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Productivity Trends in the Coal Mining Industry in Canada

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Productivity Trends in the Coal Mining Industry in Canada

Abstract

The purpose of this report is to uncover the factors behind what has been a very strong productivity performance from the coal mining industry in Canada over the past four decades. It is found that real price movements have had a substantial impact on productivity growth in the coal mining industry in Canada. The real price of coal increased sharply in the 1970s due to higher demand caused by the oil price shock. This increased the profitability of sites of marginal quality and thereby lead to operations on less productive sites than those in production at that point. This had the effect of lowering the average productivity of the overall industry. However, since the 1970s, the real price of coal has fallen steadily, reversing this effect and hence contributing to the high productivity growth of the 1980s and 1990s. Another factor in this impressive productivity performance, at least in the 1980s, was the gradual closing of underground coal mines and the concentration of production on open surface mines. Surface mines typically have higher levels of labour productivity than underground mines, so this effect reinforced the price effect in increasing the average productivity of the industry. The 1990s saw the computerization of several stages of the production process, from site planning to extraction. Despite having the image of an old-fashioned industry, the coal mining industry in Canada is actually among the most intensive users of advanced technologies, and this certainly appears to have contributed to the industry's strong productivity performance as well.

Productivity Trends in the Coal 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 coal mining industry.

The report includes a review of the literature on coal mining productivity. Several studies identify the adoption of new technologies and techniques as important drivers of productivity in coal mining. Two periods of significant change in the real price of coal are found to have had substantial impacts on productivity growth. The first is the sharp increase in the 1970s. The second is the steady downward trend throughout the 1980s. In addition, after virtually no movement in the real price of coal in the 1990s, there was a pronounced decline between 1997 and 2000. High prices encourage the exploitation of marginal reserves, which results in low productivity levels for individual mines and lower productivity growth for the industry as a whole through a composition effect. Increasing returns to scale, labour-management relations, and the adjustment to new regulations are also found to be important.

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

- the coal mining industry accounted for 0.15 per cent of total economy output in Canada in 2000, and 0.04 per cent of employment;

- in 2001 there were 20 coal mines in Canada, down from an average of around 30 in the 1980s and 1990s, and significantly lower than the 80 to 100 mines in the 1960s and 1970s;

- workers in the coal mining industry have a high level of average years of, both relative to other mining industries and to the total economy, driven by a very high proportion of workers with college or vocational training;

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

- the price of coal rose rapidly in the early 1970s – due to demand pressures caused by substitution away from oil after the oil price boom – and has declined more or less steadily since the early 1980s.

The labour productivity performance of the Canadian coal mining industry was very strong over the 1961-2000 period. In the 1960s output per hour growth was very rapid, but the level of real output per hour was below that of the total economy. In the 1970s labour productivity stagnated, but the 1980s and 1990s saw a return to very strong output per hour growth. By 2000 the coal mining industry had a level of real output per hour three times that of the total economy. The Canadian coal mining industry has also seen a substantial improvement in its level of labour productivity relative to the U.S. coal mining industry, from 20 per cent in 1961 to 85 per cent in 2000.

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

- **1960s:** strong labour productivity growth driven by strong capital intensity growth (new operating processes, conveyor systems and larger vehicles).

- **1970s:** weak labour productivity growth, partly attributable to labour disputes and adaptation to new environmental and safety regulations, but driven primarily by high demand for coal, which increased the price of coal and encouraged the exploitation of marginal reserves.

- **1980s:** a return to very high productivity growth, but not due to capital deepening as in the 1960s. Rather, falling prices forced mines on less productive sites to close, while the transition from underground to higher-productivity surface mines was also taking place.

- **1990s:** weak productivity growth in the first half of the decade but exceptional growth in the latter half. Prices continued to fall, but the more important driver seems to be technology, with the computerization of most operations.

Productivity Trends in the Coal 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 coal mining industry.[1]

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

I. Literature Review of Studies on Productivity in the Coal Mining Industry

This section reviews the literature to attempt to uncover the factors behind what has been a remarkable productivity performance from the Canadian coal industry over most of the past four decades. Unfortunately there have been very few studies done on the Canadian coal industry specifically, let alone on the productivity performance of that industry. Attention has focused especially on the U.S. coal industry. However, it will generally be possible to extend the conclusions of these studies to the Canadian industry, with one possible caveat. As will be discussed, a number of authors have identified a link between productivity gains and the shift from underground to open-pit mining in the United States. The gradual closing of underground mines in Canada in past decades may indeed have played a large role in the success of the Canadian industry in terms of productivity growth, to be discussed in the fourth section; but by the late 1990s virtually all of the underground coal mines in Canada had been closed, meaning that this factor was no longer contributing to the productivity growth of the industry.

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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 gold mining and diamond mining are available as CSLS Research Reports 2004-08 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. Anton (1981)

One important and general reference on the Canadian coal mining industry is Anton (1981), which provides an extensive overview of coal mining in Canada, the role of labour-management relations in Canadian coal production, the end-uses of coal, social and environmental factors related to coal, and Canada's role in world coal production. While not a recent reference, many of these observations are still relevant. Anton (1981) also makes some observations on the drivers of productivity in coal mining, including an early recognition of the importance of research and development in improving recovery rates and average production per shift. Factors mentioned by Anton as contributing negatively to the productivity performance of coal mining in the 1970s are an inexperienced workforce, unrest and poor labour-management relations, and slow adaptation to higher costs of complying with safety and environmental regulations.[2]

B. Ellerman, Stoker and Berndt (2001)

The most comprehensive treatment of the coal mining industry in the United States in terms of its productivity performance was undertaken by a group of researchers at the Massachusetts Institute of Technology. The culmination of this research is a study by Denny Ellerman, Thomas Stoker and Ernst Berndt (2001) appearing in a National Bureau of Economic Research volume on productivity analysis. The novelty of this research is the use of a highly disaggregated data set, allowing observations to be made concerning the specific drivers of productivity in certain types of mines and geographic areas. These observations in turn allow the identification of the effect of productivity drivers in each of these groupings of mines on aggregate coal mining productivity.

Ellerman, Stoker and Berndt first divide their sample into Western, Interior and Appalachian mines, and each of these groupings further into underground-continuous, underground-longwall, and surface operations, and study their productivity performance over the 1972-1995 period.[3] The importance of this division turns out to be that it allows the distinction between mines of typically long and short operating lives.[4] The authors develop a framework in which the productivity growth of a given aggregate can be decomposed into five effects: a scale effect; a fixed (industry-specific) effect; a price effect; a time effect; and a residual.

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[2] Chaykowski (1992) gives a more recent overview that deals particularly with labour relations and the importance of mining industries in Canada, and briefly with Canada's importance in world production. His analysis includes coal, but also many individual mineral and metal industries.

[3] Longwall mining refers to the mining of a single face of a rectangular coal deposit, with roof supports that automatically advance with the mining equipment as the operation cuts the face further back. Alternatively, continuous mining entails mining inside a rectangular deposit, which requires large amounts of coal to be left in place as support pillars (hence the common name of room and pillar mining) and the manual installation of additional supports.

[4] Another important advantage, of course, is that the average effects implied by the regression results are not affected by heterogeneity in production technologies and geological factors, as results from regressions on aggregate data would be.

The most substantial impact on the labour productivity of coal mines with long working lives is found to be scale. That is, the larger is a mine that will be in operation for the foreseeable future, the more productive its workers are likely to be. Although the authors are careful not to conclude from these results that increasing returns to scale are driving productivity growth,[5] they draw an important conclusion. This is that larger firms seem to have the ability to more effectively deal with production bottlenecks and to realize the benefits of embodied and disembodied technical advance. That is, regardless of whether there are constant or increasing returns to scale, larger firms are able to make better use of new technologies and processes than smaller firms.

For mines with typically shorter operating lives, such as continuous (room and pillar) underground mines and eastern surface mines, the fixed effect is the most important driver of productivity. The fixed effect is the portion of productivity growth accounted for by specific attributes of individual mines, which the authors interpret as driven primarily by differences in technical capacity. Therefore, when high productivity growth is largely driven by the fixed effect, it is an indication of more rapid technological advancement relative to other mines. Profitability on sites with relatively limited reserves requires rapid exploitation of these reserves. This, the authors state, is facilitated by use of the most recent technology available. Such use of state of the art equipment and processes allows the virtually instant attainment of optimal capacity and the maintenance of this capacity for the life of the operation.

