Centre for the
Study of Living Standards
Centre d'étude des
niveaux de vie
111 Sparks Street, Suite 500
Ottawa, Ontario K1P 5B5
Tel: 613-233-8891 – Fax: 613-233-8250
csls@csls.ca

Productivity Trends in the Gold Mining Industry in Canada

Jeremy Smith
Centre for the Study of Living Standards

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Abstract

The purpose of this report is to uncover the factors behind what has been, on average, a strong productivity performance from the Canadian gold mining industry over the past four decades. It is found that real price movements have had a substantial impact on productivity growth in the gold mining industry in Canada. The real price of gold declined steadily throughout the 1990s, squeezing the profits of mines on sites of marginal quality and thereby leading to the closure of the least productive gold mines. This had the effect of increasing the average productivity of the overall industry. The report also finds evidence that the gold mining industry in Canada was not in good health towards the end of the 1970s, despite the record gold prices of this period. Real gold mining output decreased sharply and steadily throughout the 1960s and 1970s, despite massive capital accumulation. This situation was reversed in the 1980s, with new discoveries of gold, and strong productivity growth driven by technological and organizational improvements. As these observations suggest, the productivity performance of the Canadian gold mining industry has been markedly different from decade to decade. The 1960s and 1970s witnessed productivity stagnation followed by sharp declines, but the 1980s and 1990s saw gold mining productivity growth exceeding that at the total economy level by a wide margin. Overall, the productivity gains of the past two decades have more than offset the earlier poor performance, so that the average productivity record of the gold mining industry over the past four decades remains strong.

Productivity Trends in the Gold Mining Industry in Canada

Executive Summary

In December 2002, the Centre for the Study of Living Standards (CSLS) delivered to Natural Resources Canada (NRCan) an overview report entitled "Productivity Trends in Natural Resource Industries in Canada." This report examined trends and drivers or determinants of labour, capital, and total factor productivity for all 20 natural resource industries in Canada over the 1961-2000 period. In February and March of 2004, CSLS prepared for NRCan in-depth analyses of the drivers of labour productivity growth for a subset of these industries, consisting of nine selected natural resource industries (coal mining, gold mining, diamond mining, electricity generation, oil and gas, logging and forestry, wood products, paper products, and earth sciences). This report is the result of the analysis undertaken for the gold mining industry.

The report includes a review of the literature on gold mining productivity. One of the most important observations from the literature review is that metal mining industries are highly innovative, especially when account is taken of the process innovations absorbed through equipment from innovative suppliers. Further, there are many indications that this technological progress is very important for labour productivity growth. The organization of work is found to have an impact on productivity growth in metal mining; and to this can be added the possible negative effects on productivity of poor labour-management relations and adjustment to new regulations discussed in the literature for the coal mining industry. The effect of output price on average productivity through encouraging or discouraging operations on lower-productivity sites is mentioned by several studies but is not highlighted by these studies as a primary determinant of productivity.

In studying these productivity drivers for the case of the Canadian gold mining industry, the report first reviews the salient characteristics of the industry. Some interesting observations are the following:

- the gold mining industry accounted for 0.15 per cent of total economy output in Canada in 2000, and 0.05 per cent of employment;

- in 2001 there were 35 gold mines in Canada, down from 70 in 1989, and distributed across six provinces and the three territories;

- in 2000, Canada was the fourth largest producer of gold in the world with about 5.8 per cent of world production;

- despite having the image of an old-fashioned industry, the mining industry in Canada is actually among the largest users of advanced technologies; and

- the real price of gold rose rapidly in the 1970s – due to demand pressures from speculative buying caused by the uncertainty associated with the oil price shocks – and declined more or less steadily throughout the 1980s and 1990s.

The labour productivity performance of the Canadian gold mining industry has varied markedly by decade. In the 1960s output per hour growth was weak, despite strong increases in capital intensity. In the 1970s labour productivity declined sharply, but the 1980s and 1990s saw a strong output per hour growth performance. The level of output per hour in the Canadian gold mining industry was above that of the total economy for the entire 1961-2000 period, but exceeded the total economy average to a much larger degree in 2000 than in the 1960s and 1970s, owing to the strong productivity growth of the 1980s and 1990s. The level of output per hour in the Canadian gold mining industry in 2000 was slightly higher than that in the U.S. gold mining industry.

The report applies a simple growth accounting framework to attempt to identify the drivers of output per hour growth in the Canadian gold mining industry in each of these periods. Capital intensity growth is found to have been an important driver of labour productivity in the 1960s and slightly less so again in the 1990s, but the impressive output per hour growth in the 1980s was driven primarily by total factor productivity growth. The report makes the following findings, based on the literature review and trends in more specific factors affecting productivity growth.

- **1960s:** rapid growth in capital intensity but declining output and only weak labour productivity growth, due to declining ore grades.

- **1970s:** a large increase in the real price of gold encouraged the mining of poor quality sites, leading to large declines in labour productivity – but the continued declines in output suggest that as much gold as possible was being extracted from existing operations, and perhaps that the high prices saved the industry from collapse.

- **1980s:** an abrupt rebound to solid labour productivity growth, due to new discoveries of richer and more accessible deposits, reinforced by technological and organizational improvements.

- **1990s:** weak productivity growth in the first half of the decade followed by very strong growth thereafter. Capital intensity growth became important once again after stagnation in the 1980s, a steady decline in the real price of gold continued to pressure low-productivity mines to close, and more importantly, most aspects of mining – from site design to extraction to the on-site transportation of materials – became computerized.

Productivity Trends in the Gold Mining Industry in Canada

In December 2002, the Centre for the Study of Living Standards (CSLS) delivered to Natural Resources Canada (NRCan) an overview report entitled "Productivity Trends in Natural Resource Industries in Canada" (CSLS, 2003). This report examined trends and drivers or determinants of labour, capital, and total factor productivity for all 20 natural resource industries in Canada over the 1961-2000 period. In February and March of 2004, CSLS prepared for NRCan in-depth analyses of the drivers of labour productivity growth for a subset of these industries, consisting of nine selected natural resource industries (coal mining, gold mining, diamond mining, electricity generation, oil and gas, logging and forestry, wood products, paper products, and earth sciences). A summary of these analyses is found in CSLS (2004). The present report is the result of the analysis undertaken for the gold mining industry.[1]

The report is divided into four sections plus a conclusion. The first section presents a review of the literature on productivity and its determinants in gold and other metal mining industries. The second section presents detailed observations on the salient characteristics of the Canadian gold mining industry. The third section presents data on labour, capital and total factor productivity growth and levels in the Canadian gold mining industry. The fourth section focuses on labour productivity, and attempts to identify the factors explaining the labour productivity growth performance of the Canadian gold mining industry over the past four decades.

I. Literature Review of Studies on Productivity in the Gold and Other Metal Mining Industries

This section reviews the literature to attempt to uncover the factors behind what has been, on average, a strong productivity performance from the Canadian gold mining industry over the past four decades. Unfortunately, there are very few studies on productivity in gold mining specifically. Attention has focused instead on other metal mining industries, such as copper and iron ore, probably because these are more important industries than gold in the United States, where much of the research has been undertaken. In most cases though, the gold mining industry resembles these other metal mining industries to an extent such that conclusions are likely to be directly applicable to the gold mining industry. Also, some important factors identified in the literature review on coal mining productivity in Smith (2004) are relevant for metal mining as well. Therefore, for some issues such as labour-management relations that are addressed by the coal literature but not by the metal mining literature, it is possible to draw lessons from the coal experience for the mining industry as a whole.

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[1] CSLS would like to thank NRCan for financial support to undertake this research. The author would like to thank NRCan officials for comments on earlier drafts and Andrew Sharpe for comments and guidance. Comments can be directed to the author at jeremy.smith@csls.ca. The reports on coal mining (Smith, 2004) and diamond mining are available as CSLS Research Reports 2004-07 and 2004-09 respectively at www.csls.ca under Publications and Research Reports, and the reports on the remaining six industries are available upon request from info@csls.ca.

A. Early Studies on Canadian Metal Mining Productivity

Stollery (1985) estimates total factor productivity growth rates through a parametric cost function approach and discusses their determinants for the following Canadian mining industries for the 1957-1979 period: asbestos, aggregated non-metal mining, copper, gold, silver, nickel, iron, aggregated metal mining, and aggregated mining. He finds the major determinants to be more or less equally important across these industries. The time period of this analysis includes a high-productivity growth period in the 1960s followed by a sharp drop in growth rates, indeed becoming negative for many industries, in the 1970s.

Stollery (1985) finds that rapidly increasing capital intensity was coincident with large increases in the scale of operations in all mining industries considered in the 1960s, hence setting the stage for productivity rewards from realizing increasing returns to scale (consistent with the theoretical predictions of Boyd (1987) for coal mining, as discussed by Smith (2004)). He finds that the productivity slowdown in the 1970s was caused in large part by a contraction in output, i.e. the increase in the scale of operations in the 1960s was reversed. He also finds large negative effects on productivity growth from higher energy prices (caused by the oil price shocks of the 1970s) and declining quality of the ores being mined. The effect of energy prices is substantial due to the fact that the increasing scale in the 1960s entailed high capital investments – which generally consisted of machinery requiring large fuel expenditures – and so a shift from labour to capital.

Although Stollery does not draw the link, several of these observations are interrelated. A broad range of natural resource commodities saw real price increases in the 1970s, although such increases were most pronounced for coal, which became a partial substitute for oil, and for gold and silver, which attracted speculative buying in this period caused by uncertainty associated with the oil price shocks. These higher prices made potential smaller mines on sites with lower quality deposits profitable enough to enter into operation, even though a part of this increased profitability was being offset by higher fuel expenses. This in turn decreased average ore grade and output, which acted to reduce productivity growth.

The method employed by Stollery (1985) to estimate TFP growth allows for the quantification of a residual effect that is not accounted for by the specific cost function specification. He finds this residual effect to be somewhat important in explaining TFP growth for the aggregate mining industry, and makes a number of speculations as to what this residual might be picking up. First, he raises the possibility of a slowdown in technological innovation in the 1970s, and quotes Richardson (1976) as indicating insufficient research and development expenditure in mining supply industries (i.e. those designing the machinery and equipment for actual mining operations). Second, he states that increased environmental and safety regulations imposed in the 1970s, along with unspecified tax disincentives, probably reduced investment in mining, citing some findings of Smithson et al. (1977). This lower investment, he states, may have indirectly reduced productivity growth through decreasing access to new technologies and thereby slowing the rate of innovation.

Despite the vintage of the Stollery study, as well as its particular focus on the productivity slowdown in the 1970s, several relevant lessons can still be drawn for productivity growth in gold mining, and more generally in metal mining and all mining industries. Chief among these are the role of operations on sites with poor ore grades in lowering the average productivity of the overall industry; and the possibility of increasing productivity growth through larger operations that realize the benefits of increasing returns to scale. Also, adoption of new technologies, especially those embodied in new capital, appear to be important drivers of productivity growth as well, although Stollery (1985) is not able to show this directly.

