*	-24.923	-68.820***	-82.916***	-101.410***
	(22.502)		(25.808)	(38.333)	(22.701)	(29.655)	(36.756)
OZ_{t-1} (Logged)		-4.822	-8.692	12.261	-41.316**	-4.079	-2.754
		(19.115)	(19.527)	(31.110)	(18.727)	(18.516)	(18.694)
$Empl._{t-1}$ (Logged)				-33.560			
				(38.648)			
$Reser._{t-1}$ (Logged)					48.722***		
					(11.145)		
$Mill_{t-1}$ (Logged)						53.895*	49.406*
						(27.408)	(28.065)
$Grade_{t-1}$ (Logged)							-30.585
							(35.494)
Constant	135.223**	57.507	246.839	143.390	78.925	-52.329	-22.543
	(66.594)	(208.190)	(259.741)	(287.089)	(228.855)	(287.808)	(291.645)
Observations	48	62	48	48	37	48	48

Description: Regression results for a panel regression of the yearly change in employment at Ontario gold mines 1939-1941. Mine fixed effects are used. *, **, and *** denote 10, 5 and 1 percent significance, respectively. The dependent variable is the yearly percentage change in total employment at a mine. AOC_{t-1} is the one year lagged average operating cost. OZ_{t-1} is the one year lagged ounces of gold produced. $Empl._{t-1}$ is the one year lagged employment level. $Reser._{t-1}$ is the one year lagged ore reserves measured in ounces of gold. $Mill_{t-1}$ is the one year lagged size of the mill measured in tons of ore per day. $Grade_{t-1}$ is the one year lagged grade of the ore mined measure in ounces of gold per ton of ore processed.

Table 5: Panel Yearly Percentage Change in Employment Regressions (1942-1945)

Yearly %Δ Total Employment	1	2	3	4	5	6	7
AOC_{t-1}(Logged)	4.842		-56.079***	-54.399***	-49.071***	-53.440***	-58.188***
	(10.686)		(9.829)	(11.986)	(11.559)	(10.275)	(11.355)
OZ_{t-1} (Logged)		-30.294***	-47.590***	-45.044***	-49.047***	-46.689***	-47.397***
		(3.832)	(5.038)	(11.456)	(5.163)	(5.146)	(5.198)
$Empl._{t-1}$ (Logged)				-2.591			
				(10.452)			
$Reser._{t-1}$ (Logged)					11.015**		
					(5.430)		
$Mill_{t-1}$ (Logged)						-15.928	-18.857
						(17.830)	(18.081)
$Grade_{t-1}$ (Logged)							-10.629
							(10.810)
Constant	-25.251	312.496***	675.399***	657.446***	536.682***	759.971***	787.543***
	(33.205)	(40.909)	(77.675)	(106.540)	(105.832)	(122.523)	(125.716)
Observations	111	132	111	111	88	111	111

Description: Regression results for a panel regression of the yearly change in employment at Ontario gold mines 1942-1945. Mine fixed effects are used. *, **, and *** denote 10, 5 and 1 percent significance, respectively. The dependent variable is the yearly percentage change in total employment at a mine. AOC_{t-1} is the one year lagged average operating cost. OZ_{t-1} is the one year lagged ounces of gold produced. $Empl._{t-1}$ is the one year lagged employment level. $Reser._{t-1}$ is the one year lagged ore reserves measured in ounces of gold. $Mill_{t-1}$ is the one year lagged size of the mill measured in tons of ore per day. $Grade_{t-1}$ is the one year lagged grade of the ore mined measure in ounces of gold per ton of ore processed.

Table 6: Panel Total Cost Curve Regressions

Total Operating Costs (Ln)	1	2	3	4	5
Ounces of Gold (Ln)	-1.234**	-0.845**	-0.841*	-10.897	-1.180***
	(0.471)	(0.380)	(0.417)	(6.830)	(0.390)
Ounces of Gold (Ln) Squared	0.083***	0.063***	0.063***	0.977	0.049***
	(0.021)	(0.017)	(0.019)	(0.621)	(0.017)
Ounces of Gold (Ln) Cubed				-0.028	
				(0.019)	
Grade (Ln) times Ounces of Gold (Ln)		-0.122***	-0.123***	-0.128***	-0.067*
		(0.033)	(0.029)	(0.029)	(0.034)
Grade (Ln) Squared time Ounces of Gold (Ln)		-0.024***	-0.029***	-0.032***	-0.034***
		(0.008)	(0.009)	(0.009)	(0.010)
Mill (Ln)			0.225*	0.241*	0.951***
			(0.126)	(0.128)	(0.321)
Mill Usage (Ln)					0.718**
					(0.281)
Constant	17.448***	14.353***	13.008***	49.566*	14.636***
	(2.634)	(2.252)	(2.274)	(24.581)	(2.050)
Observations	189	189	189	189	185
R-Squared	0.907	0.871	0.911	0.916	0.904

Description: Regression results for a panel regression of the logged operating cost per ounce of gold produced using data from 1939-1945. Mine fixed effects are used. *, **, and *** denote 10, 5 and 1 percent significance, respectively.

Table 7: Output of Gold per Worker

	1	2	3	4
Dependent Variable:	Ounces	Ounces	Logged Ounces	Logged Ounces
Total Employment	173.154***	185.812***		
	(4.608)	(8.996)		
Squared Total Employment		-0.004		
		(0.003)		
Logged Total Employment			1.052***	1.671***
			(0.058)	(0.479)
Squared Logged Total employment				-0.055
				(0.042)
Constant	-1,776.544	-5,097.259*	4.780***	3.057**
	(1,910.975)	(2,782.255)	(0.326)	(1.362)
R-Squared	0.911	0.916	0.843	0.846

Description: Panel regressions showing the relationship between output of gold in ounces or logged ounces and the number of employees at the mine. Mine fixed effects are used. *, **, and *** denote 10, 5 and 1 percent significance, respectively.

Table 8: Counter-Factual Scenario 1

	Historical		Counter-Factual		
	Operating Mines	Cost per Ounce	Operating Mines	Cost per Ounce	Savings
1942	33	$20.13	21	$17.42	13.47%
1943	33	$20.53	20	$16.37	20.26%
1944	33	$23.16	17	$16.79	27.52%
1945	33	$24.44	17	$16.98	30.52%
Total		$21.75		$16.92	22.21%

Description: The average operating costs by year in the data and in the counter-factual scenario where labour was reallocated between mines and between cities.

Table 9: Counter-Factual Scenario 2

	Historical		Counter-Factual		
	Operating Mines	Cost per Ounce	Operating Mines	Cost per Ounce	Savings
1942	33	$20.13	25	$18.79	6.68%
1943	33	$20.53	17	$17.87	12.94%
1944	33	$23.16	15	$18.38	20.65%
1945	33	$24.44	14	$18.53	24.20%
Total		$21.75		$18.41	15.37%

Description: The average operating costs by year in the data and in the counter-factual scenario where labour was reallocated between mines but not between communities.