Technical advance is hence important for both short- and longer-lived mines, but in the latter case the absolute benefit derived from technologies is mediated by the size of the operation. Ellerman, Stoker and Berndt also find the price effect to be important for all mine groupings. As the real price of coal increases, it becomes profitable to mine sites in which it would be too expensive to invest the effort and capital necessary to extract the coal if it were to be sold at a lower price. This creates a composition effect, as low productivity mines begin operation in periods of price increases, lowering the average productivity of the overall grouping.

The authors aggregate their decomposed results in order to determine which of the price, fixed, time, scale and residual effects were most important in aggregate coal mining productivity in the United States for the 1972-1995 period. They find that by far the price effect was most important for the overall period and the 1972-1978 period, but was slightly exceeded in importance by the fixed effect for the 1978-1995 period, when coal prices were more or less on a steady decline. For the earlier period, which witnessed

[5] Size is measured using a transformation of output, measured in terms of tonnes of coal. It is possible, then, that the mines identified as being large are simply those that produce more through the employment of more capital, and it is well-known that higher capital intensity leads to higher productivity, other things constant. Therefore, the result of a large size effect could be driven solely by the fact that larger mines are more capital intensive, which is not inconsistent with constant returns to scale. If there were certainly increasing returns to scale, the easy solution for improving productivity would simply be to increase both capital and labour inputs, since the resulting increase in output would be proportionately more than the increase in inputs, and labour productivity would by definition be higher. Unfortunately, since their data set did not contain information on the capital stock, the authors were not able to test for increasing returns to scale by holding capital intensity constant and observing if their size effects still held.

steep increases in the real price of coal as demand switched to oil substitutes after the oil price shock of 1973, the scale effect also made a substantial contribution to declining labour productivity. The authors state that during this period, the rising price of coal encouraged the opening of a large number of mines that were not only geologically inferior but also of relatively small scale. This meant that a large amount of effort was being expended with a very small increase in overall production, creating an overall disastrous labour productivity performance.

A brief word should also be said about a result not stressed by the authors. The time and price effects are separated by using dummy variables to separate the effect of years judged to be anomalous within individual mine groupings. However, the authors eventually find that such anomalous years occurred in different periods in the 1970s for different types of mines. They attribute this to a different schedule of the implementation of health and safety regulations for underground as opposed to open-pit mines. The first years of the sample mark years of new regulations for underground mining, and the dummy variables effectively separated the effects of adjustment in these years from the price effect. But such regulations were not imposed on surface mines until later in the 1970s. The authors deal with this situation by using dummy variables in different years for different types of mines, but the more important message from this exercise is the effect of regulations on productivity. In the first years of regulation it appears that mines did face adjustment costs in terms of productivity declines, although it would require a more normative analysis to judge whether the lost production in these years has been more than offset by the record of improved workplace safety that resulted. However, the maximized fit of the regressions when only between two and six years of adjustment are marked with dummy variables suggests that workplace safety regulations have not had a permanent depressing effect on coal mining labour productivity.[6]

C. Darmstadter (1999)

Darmstadter (1999) is a non-technical but equally comprehensive analysis of coal mining productivity, which refers to the earlier research upon which Ellerman, Stoker and Berndt (2001) is based. Without attempting to rank their importance, he discusses six factors which have been important for U.S. coal mining productivity: shifts in production between different types of mines; adoption of new technologies; regulation; periods of labour unrest; improved management; and changing market environments, especially in the 1970s.[7]

Two important shifts have occurred in the production of coal in the United States in the past few decades that have had important compositional effects in improving overall coal mining productivity. The first is the shift from underground to surface operations, and the second from continuous to longwall techniques within underground

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[6] Moreover, although this is not tested by the authors, it is possible that a separate dummy variable for years after adjustment to regulation would further improve the fit of the regressions, implying that a safer work environment may have lead to higher trend labour productivity in the long run.

[7] These changing market environments refer to what has already been discussed in terms of the rising real price of coal in the 1970s and the exit of less efficient firms as the price declined thereafter.

production. Surface mining operations have historically been much more productive than underground mining, for the simple reason that the coal is more easily accessible and so more easily mined, being free of structural concerns and small passages that limit underground operations. Longwall operations are more productive than continuous operations because larger machines that are capable of more rapidly shearing the coal can be utilized. Also, there are fewer breaks in production with longwall operations, since it is not necessary to pause production to install roof supports as it is in continuous operations. These two shifts have hence both been beneficial to average coal mining labour productivity in growth and level terms: lower-productivity underground mining has a constantly improving productivity level as production continues to shift to longwall operations; and the share of higher-productivity surface mining has continued to increase in the past few decades.

Darmstadter (1999) gives a broad definition of technological progress, including improvements in the characteristics of new investments, increases in the scale of new investments, and increases in the skills base of the operators of such new investments. This is hence a largely embodied view of innovation, i.e. technological improvements are embedded in equipment and do not include such things as process improvements unrelated to equipment. Nonetheless, the author notes improvements in each aspect made by the U.S. coal mining industry in the past several years. For example, the shovel, dragline (primarily surface), shearing (primarily underground), and hauling vehicles have all increased markedly in size, while machines specific to the site geology have increasingly been used, and computers adopted both for management of operations and for more effective site planning.

In the late 1970s and early 1980s, the coal industry was just beginning to recover from a decade of poor productivity performance. Many observers noted that the beginning of this period also marked the introduction of several safety and environmental regulations affecting mines specifically, and were quick to draw a causal link. Darmstadter quotes Denison (1985), who found that actual productivity growth in the 1968-1977 period in U.S. coal mining was -3.5 per cent per year, but that growth would have been 3.1 per cent per year if the regulations had not been implemented. The underlying cause of this six percentage point differential is that the regulations generally required much more labour effort, for example in terms of installing roof supports and accompanying mine inspectors, effort that did not lead to a commensurate increase in output. Darmstadter (1999) notes that these studies were generally undertaken soon after the period of poor productivity growth and before the productivity rebound in the 1980s, and that in hindsight it now appears that regulatory effects are transitory and often not the only factor at work. He also notes that environmental regulations imposed on coal-using industries in terms of emissions have actually improved coal mining productivity, since they have spurred demand for demand from western surface mines – whose coal has a substantially lower sulphur content – thus facilitating the productivity-enhancing shift to surface mining.

Two factors related to management are also highlighted by Darmstadter (1999), both in terms of further explaining the slow productivity growth of the 1970s and the rapid productivity growth thereafter. The first is a period of acute labour unrest in the 1970s, encompassing strikes by labour and an extended period of worker discontent. Not only did these work stoppages directly decrease labour productivity (due to the need to employ some standby and maintenance personnel while no output was being produced), but the generally frustrated attitudes of the workers while on the job likely lead to a decline in motivation and effort as well. The second management factor is management contracting and decision making, which showed some signs of innovation in the 1990s. Darmstadter quotes Pippenger (1995) in this respect, who provides a detailed case study of a particular mine and finds that increased productivity through innovation was the main driver of increased competitiveness of this mine. Some of these innovative decisions have been the reorganization of shifts throughout the week to reduce maintenance down time, allow for regularly scheduled preventive maintenance, and reduce costs associated with shift turnover; and contracting with suppliers to ensure for more appropriate use of equipment.

Overall, Darmstadter (1999) sees promising performance from the U.S. coal industry in the future, but notes that the strong innovative stance of the industry in the past several years has been driven by increasingly fierce international competition. Also, countries like the United Kingdom and Germany, who have traditionally been major international coal producers, have seen a decline in their coal industries over the past decade or so as competition from countries such as India and even Colombia has increased. That said, he states that the U.S. coal industry has shown strength in adapting to market realities in the past, and is hence well placed to face future challenges.

D. Other Studies on Innovation and Coal Mining Productivity

Flynn (2000) echoes several of the conclusions of Darmstadter (1999) and the earlier research that culminated in Ellerman, Stoker and Berndt (2001). He notes several advances in terms of mining equipment (scale and quality) and automated control, and also notes the favourable productivity impact of the shift to surface mining operations. He also notes that the falling real price of coal has contributed to the exit of inefficient firms. On the other hand, he states that existing firms are now facing difficulties in keeping up the pace of technological adoptions as continued price declines lead to lower profitability. He therefore sees an important role for policy in terms of assisting firms with the purchase of new machinery and equipment, which will in turn further increase their productivity performance and facilitate adaptation to lower prices.