Green and Green (1987) provide a study of productivity determinants in the metal mining industries in Ontario for the 1975-1985 period, with coverage for the 1960-1977 period available in an earlier report (Green and Green, 1985). The analysis is generally broken down into gold mining, iron mining and other metal mining, but the results are largely uniform. Although Green and Green (1987) make no mention of Stollery (1985), their results provide a useful way to broaden Stollery's conclusions, which focus on the exceptional decade of the 1970s. Green and Green (1985) find the same steep labour productivity declines in Ontario metal mining as Stollery observes for Canadian metal mining in the 1970s, but Green and Green (1987) note evidence of the beginning of a recovery in the early 1980s.

Green and Green (1987) note the same reductions in the scale of operations and capital accumulation during the 1970s as Stollery (1985), but identify an additional cause of the productivity slowdown in metal mining in that decade. This is the failure of mines to reduce the number of non-production workers (referred to as white collar workers, i.e. administrative and managerial workers) during periods of output declines. This, they state, is evidence that skill-specific workers are a quasi-fixed input. They conclude that the productivity declines of the 1970s were in part caused by the inability to adjust the workforce to operations on a smaller scale.

By the early 1980s, however, Green and Green (1987) find that capital accumulation in metal mining had resumed and that the employment of white collar workers had become more flexible. However, demand for raw materials such as metals was judged to be limited in that period, causing continued reliance on smaller operations and so keeping productivity growth low. The authors suggest that rising capital accumulation in the face of low demand is in fact evidence of an expected boom in demand for raw commodities, and so that the rebound in capital accumulation in metal mining in the 1980s would eventually lead to expanding output and a resumption of the strong productivity growth of the pre-1970s period.

Beyond increased flexibility in adjusting the workforce to the presiding demand conditions, the authors judge the continued adoption of new technologies through capital investment to be important for success in terms of productivity growth. It should also be noted that their prediction of a rebound in output and productivity growth later in the 1980s turned out to be correct, especially for gold, as will be seen in the section discussing the productivity performance of the Canadian gold mining industry in the third section of this report.

B. Innovation and Canadian Metal Mining Productivity

These early studies on metal mining in Canada clearly recognize the importance of technology in productivity growth. They mainly focus on innovation as embedded in new machinery and equipment. A more recent and comprehensive examination of innovation in metal mining, based on the Statistics Canada 1999 Survey of Innovation, is provided by Schaan (2002). She reports that metal mines tend to innovate more in process than in product terms. She also finds that there is a smaller proportion of innovative firms in metal mining industries specifically as compared to manufacturing industries, but notes that in an overall system approach to analyzing innovation, part of manufacturing's innovative activity passes through to metal mining industries through the supply of equipment (i.e. embodied technical progress).

Two further points should be made about this study. First, it is not surprising that metal mining firms are not large product innovators, since their output is generally demanded in raw form and so does not require innovations in presentation or content. Second, the data available do not lend themselves to an entirely suitable system approach to metal mining innovation, since no data are available on innovation in construction industries. Site development and exploration in mining are included in the engineering component of the capital stock, and innovations in this area have a potentially large-scale impact on mining processes.

Overall, then, this report suggests, that the Canadian metal mining industry is highly innovative, both in terms of employing the newest technologies in capital investments, and in using new technologies to improve mining techniques. Global Economics (2001) makes similar observations for Canadian mining in general. Given the global competitive pressure to contain costs, it is not entirely surprising that mining industries are eager to adopt cost-saving innovations.

Two specific examples provide further support for the conclusion that metal mining is a highly innovative industry. Singhal, Collins and Fytas (1995) discuss the increase in the use of computers for improving the productivity of on-site transportation through automatic dispatching, and improving productivity in general through scheduling, data logging and precision planning. Another process innovation they discuss is the substitution towards conveyors and away from trucks for the transportation of ore.

Morrison (1996) also mentions this movement to belt conveyance systems, and discusses the increased precision and effectiveness of new equipment, for example robotic machinery with sensors allowing remote control, in hardrock metal mining. He predicts a major shift towards smaller access drifts for deep hardrock mining, improving productivity through more precise control, and improving worker safety both through allowing operators to maintain distance in dangerous situations and increasing structural stability of the overall pit.

A further study, by Fred Kissell (2000) of the U.S. Bureau of Mines, should be mentioned in the context of mining innovation. This study looks at past technology policies of the Bureau of Mines in order to discover the circumstances that surrounded their success or failure in terms of effective adoption by the mining industry. While technology and innovation have been identified as key driving factors of productivity in mining industries, this study stresses the importance of appropriateness of technologies and the timing of their implementation in conjunction with the acquisition of the necessary complementary skills. It identifies five factors that were essential for the eventual adoption by mines of technologies suggested by the Bureau.

- The first factor is pressure, as in the amount of pressure faced by mines from other sources to make improvements in a given area. For example, the Bureau of Mines had done research in the 1960s into the benefits of illumination systems for underground mines and of monitoring systems for air quality, but mines did not adopt these technologies until safety regulations required them to do so.

- The second factor is the avoidance of pitfalls that seem obvious in hindsight. For example, the Bureau had recommended advanced in-mine communication systems as early as the 1970s, but widespread use did not develop because the Bureau failed to foresee that specific training and servicing was required for any meaningful benefits to be derived.

- The third factor is the specific path of technology adoption, or more accurately the delay between the announcement of a new technology and its availability. The Bureau found that when a suggested technology was a process innovation that involved only the description and perhaps demonstration of a new technique, adoption rates were higher than if a specific product had to be ordered from a manufacturer, perhaps involving customization, followed by required training in its use.

- The last two factors are financial in nature, namely the price of the innovation and the impact on mine profits. Obviously the higher the initial cost of implementation and the more limited the probable benefits, the lower is the penetration of a given innovation.

C. Studies on Gold and Metal Mining Productivity in Australia

One of the few studies focusing solely and specifically on the gold mining industry is Shebeb (2002), for Australia for the period 1968-1995. This study is primarily concerned with the effects of capital accumulation and technological change on total factor productivity growth. The rationale for including capacity utilization in the analysis is that periods of weak demand for gold lead to the idling of some capital assets.

Therefore, during these periods, productivity measures using the entire capital stock will underestimate the true level of productivity. Shebeb (2002) finds, however, that controlling for capacity utilization has very little impact on TFP growth in Australian gold mining. In contrast, the author finds strong support for the proposition that a decline in the rate of technological change contributed to slower TFP growth, especially in the 1990s. Shebeb (2002) finds that Australian gold mines have had to rely on continuously deeper operations with higher costs for extracting lower quality ores. This has lead to a small number of very large operations, but a reluctance to innovate due to fears that increased capital costs will lead to further erosion in international competitiveness.

Asafu-Adjaye and Mahadevan (2003) present another study on Australia, focusing on output and labour productivity growth in gold, copper and iron ore mining, and also in coal mining and oil and gas extraction, for the 1968-1995 period. Their results, fairly uniform across the three metal mining industries, show that output was largely input-driven in all periods, or equivalently that labour productivity growth was driven by growth in capital intensity. The authors are also able to decompose total factor productivity growth into scale, price, efficiency and technology components. In contrast to Shebeb (2002), Asafu-Adjaye and Mahadevan (2003) find that slower TFP growth was more due to declines in efficiency than in technological progress. The differing results are due to different models, and the fact that Shebeb's (2002) measure of technology reflects both technology and the part of efficiency gains not captured by the capacity utilization rate.[2]

D. Productivity in the U.S. Copper Mining Industry

A series of studies on the U.S. copper industry may provide insights into important productivity drivers in the gold mining industry as well, given that the actual technologies and processes involved are comparable. The first is by Aydin (1998), and attributes the labour productivity rebound in the U.S. copper mining industry in the 1980s to three factors. First, the author finds evidence of a shift in production towards mines with high ore grades, i.e. the closure of low-productivity mines. This effect, however, is overshadowed by the two others, namely increased capital intensity[3] and the realization of increasing returns to scale. Aydin (1998) states that an increase in capital per working hour can increase both the scale of the operation and the rate of technical change through the adoption of new technologies. He provides a case study of a particular mine and finds the computerization of mine control of specific importance.

Tilton and Landsberg (1999) largely echo these findings, and in addition state that the large labour productivity gains in the 1980s in U.S. copper mining were most likely

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[2] As with Kulshreshtha and Parikh (2002) for Indian coal mining, efficiency here refers to the fuller utilization of available production resources, while technological progress refers to an improvement in the method in which these resources are applied.

[3] Aydin (1998) also mentions the importance of growth in energy per hour in addition to growth in capital per hour. Given the fuel requirements of most machinery, it should be expected that energy intensity will be as important as capital intensity, since the latter would be mostly ineffective without the former.

responsible for the survival of the industry.[4] Although the authors do not have detailed capital stock data to work with, they state that the largest impact on labour productivity in copper mining is more likely due to innovation, both embodied within the capital stock and coming about through the development of new processes. They focus especially on the development of the solvent-extraction and electrowinning process, in-pit crushers and increased computer control.[5] Tilton and Landsberg (1999) state that these innovations certainly increased copper mining productivity in absolute terms, but that since new technological developments and machinery are available to all world copper producers, such innovations do not necessarily provide relative productivity gains compared to international competitors. However, they find that in many cases – and certainly in the case of copper – there are two reasons for which absolute gains in productivity can also be reflected as productivity gains relative to international competitors. There is a temporary advantage in being the first to adopt, since producers in other countries who have recently purchased the latest round of innovative products will be reluctant to innovate again immediately. And there are more permanent advantages since products and processes are not necessarily equally suited to all mines in all countries.

Aydin and Tilton (2000) and Garcia, Knights and Tilton (2001) make similar arguments, the latter also extending the analysis to copper mines in Chile. Again, the effect on labour productivity of compositional shifts away from mines on sites with lower quality ores is found to be overshadowed by the effect of new technologies and innovation. This holds for both countries, although to a slightly lesser degree in Chile, where the privatization of the copper mining industry has contributed to a large increase in the effort expended on identifying richer deposits. Both studies argue that labour productivity growth is the key to regaining and maintaining comparative advantage in the international copper mining industry.

Finally, Tilton (2001) finds that, in addition to its role in improving comparative advantage of the copper mining industry as a whole, labour productivity is crucial for the survival of individual mines during recessions (i.e. periods of weak demand and low prices for copper). Studying a cross-section of U.S. copper mines over 1975-1990, the author finds that both high labour productivity levels at the beginning of a recession and the ability to raise labour productivity during a recession are important in averting mine closure, and that the latter is more important than the former. Citing the studies just discussed, he states that this ability to increase labour productivity is driven by innovation. But the fact that some mines fail during recessions suggests an inability to increase labour productivity, suggesting an inability to innovate. Tilton (2001) attributes this to the lifetime of ore reserves of a particular mine. Mines with a long expected life have an incentive to acquire expensive new technologies during a recession, with the

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[4] They state that the increase in efficiency was accompanied by some other events, such as increasing revenues from by-products of copper mining and the suspension of production in some African competitors due to civil strife, but that this increased efficiency was the main factor in saving the industry from collapse.