Much has been said so far about the role of technology in improving coal mining productivity, and two further studies related to mining technology deserve mention here. The first is a study by the RAND corporation by Peterson, La Tourrette and Bartis (2001). It finds that U.S. mining managers have in recent years developed a high aversion to investment risks due to low commodity prices and increased global competition. Specifically, the report suggests that there are new technologies available to coal mines that will improve productivity – indeed, the report mentions that some have been adopted to a larger degree by Canadian mines as compared to U.S. mines – that the necessary capacity for their implementation is available, but that mines are not able to commit to adopting these technologies due to perceived risks of not being able to recoup their investments through higher production value. This reinforces the concerns raised by Flynn (2000) that mines have been putting off further expenditures on new technologies due to the expectations of lower sales revenues from lower prices.

The second is by Fred Kissell (2000) of the U.S. Bureau of Mines. 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.

E. Studies on Regulation, Scale and Other Factors Affecting Coal Mining Productivity

Returning to the possible effects of regulation on productivity mentioned by Darmstadter (1999) and Ellerman, Stoker and Berndt (2001), an earlier contribution from Naples (1998) investigates the issue in more detail. Naples closely examines the technical as well as social determinants of productivity in coal mining, and tests her hypotheses with data from 1955-1980. She finds that the studies of the 1980s attributing the productivity declines of the 1970s to stringent new safety regulations greatly exaggerated 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. Most important of these, besides the basic technical driver of capital intensity, were the rising real price of coal and the rapidly deteriorating relations between managers and workers.

While describing the difficulty of separating the individual effects of social indicators such as safety regulation and labour unrest from one another, Naples (1998) is the only study to jointly consider regulation effects with other social effects. She finds that over two fifths of the productivity decline in the 1970s was due to social factors, compared to one fifth for price effects, with the remainder accounted for by slower capital intensity growth and a slowdown in the shift towards more efficient mining techniques. Of this two-fifths share, Naples states that 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.

The author also draws a link between increasing labour dissatisfaction leading up to the implementation of the new health and safety regulations and increased demands for better working environments, especially with the increased dust level commensurate with the development of continuous mining. This suggests that once the regulations were complied with, workers' concerns were largely answered and, except for the still sour relations with management, that worker satisfaction should have been higher than before the regulations. Hence, conditional on good relations between labour and management, health and safety regulations can actually improve productivity, with the period after adjustment to the new regulations possibly marked by higher productivity growth than the pre-regulation period.

Further insight on the scale effect mentioned by Ellerman, Stoker and Berndt (2001) can be gained from Boyd (1987). In the discussion above of the more recent study, it was stated that the conclusion of higher productivity growth in larger mines could be driven either by increasing returns to scale or by the fact that larger firms are simply more capital intensive, but that it could not be determined which effect was present or dominating in that study. Of course, as was discussed, this was not an impediment to that analysis since the major role of size in improving productivity in that study was deemed to be through facilitating greater benefits from technology. However, separate from this technology effect, Boyd (1987) is able to study the effects of capital intensity and returns to scale separately.

Boyd uses a technically advanced production function[8] to model firms with fixed effects (specifically, fixed geological properties, as is relevant to mines) and where returns to scale are dependent upon some of the inputs to production. His estimations show that mines with higher investments in earth-moving machinery per worker tended to experience increasing returns to scale. This suggests that larger mines are more productive both because they are benefiting from increasing returns to scale and because they become more capital intensive, since the former is in part caused by the latter. In this sense, a possible method of increasing productivity growth may be to encourage larger operations through increased capital investment. However, Boyd (1987) also notes that it is generally the case in mining that the site geology determines how big the operation can ultimately be, therefore limiting the ability of mines to attain optimal scale.

One minor point made by some older studies on productivity in a more general setting than strictly mining is the effect of the level of unionization in the workforce on labour productivity. Brown and Medoff (1978) and Mefford (1986) are two of the principal references in this area. Several causal channels are mentioned, such as unions giving a greater voice to workers and hence improving worker satisfaction and efficiency, and unions imposing too many constraints on management and hence impeding overall efficiency. With what has already been discussed for coal mining, it is easy to see the possibly conflicting causes of unions on coal mining productivity.[9] Since unions were instrumental in calling for safety reforms to mines, it is possible that the combined observation of union activism and declining productivity in the adjustment period following regulation could imply negative effects of unions on productivity. However, by the high productivity growth 1980s there were far fewer mining strikes than in the 1970s, implying that a more or less equivalent level of unionization was associated with more cooperative labour-management relations and productivity growth in this period.

Chezum and Garen (1998) study a sample of 941 U.S. coal mines in the 1980s and find that unions are typically more prevalent in mines that are endowed with wider coal seams. Since wider coal seams are in turn related to higher labour productivity levels, this leads to a positive relationship between unionization and productivity. However, the authors note that this is a spurious rather than causal relationship, and attempt to discover the effect of unions on productivity independently of this tendency for unions to be active in exogenously more productive mines. They find that once seam thickness is controlled for, unions appear to exert an overall negative effect on productivity. However, their model has some possibly important exclusions, most important of which is likely to be capital stock. Hence, while further work would be necessary to more precisely quantify the union productivity effect, the general lesson of this work is that studies finding a large positive effect are likely overlooking the spurious nature of this relationship, and that the true relationship is likely minor.

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[8] The function is an arctangent transformation of a path-homothetic Cobb-Douglas production function, with overburden thickness, seam thickness and three types of capital intensity as inputs and each of the three capital intensities affecting returns to scale. For a discussion of its properties, see Boyd (1984 and 1987) and the references therein.

[9] Clement (1983:Chapters 7 and 8) states that Canadian miners were among the first workers in Canada to unionize, and that a large portion of the mining workforce tends to be unionized. However, he does not comment on the possible linkages between this unionization and worker productivity.

One final factor that has been identified as having a productivity effect in coal mining is changes in the structure of ownership, in terms of mergers and acquisitions. David Merrell (1999), of the U.S. Bureau of the Census, obtains panel data on all coal mines operating in the United States between 1978 and 1996, and develops a model that describes the conditions under which mines change ownership. The theory tested by Merrell is that low-productivity firms may be suffering from poor relations between owners/management and workers, so that such firms are more likely to be involved in a management/ownership change. Further, to the extent that the new owners have a better fit with workers, productivity should improve after the acquisition. Merrell (1999) finds strong support for both aspects of this hypothesis, in that acquired firms are about 10 per cent less productive than non-acquired firms before acquisition, and show stronger than average productivity gains after being acquired. To the extent that these changes in productivity actually reflect management issues as per the theory, this is further evidence supporting Naples' (1998) findings that labour-management relations are an important and somewhat overlooked factor in determining productivity performance in coal mining. In this sense the results call more for policies dealing with improving labour relations rather than easing rules for merging coal mines, although the latter may play a role in the former.

F. Studies on Coal Mining Productivity in Other Countries

Two final studies dealing with productivity in coal mining in other countries are worth briefly mentioning. First of all, Humphris (1999) provides insights on productivity drivers in the Australian coal mining industry that are interesting largely because they correspond directly with those already identified as important for the United States. He first mentions that several of Australia's underground mines have switched to longwall techniques from more traditional techniques, and that this has greatly improved average productivity. He also makes reference to the decreasing price of coal, the adoption of new technologies and processes, and improved worker flexibility and relations as contributing to strong Australian coal mining labour productivity growth.

Kulshreshtha and Parikh (2002) use a Malmquist index technique to decompose total factor productivity growth in Indian coal mines into technical advance and efficiency improvement components. Efficiency here refers to more complete use of resources that are already available, while technical advance refers to the improvement of production possibilities through the employment of new technologies or processes.[10] The main finding is that TFP growth has been driven more by technical advance in surface coal mining in India in the 1980s and 1990s, while underground coal mining TFP growth has been driven more by efficiency improvements.[11] The more interesting result in light

[10] In terms of a production possibilities frontier, efficiency gains refer to a movement from an interior point closer to the frontier, while technical advance refers to an outward shift of the frontier.
[11] Using a similar type of model, Asafu-Adjaye and Mahadevan (2003) find that technological advance has had a larger effect on Australian coal mining TFP growth than efficiency improvements (and also find that increasing returns to scale made a somewhat large contribution to TFP growth as well). However, they do not divide their sample into surface and underground mines.

of the U.S. conclusions, however, is that open-pit coal mines have tended to experience lower productivity growth in India than underground coal mines, in opposition to the situation in the United States. This may be driven by the unavailability of excavating machinery in India on as large a scale as in the United States, or poor quality reserves near the surface in India as opposed to the generally rich surface seams in the western United States.

G. Summary

In terms of attempting to quantify the importance of the productivity drivers in the coal industry discussed here, it would appear that the adoption of new technologies and techniques has been identified by the largest number of observers within the industry and those studying the sector from the outside. Two periods of significant change in the real price of coal are found to have had substantial impacts on productivity growth. The first is the sharp increase in the 1970s. The second is the steady downward trend throughout the 1980s. In addition, after virtually no movement in the real price of coal in the 1990s, there was a pronounced decline between 1997 and 2000. Increasing returns to scale, labour-management relations, and the adjustment to new regulations are also found to be important.

II. Characteristics of the Coal 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.[12] 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.[13] This results in the longest time series possible.

[12] 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, and 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.

[13] 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

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 updated from 1997 onwards with GDP by Industry series, according to NAICS, expressed in 1997 constant dollars at basic prices, based on a fixed weighted Laspeyres index.[14]

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.[15] 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

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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.

[14] CSLS (2003) includes an appendix on the concordance of natural resources industries according to NAICS and according to SIC. This change in classification does not affect the coal mining industry, as the SIC industry concords directly with the NAICS industry.

[15] 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).

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 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).[16]

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.[17]

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

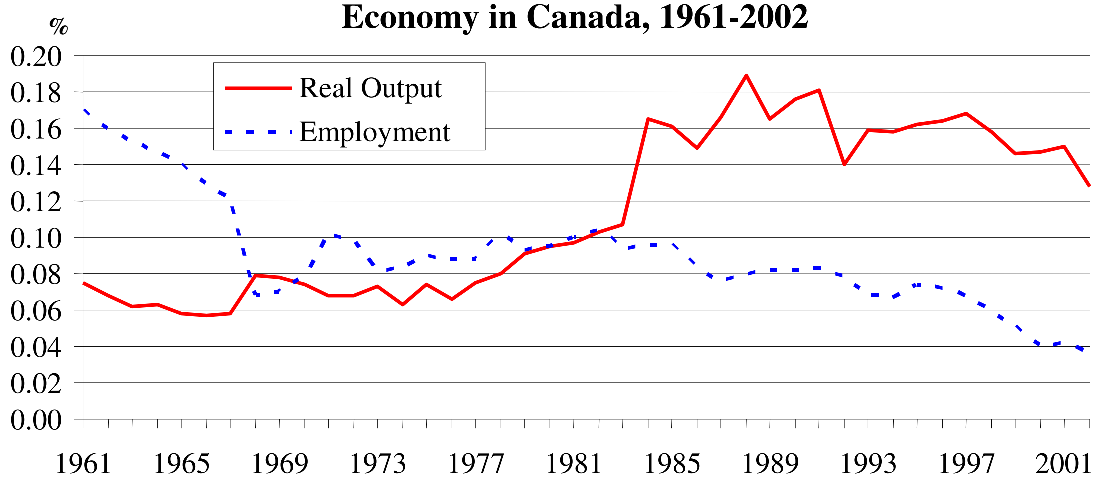
Real GDP in the coal mining industry was about $1.2 billion (1992 constant dollars at factor cost) in 2000, compared to total economy real GDP of $788 billion. Coal mining therefore accounted for 0.15 per cent of Canadian output in 2000 – up from 0.07 per cent in 1961 – and around 15 per cent of that of the overall mining industry (CSLS,

[16] 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.

[17] 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.

2003:Table 28).[18] Coal mining's share of total economy employment was lower, at 0.04 per cent, representing a decrease over the 1961-2000 period as opposed to the rising output share (Table 30). About 6,000 of the 15 million Canadian jobs in 2000 were in coal mining, down from 11,000 in 1961. The evolution of coal mining's output and employment contributions to the total economy are shown in Chart 1, and summary growth rates for coal mining are shown in Table 1.

Chart 1: Share of the Coal 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 Coal Mining Industry in Canada, 1961-2000, compound average annual growth rates, per cent

	Real Value Added	Employment	Hours Worked	Capital Stock
1961-2000	5.59	-1.54	-1.48	4.55
1961-1973	5.62	-3.05	-3.35	11.90
1973-1981	6.96	5.31	5.16	6.77
1981-1989	9.97	-0.60	0.62	3.11
1989-2000	1.52	-5.29	-5.51	-3.43

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

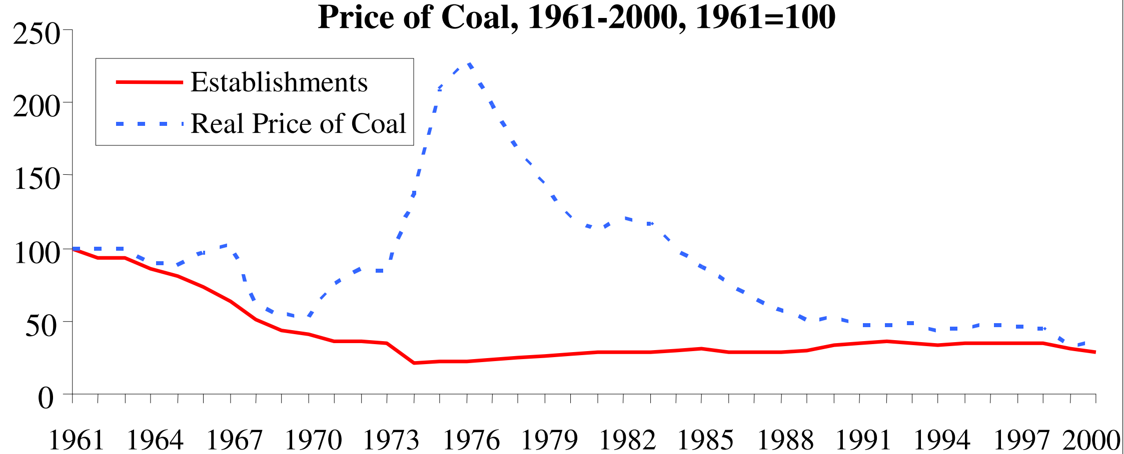
There were 21 coal mines in Canada in 2001, a sharp drop from 28 in 2000 and the average of about 30 throughout the 1980s and 1990s.[19] The number of coal mines in Canada was much higher in the early 1960s – between 80 and 100 – but declined sharply

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

[19] Data on the number of establishments are from the Annual Census of Mines carried out by Natural Resources Canada for Statistics Canada. Data are disseminated via annual Statistics Canada publications (e.g. *Coal Mining*, catalogue number 26-206) and CANSIM, Statistics Canada's online data service (e.g. tables 152-0005 and 152-0002). New estimates for 2001 are from the 2001 Annual Census of Mines, released on February 23, 2004.

in the second half of the 1960s and most of the 1970s, to as low as 20 in 1974. These mine openings and closings do not appear to be related to year-to-year changes in the price of coal (Chart 2). However, both the real price of coal and the number of coal mining establishments have shown long-term declines over the 1961-2000 period.

Chart 2: Number of Coal Mining Establishments and the Real Price of Coal, 1961-2000, 1961=100



Source: Number of establishments from CANSIM Table 152-0002. The real price of coal is the implicit price deflator for the coal mining industry from GDP by Industry data, deflated with the CPI.

The 28 mines in 2000 were concentrated in Western Canada. There were 13 mines in Saskatchewan and Alberta, eight in British Columbia, six in Nova Scotia, and one in New Brunswick. Coal mining establishments, besides being more numerous, were also of larger scale in Western Canada. Coal mines in British Columbia had 364 employees per establishment in 2000, compared to only 92 for Nova Scotia.