[5] The first is especially beneficial in terms of labour productivity since its application does not require further mining. Waste ore that has already been extracted is exposed to an acid, which can then be processed into an electrolytic solution from which pure copper can be extruded. The whole process is much less labour intensive than the actual hauling of the ore in the first place.

expectation that the improved cost efficiency will help to weather the temporary low prices but will also have additional benefits in establishing cost advantages after the recession. Firms with rapidly diminishing reserves, on the other hand, fail to innovate since the benefits expected to be conferred over the remaining lifetime of reserves will not sufficiently offset the cost of implementing the new technologies.

E. Productivity in the Iron Ore Mining Industry

Iron mining in both Canada and the United States was also, like copper mining, close to collapse in the 1980s and also survived largely due to strong gains in labour productivity. But these gains in iron mining, unlike the innovation-driven story for copper mining, were apparently not driven by technological improvements nor other traditional productivity drivers such as capital intensity. Schmitz (2001) provides a detailed study of both the Canadian and U.S. iron ore mining industries, and finds that both were close to collapse after the steep reductions in steel production in the early part of that decade. He states that labour productivity more or less doubled in the mining of iron ore in that decade, but provides a very detailed checklist of things that could not be driving this rebound.

Although certain mines implemented rudimentary computer systems for dispatching, Schmitz finds that the scale of these changes was quite small in the period of the productivity growth acceleration, and that otherwise the technology of iron ore mining remained constant. He also finds minimal contributions from changes in capital intensity, and reports that the closing of unproductive mines and concentration of production in mines with the richest deposits did not occur on a scale large enough to affect the average productivity level of the industry to any great degree.

However, Schmitz finds convincing evidence that the impressive gains in iron ore mining labour productivity were driven by improved work effort and the efficiency of that effort. In other words, an increase in the pace of work and an overhaul in the organization of that work were the key drivers of labour productivity. These changes, Schmitz argues, were due primarily to the relaxation of rules restricting the tasks that workers could perform.

Prior to the 1980s, each worker was given a specific task to perform in the overall mining operation, and there were strict rules, agreed upon by unions and management, forbidding the overlap of tasks. That is, each worker performed a single task and was not permitted to perform any other task, even if the original task was already complete. Given the variance in effort among workers required to fulfill these tasks, this typically lead to periods of idleness, with workers waiting for their task to become necessary again.

Near the beginning of the 1980s there were two changes to this structure, agreed upon by management and unions. One allowed workers to perform numerous tasks, and the other, more specifically, allowed machine operators to engage in simple repairs of their equipment. In turn, the pace of work increased as there were no longer periods of frictional idleness. The author establishes the degree to which these changes were taken seriously by quoting union labour agreements. Further, he states that the technology story discussed above for the copper industry is likely only partially correct. Although the technological process was improved in copper mining unlike in iron ore mining, the same reforms to work rules took place in copper mines shortly after they were implemented in iron ore mines. Therefore, these new work rules likely played a role in the improvement in copper mining productivity in the 1980s as well.

Galdón-Sánchez and Schmitz (2003) further observe that labour productivity gains in the 1980s in iron ore mining were not uniform. That is, some regions of the United States experienced large gains while other regions experienced very small gains. They find that the regions with the highest productivity gains were those facing the most intense competition. The authors find that steel production declined to a much larger degree in the eastern United States than in the west, and correspondingly find large labour productivity increases in iron ore mining in the east but virtually none in the west. Eastern producers, facing a much smaller local market, were forced to become much more productive so that their output would be competitively priced on world markets inclusive of high transport costs. This does not necessarily contradict the argument of Schmitz (2001) that productivity gains were driven by changing work rules, although no evidence is presented to show that the rules were implemented to a larger degree or were taken more seriously in eastern iron ore mines compared to western mines.

F. Labour Relations, Regulation, and Unionization

There are some brief lessons from the literature on coal mining productivity that apply to metal mining industries to a certain extent but that have not been taken up by the metal mining literature. A more detailed discussion of these points is provided in Smith (2004), but they can be briefly addressed here.

Naples (1998) closely examines the technical as well as social determinants of productivity in coal mining, and tests her hypotheses with data for 1955-1980. She finds that some studies of the 1980s attributing the productivity declines in coal mining during the 1970s to stringent new safety regulations greatly exaggerate the role played by these regulations. These studies, for example Denison (1985), fail to account for other drastic changes affecting the coal industry in the 1970s. She mentions especially the rapidly deteriorating relations between managers and workers. She finds that over two fifths of the productivity decline in the 1970s was due to social factors, but argues that, of this two-fifths share, the increased strike activity played a larger role than adaptation to the new safety regulations, since the increase in labour unrest was of a higher magnitude than the increase in spending associated with compliance.

Chezum and Garen (1998) investigate the possible effect of unionization on productivity in the U.S. coal mining industry. They point out that apparent positive relationships between productivity levels and unionization in coal mining are likely spurious, since unions tend to be exogenously more prevalent in mines that have favourable geological attributes. The overall lesson that can be drawn from their work is that the effect of unionization on productivity in coal mining is likely very slight.

G. Summary

One of the most important observations from the literature review is that metal mining industries are highly innovative, especially when account is taken of the process innovations absorbed through equipment from innovative suppliers. Further, there are many indications that this technological progress is very important for labour productivity growth. The organization of work is found to have an impact on productivity growth in metal mining; and to this can be added the possible negative effects on productivity of poor labour-management relations and adjustment to new regulations discussed in the coal mining literature. The effect of output price on average productivity through encouraging or discouraging operations on lower-productivity sites is mentioned by several studies but is not highlighted by these studies as a primary determinant of productivity.

II. Characteristics of the Gold Mining Industry in Canada

A. Data Sources for Industry-Level Studies

The primary source of data for this report is the set of appendix tables provided with the CSLS (2003) report prepared for Natural Resources Canada on productivity trends in natural resources industries. However, some series provided in those tables have been updated to reflect more recent data availability.

Most data presented in CSLS (2003) are from Statistics Canada's Aggregate Productivity Measures (APM) program, classified according to the Standard Industrial Classification (SIC) and available generally from 1961 through 1997. The SIC has been superseded by the North American Industry Classification System (NAICS), and the APM series have not yet become available for a long time period based on NAICS.[6] The general method has hence been to use the APM series for 1961-1997 and extend these series forward to 2002 using growth rates from alternative (generally NAICS-based) sources with more recent data available.[7] This results in the longest time series possible.

The APM real value added by industry series are expressed in 1992 constant dollars at factor cost, based on a fixed weighted Laspeyres index. These have been

[6] The Statistics Canada Productivity Program, in December 2003, released new estimates of labour statistics (jobs, hours worked and compensation) and labour productivity and related variables (output per hour, capital per hour, output per unit of capital stock and multifactor productivity) for selected business sector industries based on NAICS for the 1997-2002 period. They have since been updated to 2003. The Timeline Continuity Project aims to release these data for the 1961-2003 period sometime in the Fall of 2004.

[7] A word of caution is in order considering data for 2001 and 2002 though. 2001 was a recession year, and 2002 was a year of expansion in most industries but not a peak year, so including these years in growth rate calculations (which are generally calculated from business cycle peak to peak to achieve cyclical neutrality) will impart a cyclical bias. The discussion in the following sections will hence focus only on the period up to 2000.

updated from 1997 onwards with growth rates from GDP by Industry series, according to NAICS, expressed in 1997 constant dollars at basic prices, based on a fixed weighted Laspeyres index.[8]

The APM hours worked and jobs series are based on data from the Labour Force Survey, with adjustments made from establishment-based surveys. These have been updated from 1997 onwards with the new Productivity Program Database hours and jobs series, released on December 4, 2003. These estimates are based on a similar methodology as the APM hours and jobs estimates, but are classified based on NAICS rather than the SIC.

In contrast to the GDP, hours and employment series, the capital stock series have undergone major methodological changes at the same time as converting from SIC to NAICS.[9] Fortunately, however, the new series are available for the entire 1961-2002 period based on the new methodology and NAICS, for detailed industries. Hence, the method of extending the old series using growth rates from the new series for 1997-2002 only has not been followed for capital stock. Rather, the new series have been used for the entire period.

Based on these updated output, hours and capital stock series discussed here, new series of labour productivity, capital productivity, total factor productivity and capital intensity have been calculated. The labour productivity series are identical to those in CSLS (2003) for 1961-1997 but vary for the 1997-2000 period. The series involving capital stock differ moderately from those in CSLS (2003) for the entire 1961-2000 period due to the new capital stock methodology.

As in CSLS (2003), the total factor productivity indexes are calculated with fixed 1997 factor shares according to a constant returns to scale Cobb-Douglas production function. In this production framework, if the strong assumption of short-run profit maximization is made, the elasticity of output with respect to the labour input (hours worked) is identical to the share of total output paid to labour. The share of output paid to capital is then calculated residually as unity (the sum of the two shares with constant returns to scale) minus the labour share. The labour share in 1997 is calculated by multiplying average weekly earnings (from the Survey of Employment, Payrolls and Hours) by employment and 52 weeks and dividing by current-dollar value added, all for

[8] CSLS (2003) includes an appendix on the concordance of natural resources industries according to NAICS and according to SIC. The gold mining industry under NAICS includes silver mining, while the SIC gold mining industry did not. The effect of this difference is difficult to quantify, since output and employment data on the silver mining industry by itself are not available under either classification system. This suggests that the silver mining industry is the smaller of the two, and that the use of NAICS growth rates for 1997 onwards and NAICS capital stock over the entire period should not introduce an especially large degree of incomparability.

[9] Without presenting the details of these technical methodology updates, the motivation for the updates was a desire to present geometric-depreciated capital stock estimates on a methodologically equivalent basis as the United States. The estimates generally show a higher level and lower growth than the estimates based on the old methodology and contained in CSLS (2003). This is due to a uniform depreciation profile for a given investment cohort, in contrast to the division into sub-cohorts based on individual depreciation schedules that was used in the previous and less-preferred methodology (Statistics Canada, 2000).

1997. There are a number of problems with this approach, especially with assuming constant returns to scale in many industries and in assuming profit maximization in general. The result of these problems is that the interpretation of TFP growth must be treated as very broad. TFP growth in this framework can reflect technological progress, changes in any factors of production besides labour and capital (e.g. skills, energy), or violation of any of the assumptions. It will hence be important in the coming sections to describe the various possible drivers of measured TFP growth in detail rather than simply ascribing changes in TFP to technological change.