Canada has not historically been a major world coal producer. In 2002 Canada produced about 0.8 per cent of world coal, tenth behind China (34.6 per cent of world production), the United States (23.9 per cent), India (8.9 per cent), Australia (7.2 per cent), South Africa (5.8 per cent), Russia (4.3 per cent), Poland (2.7 per cent), Indonesia (2.6 per cent), and Colombia (1.1 per cent).[20] In 1981 Canada's share was 0.8 per cent as well, but Canada ranked 11th place. All countries except Colombia and Indonesia with higher production in 2002 had higher production in 1981 as well, and the United Kingdom, Germany and North Korea also had higher production than Canada. In 1947 and 1961 respectively, Canada's world production shares of coal were 0.7 per cent and 0.3 per cent, ranking 14th and 15th. Over the 1947-2002 period the production share of China increased significantly, from about 1 per cent to almost 35 per cent. The shares of Australia and India have also risen significantly over this period, while the United Kingdom and Germany have experienced large declines in their shares of world coal production.

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[20] These data are calculated from IEA (2003). In 2002 Canada ranked slightly lower, 13th place, in terms of coal in tonnes of oil equivalent, according to CANSIM table 130-0003.

The majority of coal mining in Canada appears to be undertaken by Canadian firms. Very limited data on ownership are available without examining individual businesses.[21] However, the data that are available show foreign ownership at about one third of all Canadian coal mining enterprises on average over the 1980-1988 period for which data are available. More recently, it would appear that the proportion of Canadian coal mines that are foreign-owned has decreased. Three major Canadian corporations, each with multiple mines in Canada, are Sherritt International, Elk Valley Coal, and Fording.

C. Resource Base

Statistics Canada estimates that in 2001, the most recent year for which data are available, there were 4,555 million tonnes of proven coal 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).[22] This includes 2,247 million tonnes of bituminous coal and 2,308 million tonnes of lower-quality subbituminous and lignite reserves. Proven reserves have been much higher in the past, for example the 6,583 million tonnes in 1987, but were somewhat lower in 1976, at 4,311 million tonnes. This implies that over the 1976-1983 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. The opposite is true between 1983 and 2001, and especially after 1998, when there was a sharp decline in proven reserves. Relative to the 4,555 million tonnes of reserves in 2001, extraction in that same year was only 68.4 million tonnes (Chart 3). At present extraction rates and profitability conditions, reserves are therefore equivalent to over 66 years of production. The ratio of extraction to total stock has declined more or less steadily since 1976, with the stock equivalent to an average of 169 years of production in that year.

D. Labour Force and Related Characteristics

The coal mining industry appears to have a well-educated workforce, with average years of education per employed worker at 14.0 years in 2001 (CSLS 2003:Table 47). This compares to 13.5 years for all Canadian workers and 12.8 years for all (metal plus non-metal) mining workers. Average years of schooling of workers in the coal mining industry increased by 1.0 per cent per year between 1976 and 2001, twice 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 2.2 per cent per year over this period, relative to 1.0 per cent per year for all industries. The slightly above-average years of schooling in coal mining reflects a very high proportion

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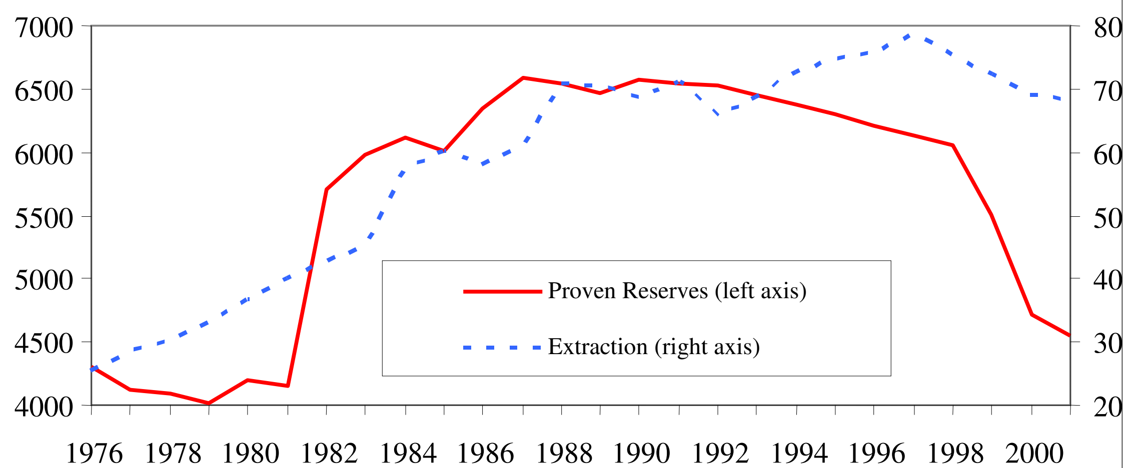
[21] Data on the foreign/domestic ownership of enterprises as well as their equity and asset holdings and profits were collected for all Canadian firms under the Corporations and Labour Unions Return Act for the 1980-1988 period. These data are available by detailed industry from Statistics Canada via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

[22] These estimates are taken from CANSIM Table 153-0017 and -0018. Earlier estimates were published in Statistics Canada (2001).

of workers with a post-secondary certificate or diploma (46.3 per cent in 2001), but a low proportion of workers with a university degree (less than 5 per cent).[23]

Chart 3: Extraction and Proven Reserves of Coal in Canada, 1976-2001, millions of tonnes



Source: Statistics Canada, CANSIM Table 153-0017 and 153-0018.

Average hourly labour compensation in the coal mining industry was $29.79 (current dollars) in 1997, representing 153 per cent of the total economy average (CSLS 2003:Table 35). This is consistent with above-average wages in both metal and non-metal mining, 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 coal mining specifically. In 1982 there were 2,958 injuries in coal mining in Canada, or 25.6 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 3.1 per 100 workers in coal mining, compared to 2.2 for both total mining and the total economy. The incidence of workplace fatalities has also shown a marked decline in coal mining – from 133.7 per 100,000 workers in 1993 to 93.2 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 coal mining workforce is higher than that of all industries. Based on custom tabulations from the 1996 and 2001 Censuses, the average age of the coal mining labour force was 40.9 in 1996, rising substantially to 44.3 in 2001. For the

[23] Educational attainment data are also available from the Census. Custom tabulations from the 2001 Census (based on a 20 per cent sample) show the proportion of coal workers with post-secondary qualifications as 46.0 per cent, and the proportion with a university degree as 6.1 per cent.

total economy, the average age of the labour force was 38.0 years in 1996 and 39.0 years in 2001.[24]

Data are also available from the Census on employment by industry and sex, and show that employment in the coal mining industry is heavily male-dominated. In 2001 males accounted for 53.1 per cent of the all industries workforce, down from 54.0 per cent in 1996. For the coal mining industry the proportion of males in total employment was much larger, at 90.7 per cent in 2001, down from 92.0 per cent in 1996.[25]

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 coal mining specifically.

E. Capital Intensity

Coal mines are very capital intensive operations. In 2000, the ratio of capital stock to hours worked in the coal mining industry was $427.82 per hour (1997 dollars), compared to $61.69 for all industries. Capital intensity also advanced much more rapidly over the 1961-2000 period in coal mining than in the total economy, at 6.1 per cent per year compared to 1.7 per cent per year. Capital intensity advanced between 1989 and 2000 by 2.2 per cent per year in coal 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 a large proportion of the capital stock of the coal mining industry (71.5 per cent in 2002) was in engineering capital stock, with smaller proportions in structures capital stock (15.0 per cent) and machinery and equipment (13.5 per cent). Absolute declines in investment and capital stock in coal mining in the 1990s, especially in machinery and equipment, may mean that the coal mining sector has not benefited from technological advance embedded in new capital. On the other hand, the high level of engineering products (which includes exploration expenditures) per hour worked 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. The engineering capital stock also includes expenditure on construction of and supporting structures for mine shafts and pits, and on conveyor systems to move coal from the pit.

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[24] These tabulations are based on a 20 per cent sample, and refer to the SIC definition of the coal mining industry. However, as stated above, the SIC and NAICS definitions of the coal industry are identical, and indeed, the estimate of average age based on NAICS (available for 2001 only) is 44.3 years, identical to the SIC estimate.

[25] Again, these estimates are custom tabulations from the 1996 and 2001 Censuses, based on a 20 per cent sample and referring to the SIC definition of the coal mining industry.

F. Technological and Process Developments

Coal mining technology is somewhat specific to the geology of individual mines. Open-pit mining relies heavily on large earth-moving machinery and high-capacity hauling vehicles. Underground mines rely on large vehicles specifically designed for coal shearing, with most haulage requirements fulfilled by conveyor systems. The website of the Coal Association of Canada states that there is currently only one underground coal mine in Canada, although the coal mines in Nova Scotia that have gradually been closing in recent years were underground operations.

There have been several basic improvements in each of these coal mining processes in the past several decades, especially in the continually increasing capacity of large vehicles for extracting and hauling the coal. Perhaps most importantly in the past decade, the control of many operations has been computerized, along with pre-mining planning and site design.

Two specific innovations of recent years are worth noting briefly here. First, although specific to underground room and pillar mining, the Commonwealth Scientific and Industrial Research Organisation has announced the development of a new continuous mining system of machines that simultaneously extracts coal and installs roof-supporting bolts (CSIRO, 1998). This is intended to remove the need to halt production in order to manually install the roof bolts, both increasing worker safety, and improving productivity through decreasing pauses in production. This is an example of the general trend towards more effective automated-control equipment in coal mining.

Secondly, 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 coal mining, but rather are mentioned here as evidence of increasing computerization in mining operations in general.

Lonmo (2003:17) shows that mining industries in Canada have tended to invest very little in research and development relative to their 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 other industries.[26] Further, Uhrbach and van Tol (2004) show that large firms – defined as those with more than 100 employees, which many coal mining

[26] Lonmo (2003) also shows that mining industries have 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.

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

Given the different grades of coal (e.g. bituminous versus lignite), differential prices for different end-uses (e.g. electricity generation versus steel production), different pricing conventions (e.g. including versus not including freight charges), and the fact that Canada both imports and exports coal, it is difficult to identify a single price series to monitor.[27] The method here is to treat the implicit price index for the coal mining industry – calculated by dividing nominal coal mining GDP by real (constant dollar) coal mining GDP) – as an index of the nominal average price of coal paid by Canadians. To convert this to a real price, the implicit price index can be deflated with the Consumer Price Index. The real price series is shown in Chart 2 above.

The major characteristic of the real price of coal since 1961 has been the rapid increase in the mid-1970s in response to increasing demand after the first oil price shock in 1973, as businesses substituted cheaper coal for more expensive oil and gas. Until then the price had been falling fairly steadily as new equipment and mining techniques meant that the relatively constant demand could be met with decreasing effort. From 1973 to 1976, the peak price after the oil shock, the real price of coal increased by about 171 per cent. After 1976 the real price of coal fell more or less steadily, reaching the level of the early 1970s by about the mid-1980s. Between 1981 and 1989 the real price of coal fell by 54 per cent, and by a further 33 per cent between 1989 and 2000.

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[27] The website of the Coal Association of Canada states that about one half of Canadian coal production is of bituminous coal, one third is subbituminous, and the remainder is lignite. About 40 per cent of coal production is used for steel making, with the remaining 60 per cent for heating/electricity generation. Major importers of Canadian coal are Japan, Korea, Germany and the United States. Coal imports from Colombia and the United States are used in electricity generation and steel making in eastern Canada, although some coal from Western Canada is also used for electricity generation in Ontario.

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 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.[28]

[28] 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

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.[29] 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 unemployment rate in coal mining in 2001 was 7.0 per cent, compared to 7.4 per cent in the total economy. These estimates are from 2001 Census custom tabulations, and thus are not available for a long time period. The Labour Force Survey only has data on the unemployment rate by industry publicly available for broad industry groups, but these data are available annually back to 1987 based on NAICS. For mining and oil and gas the unemployment rate was 5.1 per cent in 2001. This 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

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to companies and governments to reduce mining costs (i.e. through the adoption of new technologies and processes).

[29] Not related to coal mining, the authors also mention tailings and contaminants from the ore concentration process, and air pollution during the smelting process.

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

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

A. Labour Productivity

The level of output per hour in coal mining in 2000 was $90.83 per hour in constant 1992 dollars, above the level for all mining industries of $66.13 and much higher than the all industries average of $28.99 per hour (CSLS, 2003:Table 33). This has not historically been the case. In the 1990s coal mining had a level of real output per hour well above that of the total economy average, but in the 1970s and 1980s coal mining's relative level of real labour productivity was near the all industries average, and in the 1960s coal mining was less than half as productive as the total economy based on output per hour estimates in 1992 constant dollars.[30] The turnaround has been due to phenomenal productivity growth in the 1960s, 1980s and 1990s (Chart 4).

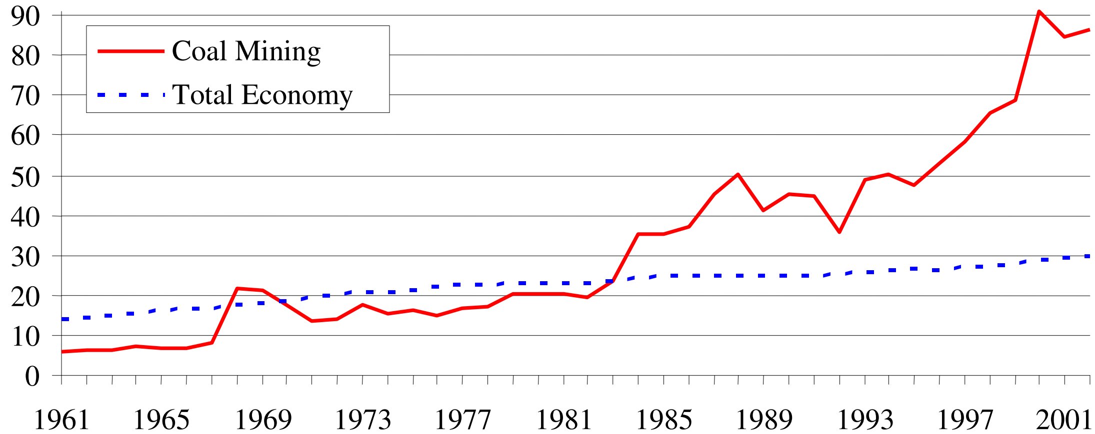
In the 1960s (1961-1973), output per hour advanced at an average annual rate of 9.3 per cent per year in coal mining, towering over the all industries average of 3.4 per cent per year and the average for all mining industries of 4.9 per cent per year. This growth gap allowed the coal mining industry to increase its productivity level relative to all industries from 44 per cent in 1961 to 85 per cent in 1973.

The decade of the 1970s (1973-1981) was a poor time for productivity growth for virtually all industries, and coal mining was no exception. After the impressive performance of the 1960s, output per hour growth in coal mining fell to just 1.7 per cent per year, albeit still somewhat higher than total economy labour productivity growth of 1.2 per cent per year. The first oil price shock of 1973 lead to a sharp increase in the

[30] Comparisons of productivity levels should ideally be made based on estimates in current dollars, which account for changes in relative prices over time. Since the real price of coal was lower in 1992 than it was in 1961, the true level of coal mining output per hour in 1961 relative to that of the total economy is higher than that implied by comparisons based on 1992 dollar estimates. Nonetheless, the point remains that there was a large upward shift in coal mining's labour productivity level relative to that in the total economy between 1961 and 2000.

demand for coal, and the consequent higher prices encouraged the exploitation of poorer quality coal reserves. The increased effort required to extract these reserves had a diminishing effect on coal mining productivity growth.

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



Source: CSLS (2003:Table 33).

By 1981 the price of coal had stopped rising, and the 1980s (1981-1989) saw a return to the 1960s output per hour growth rate of 9.3 per cent per year (Table 2). The total economy saw output per hour grow by only 1.0 per cent per year over this same period, and by 1989, coal mining's labour productivity level was 166 per cent that of all industries.