Finally, it should be mentioned that there are at least two other sources of productivity and related variables by industry in Canada. The Productivity Program Database, from which data on hours and jobs for 1997-2002 are taken for the present analysis, also includes estimates of labour productivity, capital productivity, capital intensity and multifactor productivity for certain industries. The unfortunate aspects of this dataset are that data are presently only available from 1997-2003, data are not released for some detailed industries due to data quality concerns, and data are only available in index form (i.e. growth rate analysis is possible but not level analysis).[10]

The Centre for the Study of Living Standards also maintains a productivity data base. Data are available for about 230 detailed industries (all for which the underlying data are available), for Canada and all ten provinces. Real value added data are from the GDP by Industry program, hours and employment are from the Labour Force Survey, and capital stock data are provided by the Capital Stocks Division. Total factor productivity estimates are calculated according to the same methodology described above. The data base is updated once or twice annually, with annual data available currently from 1987-2003, according to NAICS.[11]

B. Size, Regional Distribution, and Organization of the Gold Mining Industry in Canada

Gold mining accounted for 0.15 per cent of Canadian real output in 2000 – down from 0.64 per cent in 1961 – and around 20 per cent of that of the overall metal mining industry (CSLS, 2003:Table 28).[12] Real GDP in the gold industry was just over $1 billion (1992 constant dollars at factor cost), compared to about $770 billion for the total economy. Gold mining's shares of total economy employment was lower than the real output share, at 0.05 per cent in 2000, having fallen from about 0.26 per cent in 1961.

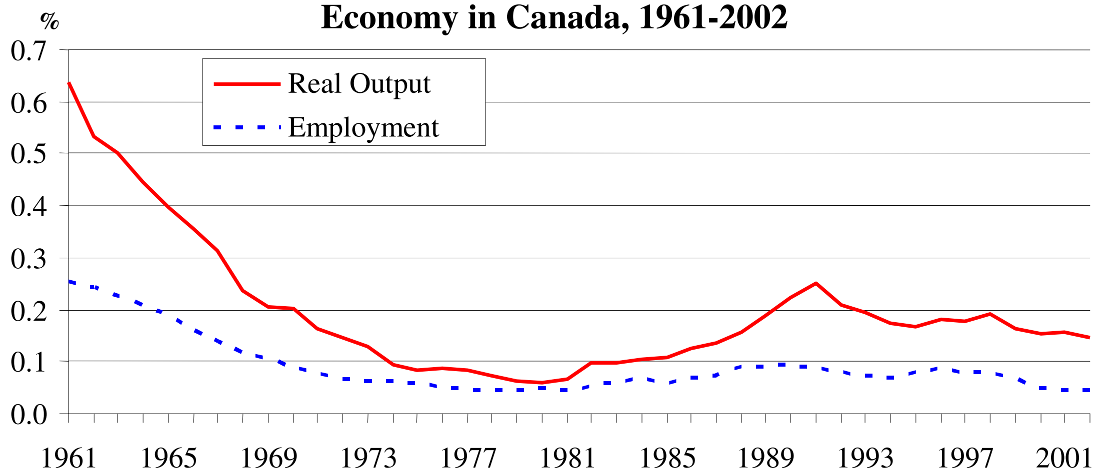
[10] As mentioned previously, the Timeline Continuity Project, expected to be completed sometime in the Fall of 2004, will extend these series back to 1961. The series used in the present study correspond with those from the Productivity Program Database for 1997 onwards due to common data used in their construction. It is not known how the present series will correspond with the Productivity Program series once data are available for 1961-1997, since the new data for this period will be based on NAICS.

[11] The estimates employed in this report differ slightly from those in the CSLS productivity data base, due to a different source for hours and employment data, but growth rates are broadly similar for the time period for which both sets of estimates are available. In general, the Productivity Program Database/APM hours estimates are probably more comprehensive than the Labour Force Survey estimates, but the CSLS data base does not employ them since they are available to less industry detail.

[12] The data from CSLS (2003) have been updated throughout, as discussed above.

About 7,400 of the 15.2 million Canadian jobs in 2000 were in gold mining, down from 16,500 in 1961. The evolution of gold mining's output and employment contributions to the total economy are shown in Chart 1, and summary growth rates for gold mining are shown in Table 1.

Chart 1: Share of the Gold Mining Industry in the Total Economy in Canada, 1961-2002



Source: CSLS (2003:Tables 28 and 30).

Table 1: Output, Employment, Hours and Capital Stock Growth in the Gold Mining Industry in Canada, 1961-2000, compound average annual growth rates, per cent

	Real Value Added	Employment	Hours Worked	Capital Stock
1961-2000	0.05	-2.03	-2.27	3.10
1961-1973	-7.44	-8.25	-9.13	6.71
1973-1981	-5.04	-1.28	-0.89	3.51
1981-1989	17.33	10.89	11.27	2.57
1989-2000	0.74	-4.36	-4.69	-0.63

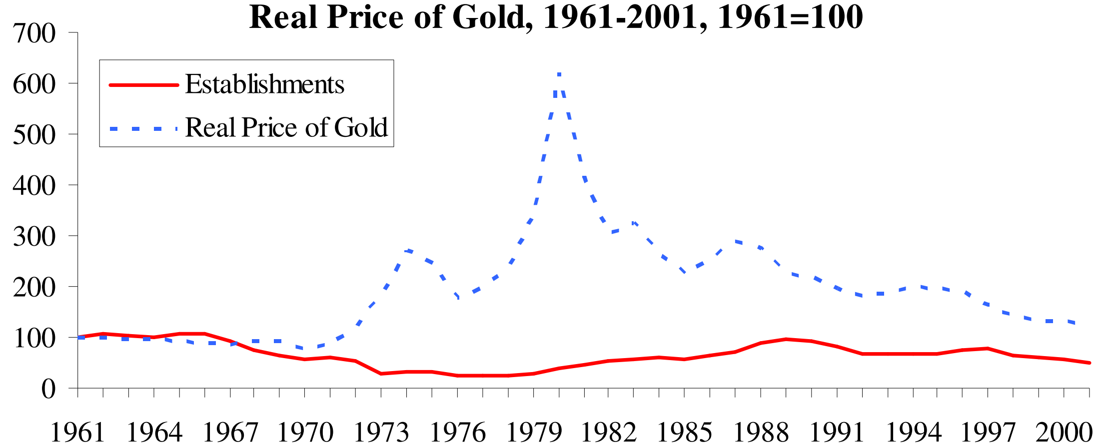
Source: CSLS (2003), with updates from GDP by Industry, the Labour Force Survey, and the Capital Stocks Division. Figures for 1997 to 2000, and all figures for capital stock, are based on growth rates of the series corresponding to gold and silver mining. It is not known how much of silver production was included in gold mining statistics before 1997.

There were 35 gold mines in Canada in 2001, down from 56 in 1997 and 70 in 1989.[13] The number of gold mines in Canada was higher in the 1960s, but declined in the 1970s, to 18 in 1978. The number increased steadily throughout the 1980s, but has been declining once again since 1989. These mine openings and closings over the entire 1961-2001 period do not appear to be related to the price of gold, which increased strongly in

[13] Data on the number of establishments are from surveys of mining industries carried out by Natural Resources Canada for Statistics Canada. Data are disseminated via annual Statistics Canada publications (e.g. *Metal Ore Mines*, catalogue number 26-223) and CANSIM, Statistics Canada's online data service (e.g. tables 152-0005 and 152-0002).

the 1970s and has exhibited a slight downward trend since the 1980s (Chart 2).[14] Alternatively, this entry and exit is more likely due to finds of new deposits, and profitability conditions in terms of the availability of new mining equipment and techniques.

Chart 2: Number of Gold Mining Establishments and the Real Price of Gold, 1961-2001, 1961=100



Source: Number of establishments from CANSIM Table 152-0002. Gold prices from www.kitco.com, deflated with the CPI.

The 35 mines in 2001 were distributed across six provinces and the three territories, but were concentrated in Ontario and Quebec. There were 13 mines in Ontario, 10 in Quebec, three in British Columbia, two each in the Northwest Territories, Manitoba and Newfoundland, and one each in Nunavut, the Yukon Territories and Saskatchewan.

Output and employment are more concentrated in Ontario than is the number of establishments, implying that Ontario's gold mines are of larger scale than in other provinces. This is confirmed for the limited number of provinces for which output and employment data are available.[15] Gold mines in Ontario had on average 243 employees per establishment in 2001, compared to 212 for British Columbia, 196 in Quebec and 199 for all of Canada (including individual provinces for which data are not available).

In 2000, Canada was the fourth largest producer of gold in the world with about 5.8 per cent of world production, after South Africa (16.6 per cent of world production), the United States (12.8 per cent) and Australia (11.5 per cent). In the 1970s, Canada was the third largest producer, behind South Africa and Russia, but throughout the 1980s and 1990s production in the United States and Australia climbed and production in Russia

[14] However, Jen (2001) states that mine closures since 1997 are likely linked to more recent trends in the price of gold, which fell from about $384U.S. per ounce in 1994 to $271U.S. in 2001 (www.kitco.com). The price of gold rebounded to $310US in 2002 and has been rising steadily since then, but data are not yet available on mine openings and closures in 2002.

[15] Statistics Canada does not release output or employment data for the gold mining industry (derived from surveys of mining industries) for several provinces due to confidentiality concerns.

tailed off. Canada's long-term share of world gold production has been between four and seven per cent (http://goldsheetlinks.com/production.htm).

Most gold mining in Canada appears to be undertaken by Canadian firms. Very limited data on ownership are available without examining individual businesses.[16] However, the data that are available show foreign ownership at only about 13 per cent of all Canadian gold mining enterprises in 1988. This represents an increase from about 7 per cent in 1980. Indeed, Canada is regarded as a world leader in gold mining, with several Canadian companies operating and controlling mines in the United States, Mexico, Central America, South America, Greenland and other countries.[17]

C. Resource Base

Statistics Canada estimates that in 2001, the most recent year for which data are available, there were 1,070 tonnes of proven gold reserves in Canada (i.e. that were known to exist with a high degree of certainty and that were judged to be consistent with profitable extraction).[18] This figure was much lower, at 493 tonnes, in 1977, implying that over the 1977-2001 period there was either increased proven reserves through exploration and new discoveries, increased commercial viability through price changes and the diffusion of new mining techniques, or both. However, throughout the 1990s the stock of proven gold reserves declined – from a historical high of 1,801 tonnes in 1988 – reflecting faster growth in extraction relative to finds of new deposits. Relative to the 1,070 tonnes of reserves in 2001, extraction in that same year was only 158.9 tonnes (Chart 3). At present extraction rates and profitability conditions, reserves are therefore equivalent to 6.7 years of production. The ratio of extraction to total stock has been much higher in the past, with the stock equivalent to an average of 15 years of production in the mid-1980s.

D. Labour Force and Related Characteristics

The gold mining industry appears to have a well-educated workforce. Labour Force Survey data on educational attainment are only available for the overall metal mining industry, which includes iron, copper and other metal mines in addition to gold mines.[19] However, the average years of schooling for gold miners is not likely different

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[16] Data on the foreign/domestic ownership of enterprises as well as their equity and asset holdings and profits were collected for all Canadian firms under the Corporations and Labour Unions Return Act for the 1980-1988 period. These data are available by detailed industry from Statistics Canada via CANSIM table 179-0002. Such data do not appear to be available beyond this period by industry.

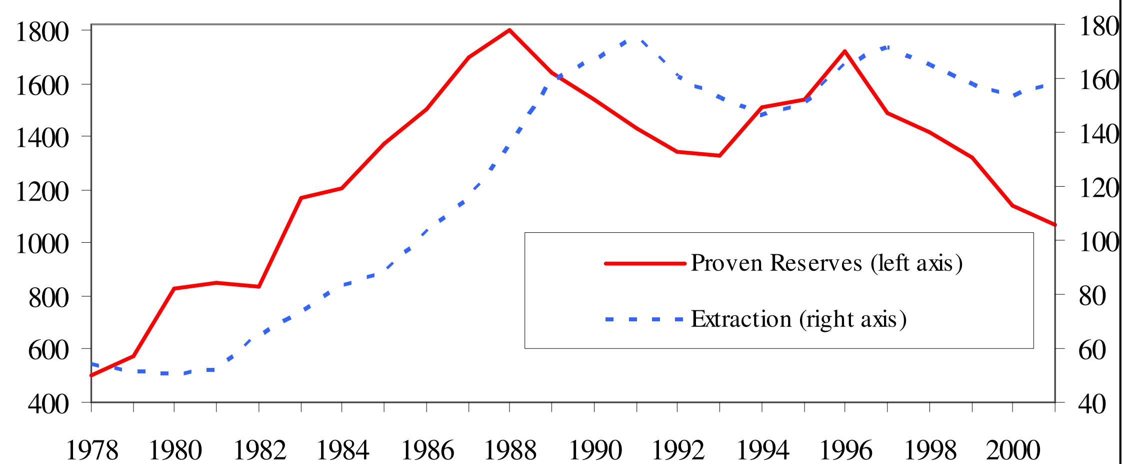
[17] The website of Canadian Miner magazine (www.canadianminer.com) lists over 170 Canadian mining companies, with links to their webpages that list property holdings and operation and exploration activity in all types of mining, in Canada and internationally. Two major Canadian gold mining companies are Barrick and Teck Cominco, both with exploration activity and operations in several countries internationally. The latter is also a world leader in coal and zinc mining, with interests in refining and smelting as well.

[18] These estimates are taken from CANSIM Table 153-0021. Earlier estimates were published in Statistics Canada (2001).

[19] Custom tabulations from the 2001 Census on educational attainment by industry are likewise not available to a level of industry detail beyond all metal mining.

than the average for all metal mine workers, and this was about 13.03 years in 2001 (CSLS 2003:Table 48). This compares to 13.47 years for all Canadian workers and 12.80 years for all (metal plus non-metal) mining workers. Average years of schooling of metal miners increased by 0.6 per cent per year between 1976 and 2001, slightly higher than the all industries growth rate of 0.5 per cent per year. This growth gap increased in the 1989-2001 period, with average years of education advancing at an average annual rate of 1.4 per cent per year over this period, relative to 1.0 per cent per year for all industries. The near-average years of schooling in metal mining reflects a very high proportion of workers with a post-secondary certificate or diploma (43.5 per cent) but a low proportion of workers with a university degree (11.5 per cent).

Chart 3: Extraction and Proven Reserves of Gold in Canada, 1978-2001, tonnes



Source: Statistics Canada, CANSIM Table 153-0021.

Average hourly labour compensation in the gold mining industry was $32.58 (current dollars) in 1997, representing 167 per cent of the total economy average (CSLS 2003:Table 35). More recent data are not available due to greater confidentiality concerns with the implementation of the new North American Industry Classification System. Gold mining's above-average hourly labour compensation is consistent with that in metal and non-metal mining in general, with the entire mining sector at 143 per cent of the total economy average.

The remarkable reduction in the incidence of injuries in mining in general has also been experienced by metal mining specifically.[20] In 1982 there were 4,688 injuries in metal mining in Canada, or 8.7 per 100 workers. This compares to 11.4 per 100 workers in all mining and 4.3 per 100 workers in the total economy on average. However, by 2002 the incidence of injuries had declined sharply to 2.2 per 100 workers in metal mining. The incidence of workplace fatalities has also shown a marked decline

[20] Again, data are not available to greater industry detail beyond metal mining. However, it is likely that trends for gold mining are close to the average for all metal mining.

in metal mining – from 179.9 per 100,000 workers in 1993 to 125.9 per 100,000 workers in 2002 – but still shows a level much higher than the 6.0 per 100,000 workers at the total economy level.

The average age of the overall mining workforce appears to be somewhat above that for all industries. Based on publicly-available aggregations from the Labour Force Survey, the average age of employees in mining, forestry, oil and gas and fishing industries was about 38.3 years in 2001, compared to 37.6 years for all industries.[21] For the primary industries this represents a somewhat large increase, from 37.6 years in 1997. At the all industries level the average age of the workforce was virtually unchanged over the 1997-2001 period, rising just 0.3 years from 37.3 years in 1997.

Data on employment by major industry and sex are also available from the Labour Force Survey, and show that employment in the primary industries is heavily male-dominated. In 2001 males accounted for 51.6 per cent of the all industries workforce, down from 52.4 per cent in 1997. For primary industries the proportion of males in the total workforce was much larger, at 84.1 per cent in 2001, down from 85.9 per cent in 1997.[22]

The proportion of mining employees covered by a union declined rapidly between 1976 and 1995. In 1976 the rate of union density was 44.3 per cent in mining, declining fairly steadily and reaching 24.7 per cent in 1995 (CSLS, 2003:Table 44). Data from the Labour Force Survey on all primary industries excluding agriculture show a continued decline after 1997. The rate of unionization remained fairly steady at the all industries level over 1976-1995, at between 27 and 29 per cent, and has not shown any marked trend since 1997 based on the Labour Force Survey data. It is not known how well these average rates and trends hold for gold mining specifically.

E. Capital Intensity

Gold mines are highly capital intensive operations. In 2000 the ratio of capital stock to hours worked in the gold mining industry was $669.93 per hour (1997 dollars), compared to just $61.69 for all industries on average (CSLS, 2003:Table 38). Capital intensity also advanced much more rapidly over the 1961-2000 period in gold mining than in the total economy, at 5.5 per cent per year compared to 1.7 per cent per year. Capital intensity advanced between 1989 and 2000 by 4.3 per cent per year in gold mining and by 1.3 per cent per year in the total economy.

Unpublished data from the Capital Stocks Division of Statistics Canada show that most of the capital stock of the gold mining industry (77.1 per cent in 2002) was in

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[21] Custom Census tabulations (based on a 20 per cent sample) on average age by detailed NAICS industry are available for 2001 only. For metal mining, the average age of the labour force in 2001 was 43.1 years, compared to 39.0 years in all industries.

[22] Custom Census tabulations (based on a 20 per cent sample) on employment by gender and detailed NAICS industry are available for 2001 only. For metal mining, the proportion of males in total employment in 2001 was 91.1 per cent, compared to 53.1 per cent in all industries.

engineering capital stock, with much smaller proportions in structures capital stock (17.6 per cent) and machinery and equipment (5.3 per cent). The machinery and equipment capital stock actually declined throughout the 1990s, while the total capital stock experienced slight decreases but the engineering capital stock showed slight increases. These declines in the machinery and equipment capital stock, driven by weak investment, may mean that the gold mining sector has not benefited from technological advance embedded in new machinery. This, however, cannot be stated with certainty, since computers embody a high level of technology but are relatively inexpensive relative to other machinery and equipment investments. A declining machinery and equipment capital stock can reflect investment in cheap but high-technology computers offsetting depreciation of expensive but low-technology equipment. Also, the stronger investment in engineering products (which includes exploration expenditures and site development) may indicate that high and increasing effort is focused on searching for sites with more abundant deposits before mining begins, and on more efficiently extracting the deposits. Engineering capital also includes the roads constructed on mine sites and the actual construction and support of mine shafts and pits.

F. Technological and Process Developments

There have been several improvements in the mining of metals in the past several decades. For some metals one of the major developments has been the extraction of metals from ores using solvents. The more traditional hard-rock extraction process pulverizes ores containing gold and applies chemicals and heat to separate the pure gold from the other materials.[23] There has been much improvement in this process, for example developing in-pit crushers and improved methods for hauling crushed ore from pits, and the computerization of the handling of some processes. One important innovation, mentioned in the literature review, has been the use of robotic equipment in the extraction process.

In addition to these somewhat specific developments in gold mining, the path of technological progress in gold mining is likely affected by broadly the same technological developments as other mining industries. For example, Gemcom, a mining consulting company based in Vancouver, British Columbia, has developed the GEMS software package for assistance with each stage of mining, from exploration to site planning to extraction. Such software and consulting are of course not specific to any particular type of mining, but rather are mentioned here as evidence of increasing computerization in mining operations in general.

Lonmo (2003:17) shows that the mining industry in Canada has tended to invest very little in research and development relative to its output compared to other industries. This should not be regarded as firm evidence of technological decline and failure to innovate though. Most technological advance in mining happens somewhat naturally through the availability of improved machinery and new tools and equipment supplied by

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[23] Placer gold mining makes up a very small proportion of total gold mining.

other industries, much of which is produced in other countries.[24] Further, Uhrbach and van Tol (2004) show that large firms – defined as those with more than 100 employees, which most gold and other mining operations have – virtually all use information technologies such as personal computers and high-speed internet access. This suggests that, while groundbreaking technical advances may be difficult to identify, mining industries are not lagging in their innovative efforts.

Indeed, a detailed study on the Canadian mining industry in general – commissioned by the Mining Association of Canada and prepared by Global Economics (2001) – finds that, despite having the image of an old-fashioned industry, the mining industry in Canada is actually quite dynamic and among the most intensive users of advanced technologies. An earlier report by the Mining Association of Canada (1999) states that these technologies have focused on the use of global positioning systems in exploration, low-impact seismic excavation methods, underground communications systems, computer organization of mining activities, and internet use in procurement. Besides aiding the industry in adapting to global competition and uncertainty based on fluctuating prices and the margin of error in assaying during exploration, the report finds that these investments in technology have also contributed to impressive records in workplace safety and environmental performance.