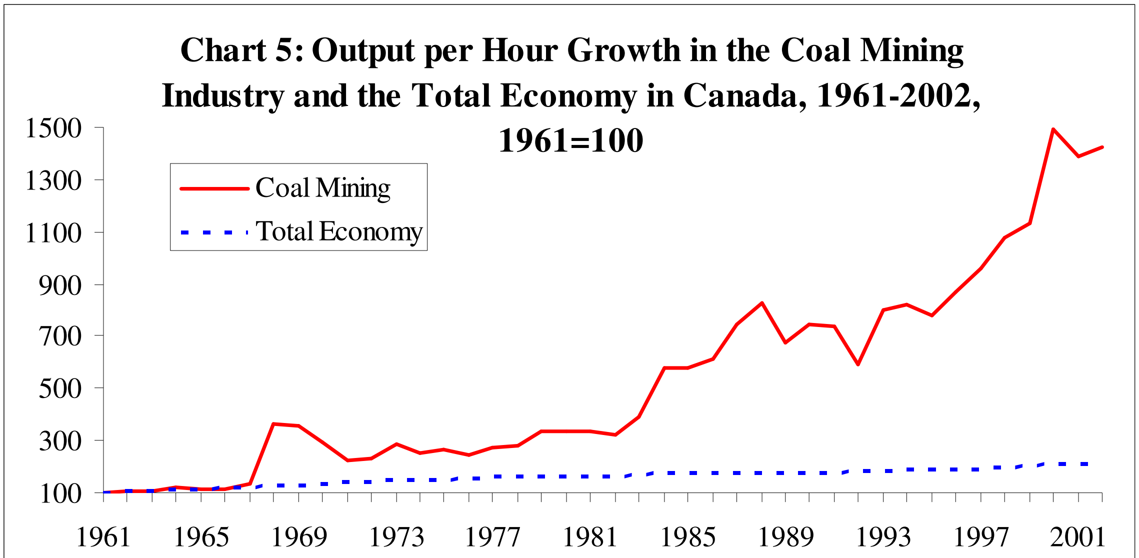
Table 2: Productivity Growth in the Coal Mining Industry in Canada, 1961-2000, compound average annual growth rates, per cent

	Output per Hour	Output per Unit of Capital Stock	Total Factor Productivity
1961-2000	7.18	1.00	3.66
1961-1973	9.29	-5.61	0.64
1973-1981	1.71	0.17	0.84
1981-1989	9.30	6.65	7.80
1989-2000	7.44	5.13	6.14
1989-1995	2.38	4.10	3.34
1995-2000	13.85	6.38	9.59

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

Output per hour growth for the 1989-2000 period was a strong 7.4 per cent per year in coal mining. This compares to 1.4 per cent per year for the total economy and 4.6 per cent per year for mining. For coal mining this includes weaker productivity growth of 2.4 per cent per year for the 1989-1995 period, following the recession of the early

1990s, and incredible 13.9 per cent per year average annual growth for the 1995-2000 period. For the overall 1961-2000 period, output per hour growth in coal mining was extremely rapid relative to the total economy, at 7.2 per cent per year compared to 1.9 per cent per year (Chart 5).



Source: CSLS (2003:Table 33).

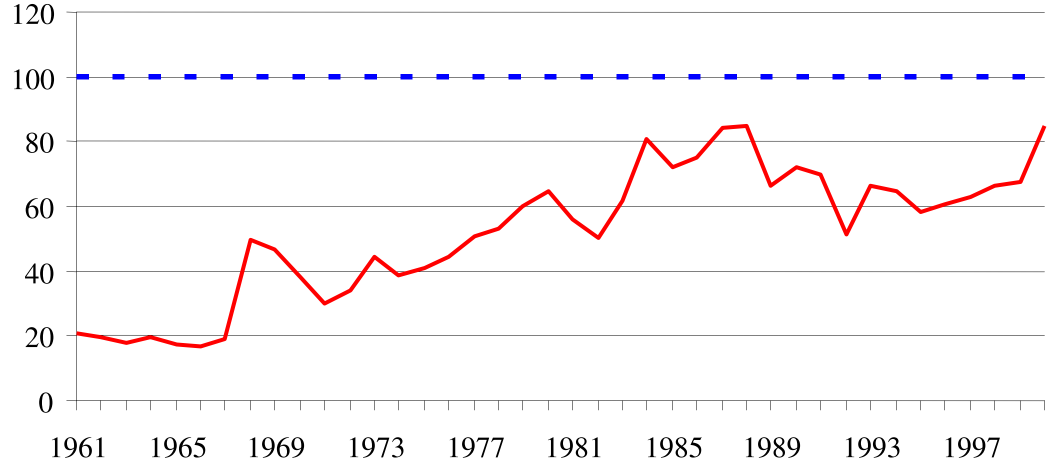
Canada's coal mining industry appears to have performed fairly well in terms of labour productivity growth relative to other countries as well as to other Canadian industries. Data from the U.S. Bureau of Labor Statistics show that output per hour growth in the U.S. coal mining industry for 1961-2000 was 3.4 per cent per year.[31] This compares to growth of 7.2 per cent per year for the Canadian coal mining industry, more than twice as fast as growth in the U.S. industry. For the more recent 1989-2000 period, the growth rates were 5.0 per cent per year in the United States and 7.4 per cent per year in Canada. The International Labour Organization (2002) reports that labour productivity in coal mining increased by over 100 per cent in Canada, India and the United States between 1985 and 2000. Australia and South Africa performed even better though.

Global Economics (2001) reports that Canada's level of coal mining labour productivity was about 85 per cent that in the United States in 2000 (i.e., 5.9 tonnes of coal were produced per hour of work in the United States, compared to 5.0 tonnes per hour of work in Canada). Combining this level estimate with estimates of productivity growth in each country shows that this labour productivity relative of 85 per cent in 2000 is about the same as that achieved in 1989, meaning that the incredible output per hour growth of the Canadian coal mining industry in the 1990s was matched by an equally strong performance in the U.S. industry (Chart 6). But the high levels of labour productivity relative to the United States after the late 1980s represent a significant

[31] These data are from the Industry Productivity and Costs program of the U.S. Bureau of Labor Statistics. A series based on the U.S. SIC has been linked to a NAICS-based series in 1987. Data are available at www.bls.gov, and the NAICS data for 2001 are also available in Bureau of Labor Statistics (2003).

turnaround from earlier decades. In 1961 the level of output per hour in the coal mining industry in Canada relative to the United States was only 20 per cent.

Chart 6: Relative Level of Output per Hour in Coal Mining in Canada, 1961-2000, United States = 100



Source: Statistics Canada, Bureau of Labor Statistics, CSLS.

B. Capital Productivity

Output per unit of capital stock showed strong declines in coal mining in the 1960s, falling by 5.6 per cent per year between 1961 and 1973 (Table 2). Capital productivity growth in all industries was 1.1 per cent per year in 1961-1973. Capital productivity growth in coal mining began to rebound in the 1970s, growing by an average annual rate of 0.2 per cent per year, compared to declines of 5.2 per cent per year in all mining industries and 0.8 per cent per year in the total economy. After 1981, capital productivity in coal mining, like labour productivity, grew rapidly.

C. Total Factor Productivity

Total factor productivity in coal mining was weak in the 1960s and 1970s at the same time that labour productivity growth was strong, explained by the rapid growth in this period of the capital stock. TFP growth rebounded sharply in the 1980s and continued with strong growth in the 1990s. 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 (Table 2). 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 Coal 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 by far the most important component of labour productivity growth in coal mining since 1981 has been total factor productivity. One view on 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 – along with the bias of restricting production to exhibit constant returns to scale – 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.

First, however, it is worth briefly mentioning capital intensity's contribution to output per hour growth in coal mining. Growth in capital stock per hour worked accounted for almost all of labour productivity growth in the 1960s and early 1970s (1961-1973) and about half of labour productivity growth in the 1970s (1973-1981). Its contribution after 1981, although large in absolute terms, was much smaller in relative terms. In the 1960s, growth in the engineering capital stock per hour worked was the most important contributor to output per hour growth, followed by growth in building capital stock per hour worked and in machinery and equipment capital stock per hour worked. The engineering capital stock for mining industries includes exploration and site development activity, implying that the extremely high productivity growth of this period may have been driven by the search for and subsequent exploitation of high quality reserves. In general, the high contribution of capital intensity suggests that production in the 1960s was driven by adoption of new machinery and increased investment in haulage and conveyance equipment. This type of investment of course continued, at least until the declines of the late 1980s and 1990s, but was overshadowed after the 1960s by other factors.[32]

[32] 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 rather limited contributions made by capital intensity in the 1980s and 1990s should not be regarded as wholly accurate. However, these objections do not obviate the need to examine other factors contributing to labour productivity growth.