G. Output Price

The price of gold has boomed since the 1970s, rising from $35.94U.S. per ounce in 1971 to $309.73U.S. in 2002 (www.kitco.com). Although an increase of nearly nine times (in nominal terms), the price of gold had actually been falling through most of the 1980s and 1990s. On an annual basis the highest recorded price per ounce of gold occurred in 1980, when it reached $612.56U.S. In real terms (i.e. deflated using the Consumer Price Index), the price of gold increased by about 38 per cent between 1961 and 2002, or 0.8 per cent per year (Chart 2).

H. Regulation and Taxation

Castrilli (1999) provides a detailed discussion of regulations, especially environmental, facing the Canadian mining industry. Without repeating this analysis in detail, it is sufficient to mention only a few limited examples. The most significant regulations facing mines in terms of their effect on increasing mining costs or altering mining behaviour are probably those concerning the health and safety of workers, and the reclamation of landscape and clean-up of the site at closing. It is, however, difficult to tell how these regulations would affect the costs and productivity of mining industries

[24] Lonmo (2003) also shows that the mining industry has a high concentration of research and development, meaning that most R&D is performed by a limited number of firms in the industry. Most natural resource industries have this same combination of high R&D concentration but low overall R&D intensity. This is not necessarily detrimental, as it might be in manufacturing industries with limited inter-firm cooperation, since the largest mining companies with the greatest capacity to undertake research and development do so while smaller companies can simply buy into new innovations when they become available. According to Global Economics (2001:11), Canadian corporations with mining operations that invested in R&D were, in descending order of the amount spent in 2000, Alcan, Noranda, Inco, Cominco and Falconbridge.

relative to the regulations facing other industries in Canada or mining industries in other countries. Certainly in the past few decades, after the most significant safety regulations were passed in the 1970s, it does not appear that regulation in the mining industry has increased at a faster pace than for other industries.

Statistics Canada (2001:110) provides estimates of expenditures on pollution abatement by industry, which can serve as a rough proxy of how environmental regulations affect costs under the assumption that the majority of environmental expenditures are motivated by regulation. In 1997, the mining industry spent an estimated $66.7 million complying with environmental regulations. This is equivalent to about 0.9 per cent of the current dollar value added of the mining sector. For the overall business sector, expenditures on pollution control were $1,545.8 million in 1997, or about 0.2 per cent of current dollar value added. This suggests that the mining industry faces a higher regulatory burden relative to other industries. However, it is also likely that some of these regulations have ultimately benefited the industry in terms of worker performance in a safer environment and have brought social benefits in terms of an improved state of the environment.

Related to innovation in the mining industry is the taxation policy facing the industry, since such policies affect the incentives to invest. Brewer, Bergevin and Arseneau (1999) and Dahlby (1999) provide detailed reviews of the taxation policies facing Canadian mining industries. Mining companies face both corporate taxes and resource royalties, the latter designed to capture the economic rent of mineral extraction, or in other words the return over and above the cost of extracting the resource. There are, however, special provisions in the corporate tax code for mining industries, including deductibility of exploration expenses and accelerated depreciation on some capital investments. Overall Dahlby (1999) finds that the taxation burden for Canadian mining industries is below that for other Canadian industries and comparable to that for mining industries in other countries. Therefore, the Canadian taxation system does not appear to be impeding innovation in the mining industry.[25]

I. Environmental Performance

MiningWatch Canada is a non-profit organization that expresses concern for what it sees as irresponsible environmental and social behaviour of mining industries. In a report titled *Looking Below the Surface* and jointly published by MiningWatch and the Pembina Institute, Winfield et al. (2002) state that much waste is created in the mining process, including overburden and other waste from the excavation process, tailings and

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[25] An earlier study by Boadway et al. (1987) finds that some mining taxation provisions may be biasing investment towards exploration and development and away from other types of investment, such as innovation in the extraction process (although this does not conflict with the proposition that the disincentives to innovate are less in mining than in other Canadian industries). They argue that a tax on pure profits, as opposed to the corporate tax with special provisions, would remove this distortion. More recently and not specific to Canada, Andrews-Speed and Rogers (1999) also suggest that directing taxes only at mining companies' profits would be best for innovation, since this would provide a joint incentive to companies and governments to reduce mining costs (i.e. through the adoption of new technologies and processes).

contaminants from the ore concentration process, and air pollution during the smelting process. The report is especially concerned with an apparent shift in the concerns of governments towards providing greater support for mining industries and away from supporting environmental protection.

A different view on the environmental performance of mining industries is expressed by the Mining Association of Canada (2003). This annual *Environmental Progress Report* states that combined releases to air and water of eight dangerous substances have been significantly reduced since 1993. For example, releases of mercury fell by 94 per cent, and releases of arsenic by 54 per cent. The report also discusses progress on a number of projects undertaken by the mining industry to reduce emissions and make environmental improvements, such as the Mine Environment Neutral Drainage research program and the National Orphaned/Abandoned Mines Initiative.

This divergence in views is in part driven by different perspectives, the first judging environmental performance at a given point in time and the second judging improvements over time. It is not clear what the best way to measure environmental performance is, but it is also not clear what the linkages are between environmental progress and productivity. Increased effort spent on environmental issues not related to the production process will decrease productivity, but such efforts may indirectly lead to productivity-enhancing process improvements. In any case, the Mining Association of Canada (2003) report presents convincing evidence that there have been significant environmental improvements in the past decade, although it is not known what degree of selectivity was exercised in choosing which issues to report.

J. Unemployment and Capacity Utilization

The Labour Force Survey only has data on the unemployment rate by industry publicly available for broad industry groups. For mining and oil and gas, the unemployment rate was 5.1 per cent in 2001, compared to 7.2 per cent for all industries.[26] 2001 was a recession year for the overall Canadian economy, but unemployment actually declined in the mining and oil and gas industry, from 5.3 per cent in 2000 and 7.9 per cent in 1999. This same pattern did not hold for the recession in the early 1990s, with unemployment in all industries increasing from 8.1 per cent of the labour force in 1990 to 10.3 per cent in 1991, and from 6.7 per cent in mining and oil and gas in 1990 to 8.6 per cent in 1991.

Capacity utilization in mining and oil and gas, which accounts for the proportion of available capital resources being used, was below the average for goods-producing industries in 2000, at 76.6 per cent relative to 85.5 per cent (CSLS, 2003:Table 43). However, some data are available for a more detailed industry breakdown, and show that for mining only the capacity utilization rate was 89.7 per cent in 2000, implying a very low rate of utilization for oil and gas. Capacity utilization is strongly procyclical for both

[26] Custom Census tabulations (based on a 20 per cent sample) on unemployment by detailed NAICS industry are available for 2001 only. For metal mining, the unemployment rate in 2001 was 5.7 per cent, compared to 7.4 per cent in all industries.

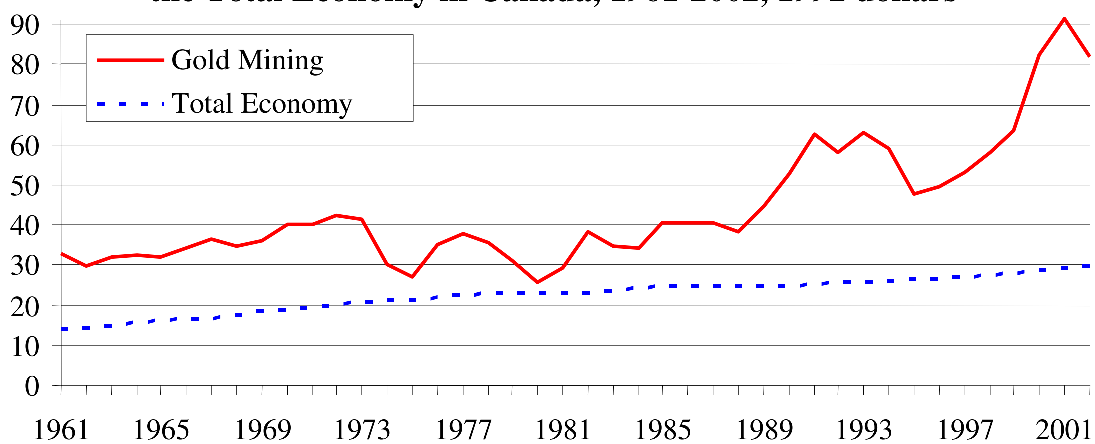
mining and all industries, falling during recessions and rising during expansions. It is not known how well these average trends hold for individual mining industries.

III. Productivity Levels and Trends in the Gold Mining Industry in Canada

A. Labour Productivity

The level of output per hour in gold mining in 2000 was $82.44 per hour in constant 1992 dollars, slightly above the level for all mining industries of $68.13 and much higher than the all industries average of $28.99 per hour. This has historically been the case, with the level of real output per hour in gold mining about 175 per cent that in all industries on average over the 1961-2000 period (Chart 4).

Chart 4: Output per Hour in the Gold Mining Industry and the Total Economy in Canada, 1961-2002, 1992 dollars



Source: CSLS (2003:Table 33).

Productivity growth in gold mining is very sensitive to the period examined. For example, between the 1981 and 1989 cyclical peaks, output per hour growth in gold mining was a strong 5.4 per cent per year. But in the 1960s and early 1970s (1961-1973) growth was much weaker, at 1.9 per cent per year, and output per hour actually declined sharply in the 1970s (1973-1981), by 4.2 per cent per year. These results contrast sharply with developments in other industries. The 1960s were generally years of high productivity growth, with output per hour advancing at a 3.4 per cent average annual rate in all industries. Productivity growth was also high in mining industries (4.9 per cent per year on average), including some other metal mining industries (e.g. 7.6 per cent per year in iron mining). The 1970s were generally years of weaker productivity growth, with output per hour advancing by only 1.2 per cent per year in all industries. But the strong negative productivity growth in gold mining (as well as other metal mines) was in general not experienced by other industries.

Output per hour growth for the 1989-2000 period was a strong 5.7 per cent per year in gold mining (Table 2). This compares to 1.4 per cent per year for the total economy, 4.6 per cent per year for mining and 5.1 per cent per year for metal mining. For gold mining this represents a rebound from very weak productivity growth of 1.0 per cent per year for the 1989-1995 period, following the recession of the early 1990s, to an impressive 11.6 per cent per year for 1995-2000. For the overall 1961-2000 period, output per hour growth in gold mining was above average, at 2.4 per cent per year compared to 1.9 per cent per year for the total economy (Chart 5).

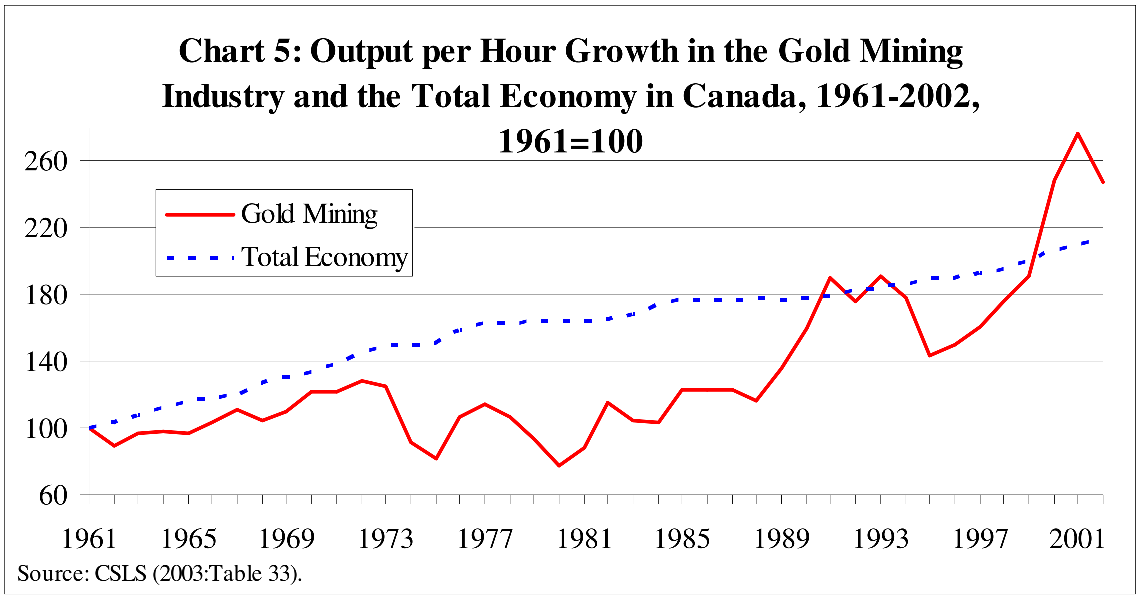


Table 2: Productivity Growth in the Gold Mining Industry in Canada, 1961-2000, compound average annual growth rates, per cent

	Output per Hour	Output per Unit of Capital Stock	Total Factor Productivity
1961-2000	2.37	-2.96	-0.93
1961-1973	1.86	-13.26	-7.70
1973-1981	-4.19	-8.27	-6.71
1981-1989	5.44	14.38	10.84
1989-2000	5.70	1.38	3.03
1989-1995	1.02	0.58	0.75
1995-2000	11.59	2.35	5.83

Source: CSLS (2003), with updates from GDP by Industry, the Labour Force Survey, and the Capital Stocks Division.

The Bureau of Labor Statistics (2001) reports that output per hour growth in gold and silver mining in the United States was 5.6 per cent per year over the 1990-1999 period. In Canada, output per hour growth in gold mining was 2.1 per cent per year for this same period. However, these growth rates are very sensitive to the particular beginning and end years. The 1990-1999 period leaves out strong growth in Canadian gold mining in 1990 (17.7 per cent) and 2000 (30.0 per cent). The more important message is that gold mining labour productivity growth has shown a significant acceleration in both Canada and the United States since the second half of the 1990s, although it appears that this acceleration has taken place with a lag in Canada. This may suggest that improved technologies or productive processes were developed in the United States in this period and were later adopted by Canadian gold mines. Global Economics (2001:9) states that the number of troy ounces of gold produced per hour worked was 0.33 in Canada in 2000, compared to 0.29 for the United States.

B. Capital Productivity

Output per unit of capital stock has shown strong declines in gold mining since 1961, falling by 13.3 per cent per year in the 1960s and by 8.3 per cent per year in the 1970s. Capital productivity growth in all industries was 1.1 per cent per year in 1961-1973 and -0.8 per cent per year in 1973-1981. Capital productivity growth was strong in gold mining in 1981-1989, growing by 14.4 per cent per year, while output per unit of capital remained virtually constant in all industries over the same period. From 1989 to 2000 capital productivity grew by an average annual rate of 1.4 per cent per year in gold mining, compared to 0.1 per cent per year in all industries.

The sharp declines in gold mining capital productivity in the 1960s and 1970s reflect declining output at a time of rapid capital accumulation. At the same time, hours worked were declining, so that capital intensity was advancing at an incredible pace (e.g. 17.4 per cent per year in the 1960s). This situation, in the 1960s especially, is perplexing. High capital intensity growth was observed with weak labour productivity growth and declining output, the opposite of what would be expected. This issue will be examined in more detail in the next section.

C. Total Factor Productivity

Total factor productivity, like capital productivity, fell through most of the 1960s and 1970s in gold mining, before rebounding sharply in the 1980s and continuing with more moderate growth in the 1990s (Table 2). At the total economy level, TFP growth was strongest in 1961-1973, falling off thereafter but remaining positive, and showing some signs of acceleration since the mid-1990s. Total factor productivity growth rates are very sensitive to the method used to calculate the TFP index. As was discussed previously, a simple Cobb-Douglas production function has been assumed, with constant returns to scale in capital stock and hours worked and fixed factor shares over the entire 1961-2000 period examined.

IV. Explaining Labour Productivity Trends in the Gold Mining Industry in Canada

A. Decomposition of Labour Productivity Growth

Following the same production function methodology briefly explained in the second section for total factor productivity, it is possible to decompose labour productivity growth into TFP growth and growth in capital intensity. Further, capital intensity can be divided into the three component classifications, namely building construction, engineering construction and machinery and equipment. Contributions for various periods are shown in Table 3 below.

The table shows that the most important component of labour productivity growth in gold mining for the overall 1961-2000 period and the 1961-1973 period was growth in the capital stock per hour worked, and that the most important component of overall capital intensity was engineering capital intensity. As mentioned previously, the engineering capital stock represents a much larger proportion (over 77 per cent) of the overall gold mining capital stock compared to other industries. This appears to be driven by the fact that exploration activities and mine site development are included in the engineering capital stock. This suggests that in the 1960s, weak labour productivity growth was driven by exploration and site development. But presumably this exploration and development had limited success in terms of bringing high quality deposits into production, since output was falling in this period. The engineering capital stock also includes the actual construction of mines. The high level of engineering investment in this period may therefore also suggest that deeper mines were constructed in order to access lower quality ores since new sites with more accessible ores were not available. This would partially explain increased capital investment coincident with low labour productivity and declining output. The engineering capital intensity became important for labour productivity growth again in the 1990s, but to a much lesser degree.

After 1973, labour productivity growth in gold mining was driven principally by total factor productivity growth. In the 1970s, the large declines in labour productivity were met with even larger declines in TFP. But the rebound in labour productivity growth in the 1980s and 1990s was driven by phenomenal TFP growth (10.8 per cent per year) in 1981-1989, and less impressive but still strong TFP growth from 1989 to 2000 (3.0 per cent per year).

Table 3: Average Annual Growth in Output per Hour and its Components in the Gold Mining Industry in Canada, 1961-2000						
	Output per Hour Growth	Total Factor Productivity Growth	Growth in Total Capital Stock per Hour Worked	Growth in Structures Capital Stock per Hour Worked	Growth in Engineering Capital Stock per Hour Worked	Growth in Machinery and Equipment Capital Stock per Hour Worked
	1) Compound Average Annual Growth Rates, per cent					
1961-2000	2.37	-0.93	5.49	4.35	6.64	1.79
1961-1973	1.86	-7.70	17.43	16.26	19.10	14.34
1973-1981	-4.19	-6.71	4.44	2.77	5.89	0.87
1981-1989	5.44	10.84	-7.81	-9.96	-6.96	-9.26
1989-2000	5.70	3.03	4.26	4.40	4.92	-1.89
	2) Absolute Contributions to Output per Hour Growth, percentage points					
1961-2000	2.37	-0.93	3.37	0.55	2.75	0.13
1961-1973	1.86	-7.70	10.69	2.80	6.32	1.58
1973-1981	-4.19	-6.71	2.73	0.37	2.30	0.08
1981-1989	5.44	10.84	-4.79	-1.17	-2.97	-0.64
1989-2000	5.70	3.03	2.61	0.46	2.25	-0.10
	3) Relative Contributions to Output per Hour Growth, per cent					
1961-2000	100	-39.4	142.1	23.1	116.1	5.5
1961-1973	100	-413.7	574.4	150.5	339.5	84.9
1973-1981	100	160.2	-65.1	-8.9	-55.0	-1.8
1981-1989	100	199.0	-88.0	-21.5	-54.6	-11.7
1989-2000	100	53.2	45.8	8.1	39.4	-1.7

Source: Calculated from CSLS (2003:Tables 33 through 40) and updated with more recent unpublished data from Statistics Canada, Capital Stocks and GDP by Industry Divisions.
Note: The contribution of capital intensity growth to output per hour growth is defined as growth in the total capital stock per hour work multiplied by capital's share of value added (0.5623, from the CSLS productivity data base by industry and province). The growth rate of capital per hour is the weighted average of the three components of capital divided by hours worked, where the weights are the average shares of each component in the total capital stock over each period. Contributions do not sum exactly to totals due to rounding and the approximate nature of the decomposition.

One view of total factor productivity growth is that it represents the pace of technological advance of an industry, or at least the part of technical progress that is not related to new technologies embedded in the capital stock. However, given the limited production function framework utilized, there is a strong possibility that several important factors of production have not been explicitly accounted for. This implies that these other factors have been pushed into the contribution of TFP growth to output per hour growth. For a more complete explanation of productivity trends, these other important factors of the production process need to be examined individually.[27]

B. The Contributions of Price, Technology, Skills and Other Factors to Productivity Growth

Total factor productivity growth as calculated here indicates the proportion of output growth that is not accounted for by growth in hours worked and in capital accumulation. This implies that TFP is affected by all other factors related to the production process, such as the skills and quality of the workforce, improvements in the organization of production and the technology available, compositional effects of closing lower productivity mines, and so on.

As discussed above, the limited evidence available suggests that the gold mining workforce is highly skilled. Average years of education per worker are nearly equivalent to the all industries average, but this is driven by a lower proportion of workers with a university degree. University degrees may not be particularly relevant for most mining workers since they generally do not embody skills germane to the type of labour traditionally required of miners. A more relevant distinction may be post-secondary certificates, since colleges and trade schools are more focused on teaching applied skills than are universities. The proportion of the mining workforce with a post-secondary certificate or diploma is above average, indicating that workers are well trained for the work they do. As well, the slightly above-average age of the mining workforce may suggest a higher level of experience than other industries. While there is no doubt that these credentials are important in maintaining the relatively high level of output per hour in the gold mining industry, and that their gradual growth has played a part in productivity growth, there is no evidence of a large erosion of skills that could explain the contraction in measured TFP in the 1973-1981 period.

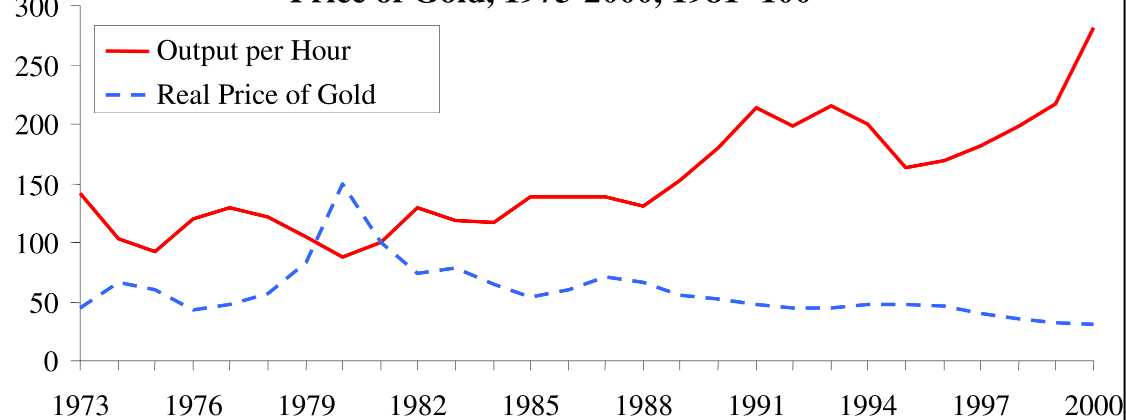
This same observation applies in terms of technological progress as well. It appears that new technologies have been adopted by mining industries through the gradual purchase of new equipment, and that mining techniques have evolved through a natural refinement and learning-by-doing process. While integral to productivity improvement in the long-run, it does not appear that there have been groundbreaking process or technological improvements in gold production that could account for the spurt in TFP growth in the 1980s, nor of technical regress that might explain the negative TFP growth in the 1970s. Indeed, the slow growth in the capital stock (and large declines in capital intensity) in the 1980s suggests that gold mines were exploiting capital accumulated during the high-investment years of the 1960s and 1970s, so that there were limited opportunities for acquiring new technologies embodied in new equipment in this

[27] Another consequence of the limited production function utilized is that the role of capital intensity is likely underestimated. Romer (1987) casts much doubt on the precision of the type of decomposition technique utilized here, and states that such methods probably underestimate the role of capital to a large degree. Therefore, the magnitude of the capital intensity contributions in the 1980s and 1990s should not be regarded as wholly accurate. However, these objections do not necessarily imply that labour productivity is driven entirely by capital intensity, and so do not obviate the need to examine other factors contributing to labour productivity growth.

period. However, the rebound in capital intensity growth in the 1990s may suggest that the computerization of operations contributed to the labour productivity surge in the late 1990s.[28]

A main driver of labour productivity growth in gold mining – mentioned but not analyzed in CSLS (2003) – appears to be changes in the real price of gold. The inverse relationship between these two variables is shown in Chart 6, which shows declining labour productivity in 1973-1981 coincident with increases in the real price of gold, and the opposite after 1981.

Chart 6: Output per Hour in Gold Mining and the Real Price of Gold, 1973-2000, 1981=100



Source: Output per Hour from CSLS (2003:Table 33) and unpublished GDP by Industry data. Gold prices from www.kitco.com, deflated with the CPI.

As discussed in the literature review, the relationship between the real price of gold and gold mining productivity is that increases in the price of gold lead to unfavourable compositional shifts as mines that were previously unprofitable (due, for example, to poorer quality ores) begin production since the output can then fetch a higher price. These newly opened mines will have lower productivity due to the increased effort required to draw gold from the lower quality ores, lowering the productivity of the overall industry.

Certainly in the 1990s this hypothesis is confirmed with data on the number of gold mining establishments. Between 1989 and 2001 the number of gold mines in operation in Canada was cut in half, from 70 to 35, as the real price of gold fell by 46 per cent. During the 1970s, as the price of gold began a sharp increase ending in 1980, the number of establishments stayed relatively constant rather than increasing as would be

[28] Capital intensity growth in the 1990s was actually driven primarily by large decreases in employment and hours worked, with the capital stock showing slight declines. But this does not disprove the proposition that output per hour growth was driven by investment in computers in the 1990s. Investment in computer systems may have substituted for investment in more expensive machinery, and further, computerized operations may have enabled the production of more ore with fewer hours of work to a larger degree than more conventional machinery would have.

expected. However, the declining gold mining labour productivity of this period suggests that existing establishments began operations on sites with poorer quality mining conditions.

But the price effect may still only be part of the story. The fact that the number of gold mining establishments stayed fairly constant during a period of price increases suggests that the general quality of deposits was declining during this period. Compositional shifts can entail new mines opening on lower quality sites, which leads to increases in output since the high quality mines still stay in operation. But in the 1970s it appears that the lower quality of sites reflects more simply an unavailability of high quality sites, as output was actually falling. It is therefore possible that, had the real price of gold not increased in the 1970s, gold mining would have shut down in Canada as the grade of ores seems to have been diminishing and profitability at a constant price would eventually have been exhausted.

In turn, the rebound in output and productivity growth in gold mining after 1981 suggests either that new high-quality reserves were eventually discovered, or that the years of poor growth in the 1970s prompted some sort of change in work rules or innovation in process. Data on the proven reserves of gold in Canada from Statistics Canada show that additions to the stock (i.e. new discoveries) outpaced extraction by a wide margin in 1983-1988, confirming that there was a large increase in the amount of reserves consistent with profitable extraction during this period. This is consistent with the large Hemlo discovery in northwestern Ontario in 1980, which stimulated further exploration. The literature review discussed the overhaul in the organization of work in iron mines in Canada and the United States in the 1980s, and it was also suggested there that such reorganization probably took place in copper mines as well. It is therefore also quite likely that changing work rules in terms of broadening the tasks that can be assigned to individual workers had an impact on labour productivity in Canadian gold mining as well. The continued success of the industry after the 1980s probably owes much to the discovery of high quality deposits and the development of new techniques in more efficiently extracting gold from lower quality ores.

C. Summary of Labour Productivity Determinants by Decade

Based on these observations, the following proximate drivers of productivity growth in the Canadian gold mining industry have been identified.

- **1960s:** rapid growth in capital intensity but declining output and only weak labour productivity growth, due to declining ore grades.

- **1970s:** a large increase in the real price of gold encouraged the mining of poor quality sites, leading to large declines in labour productivity – but the continued declines in output suggest that as much gold as possible was being extracted from existing operations, and perhaps that the high prices saved the industry from collapse.

- **1980s:** an abrupt rebound to solid labour productivity growth, due to new discoveries of richer and more accessible deposits, reinforced by technological and organizational improvements.

- **1990s:** weak productivity growth in the first half of the decade followed by very strong growth thereafter. Capital intensity growth became important once again after stagnation in the 1980s, a steady decline in the real price of gold continued to pressure low-productivity mines to close, and more importantly, most aspects of mining – from site design to extraction to the on-site transportation of materials – became computerized..

Conclusion

On average the gold mining industry in Canada has shown a strong productivity performance over the past four decades, although this performance has varied by decade. For the past two decades, growth in output per hour has been very strong, exceeding the total economy average by a wide margin. But in the 1960s, growth was comparatively weak, and the 1970s witnessed sharp declines in gold mining labour productivity.

In general, the labour productivity performance of gold mining is capital driven. Increased effort in locating sites with abundant reserves of high-quality ores – captured in the engineering capital stock – can have a large payoff in terms of increased efficiency in the extraction of gold. Engineering capital intensity, which is driven in part by exploration activity, has historically been quite high in gold mining. Growth in total capital intensity has been strong in most periods, except in the 1980s when it was possible to exploit the stock that had been rapidly built up in the 1960s and 1970s with little replacement. In the 1990s, capital intensity growth, driven by declines in hours of work and slow growth in the capital stock, likely embodied important technological developments, including the computerization of mine operations.

In recent decades, however, the contribution of capital intensity to labour productivity growth has been eclipsed by those of other factors, the most important of which appear to be the price of gold and declining ore grades. The productivity declines in the 1970s and the strong rebound in the 1980s and 1990s have been accompanied first by sharp increases in the CPI-deflated price of gold and second by steady declines in this price after the peak in 1980. Especially in the 1990s, the low and falling real price of gold appears to have given lower-productivity mines an incentive to close, leaving only the most productive mines in operation. In the 1970s the rising price of gold was coincident with the mining of lower quality sites, that is, a shift towards unfavourable inefficient production. Increased effort was necessary to extract a given amount of gold from these poor quality and formerly unprofitable mine sites. The decline in ore grades was mostly to blame for this situation though, with the rising real price merely allowing the less efficient operations to remain profitable.

It is likely then that the increasing real price of gold in the 1970s made the survival of the gold mining industry possible. This has turned out to be fortunate, as the industry has made large contributions to aggregate labour productivity growth since the 1980s. This turnaround from the performance of the 1970s was possibly driven at first by the adoption of work rules that allowed workers to perform tasks more fluidly. Later in that decade, with output and productivity advancing at an above-average pace, the importance of these new work rules was likely offset by the discovery of new deposits or the development of more efficient techniques for extracting gold from lower quality ores.

It is also important to stress once again the high quality of the gold mining workforce and the role that these skilled workers have played in maintaining the level of output per hour in gold mining much above the average for all industries. Despite some evidence of limited research and development effort, the passive technological advance in the gold mining industry appears to be serving the industry well in terms of labour productivity growth. From this perspective, it would not seem a fruitful approach to provide additional incentives for independent research and development within the mining industry, although neither should such efforts be discouraged. R&D within sectors producing equipment used by the mining industry can have a potentially large impact on mining productivity growth, especially in combination with incentives to invest in the most up-to-date equipment available coupled with training programs in the effective use of such new equipment.

The large role played by the price of gold in gold mining labour productivity makes direct policy suggestions difficult – since the price of gold lies outside the influence of anything but international regulatory intervention – but a general lesson can be drawn. This is simply that the price of gold does indeed have an impact on the decisions of mining companies. As the price of gold rises – which it appears to be doing recently, although it is difficult to separate short-term movements from long-term trends – mining companies will turn to lower quality mining sites where more effort is needed to extract gold. This will have negative implications for the productivity of the industry overall, but productivity need not be the only or even primary concern. To the extent that an exploitable opportunity for profit exists where none existed before, the benefits created by this profit may outweigh the lower contribution made to aggregate productivity and well-being by the gold mining industry. However, it may be the case that the greater effort required to mine lower quality sites leads to a less safe working environment for miners or to greater environmental harm. In general it would seem beneficial to encourage gold mining companies to exploit the highest quality reserves known to exist before moving on to lower quality reserves, although the higher profit available from better quality reserves provides an incentive for this behaviour in any case.

This leads to a last important point, namely the role of new exploration techniques in identifying the highest quality sites and in finding new reserves. Computer-driven and other enhanced mapping and exploration methods can directly contribute to the productivity of the gold and other mining industries through the identification of the richest and most easily exploitable reserves.

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