Table 3: Average Annual Growth in Output per Hour and its Components in the Coal 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	7.18	3.66	6.12	6.48	6.51	4.46
1961-1973	9.29	0.64	15.78	17.16	16.33	13.33
1973-1981	1.71	0.84	1.53	1.10	1.83	0.84
1981-1989	9.30	7.80	2.48	3.08	3.21	-1.17
1989-2000	7.44	6.14	2.20	2.00	2.26	2.09
	2) Absolute Contributions to Output per Hour Growth, percentage points					
1961-2000	7.18	3.66	3.44	0.55	2.49	0.42
1961-1973	9.29	0.64	8.87	1.38	5.97	1.55
1973-1981	1.71	0.84	0.86	0.09	0.69	0.09
1981-1989	9.30	7.80	1.40	0.28	1.21	-0.11
1989-2000	7.44	6.14	1.24	0.17	0.90	0.16
	3) Relative Contributions to Output per Hour Growth, per cent					
1961-2000	100	51.0	47.9	7.6	34.8	5.9
1961-1973	100	6.9	95.5	14.8	64.3	16.7
1973-1981	100	49.3	50.4	5.1	40.2	5.3
1981-1989	100	83.9	15.0	3.0	13.0	-1.2
1989-2000	100	82.5	16.6	2.3	12.1	2.2

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.

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, the effects of possible increasing returns to scale, and so on.

As discussed above, the limited evidence available suggests that the coal mining workforce is highly skilled. Average years of education per worker are slightly above 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 mining workers since they generally do not embody skills germane to the type of labour required of miners. A more relevant distinction may be post-secondary certificates, since colleges and trade schools are more focused on teaching skills directly. 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. There is no doubt that these credentials are important in maintaining the relatively high level of output per hour in the coal mining industry, and that their gradual growth has played a part in productivity growth. It is therefore reasonable to suppose that skills have accounted for a proportion of measured TFP growth.

It is possible that some coal mines experience increasing returns to scale – i.e. a doubling of all their production inputs would lead to more than a doubling of coal production – but that it is not possible for these mines to reach optimal scale due to the fixed geology and organization of the mining site. In these circumstances the contribution of TFP growth to output per hour growth would be less in periods in which capital and labour were both increasing. Correspondingly, the contribution of capital intensity during these periods would be higher, which follows since by the nature of increasing returns, the additional capital and labour would increase output more than proportionately. Therefore, a further cause of upwardly biased measured TFP growth, at least in the 1970s and 1980s before the capital stock began to decline, may be the existence of increasing returns to scale. This would in turn imply that the capital-driven productivity growth of the 1960s continued at least in part into the 1970s and 1980s. There is some evidence of increases in the size of operations in the 1970s and to a lesser extent in the 1980s. The average number of jobs per coal mining establishment was 115 in 1961, which rose rapidly to 224 in 1973 and 427 in 1981, and then declined slightly to 378 in 1989 and further to 308 in 2001.

As has been mentioned previously, the price of coal may also be driving part of the output per hour performance of the coal industry, and this effect would be captured in the catch-all TFP growth. When the real price of coal increases, as it did sharply in the mid-1970s, it becomes profitable to mine coal seams that were previously unprofitable to mine due to high costs, e.g. in removing overburden or in sinking deep shafts. These mine sites typically require high labour input to produce a comparable amount of output to sites with richer and more easily accessible deposits. As such, the lower labour productivity of these new mines decreases the average labour productivity of the overall industry. This price effect may partially explain the low productivity growth of the 1970s and the extraordinary growth of the second half of the 1990s. The real price of coal has fallen steadily since the mid-1970s, but the pace at which it has declined accelerated somewhat in the second half of the 1990s relative to the first half. This may have pushed some smaller and less productive mines across the line of profitability, thereby increasing the average productivity of the overall industry.

One other contribution to the acceleration in coal mining output per hour growth in the second half of the 1990s may be the gradual closing of the mines in Cape Breton. These mines tended to be of smaller scale, and small-scale underground mining is in general less productive than large-scale open-pit operations.[33] This last observation, along with the probable link between declines in the price of coal and the closure of less productive mines, is certainly borne out by the declining number of coal mining establishments in Canada throughout the second half of the 1990s, from 34 in 1995 to 21 in 2001.

A final driver of measured TFP growth indeed appears to be technological advance. Although embedded in the engineering capital stock, conveyor and haulage systems represent a process innovation not captured by investment expenditures. Further, many investments in the 1970s were made in part to comply with safety regulations, and it appears that a safer work environment – captured partially in the incidence of workplace injuries and fatalities statistics – has paid off in terms of higher labour productivity. Safer mines are less prone to suspensions in production, and allow workers to concentrate more fully on their primary tasks. In the 1990s, although investment in coal mining declined, it is likely that the investment that did take place was in advanced software and computer systems. These investments have provided an ability to plan and implement optimal extraction strategies not previously available.

C. Summary of Labour Productivity Drivers by Decade

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

- **1960s:** strong labour productivity growth driven by strong capital intensity growth (new operating processes, conveyor systems and larger vehicles).

- **1970s:** weak labour productivity growth, partly attributable to labour disputes and adaptation to new regulations, but driven primarily by high demand for coal, which increased the price of coal and encouraged the exploitation of marginal reserves.

- **1980s:** a return to very high productivity growth, but not due to capital deepening as in the 1960s. Rather, falling prices forced mines on less productive sites to close, while the transition from underground to higher-productivity surface mines was also taking place.

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[33] Indeed, the Energy Information Administration (2002:Table 7.6) shows that surface mines in the United States had a higher level and faster growth rates of labour productivity than underground mines over the entire 1949-2002 period.

- **1990s:** weak productivity growth in the first half of the decade but exceptional growth in the latter half. Prices continued to fall, but the more important driver seems to be technology, with the computerization of most operations.

Conclusion

Coal mining has had a phenomenal record in terms of labour productivity growth. For the past two decades, growth in output per hour has been on the order of 8 per cent per year or more, exceeding the total economy average by a factor of five. Such strong productivity growth was also evident in the 1960s, with the only period of weak growth being the decade or less following the first oil price shock.

One important driver of this impressive growth appears to be technological advance. Although mining industries tend to undertake very little research and development on their own, there is a continual absorption of new technology and processes through the purchase of new equipment. R&D within sectors producing equipment used by the coal industry hence has a larger impact on coal mining productivity growth, especially when the coal mining industry has incentives to invest in the most up-to-date equipment available coupled with training programs in the effective use of such new equipment. The most important of such investments in recent years appears to be those made in computer systems, both for controlling and monitoring operation and in detailed extraction planning.

It is also important to stress once again the high quality of the coal mining workforce and the role that these skilled workers have played in maintaining the level and growth of output per hour in coal mining much above the average for all industries. Continued growth in the proportion of the coal mining workforce with post-secondary experience will have beneficial productivity effects, especially in combination with increased computerization of the mining process.

A final mention should be made of the apparent effect of the real price of coal on productivity in the coal mining industry. The sluggish productivity growth in the 1970s and the strong growth in the 1990s have been accompanied respectively by a sharp increase in the CPI-deflated price of coal and by persistent declines in this price in the 1990s. Especially in the second half of the 1990s, the low and falling real price of coal appears to have given lower-productivity mines an incentive to close, leaving only the most productive mines in operation.

References

Andrews-Speed, Phillip and Christopher D. Rogers (1999) "Mining Taxation Issues for the Future," *Resources Policy* volume 25, p. 221-227.

Anton, Frank R. (1981) *The Canadian Coal Industry: Challenge in the Years Ahead*, (Calgary:Detselig Enterprises).

Asafu-Adjaye, J. and R. Mahadevan (2003) "How Cost Efficient are Australia's Mining Industries?" *Energy Economics* volume 25, p. 315-329.

Boadway, Robin, Neil Bruce, Ken McKenzie and Jack Mintz (1987) "Marginal Effective Tax Rates for Capital in the Canadian Mining Industry," *Canadian Journal of Economics* volume 20, number 1 (February), p. 1-16.

Boyd, Gale A. (1984) *Scale and Productivity in Coal Strip Mining*, PhD dissertation, Southern Illinois University – Carbondale.

Boyd, Gale A. (1987) "Factor Intensity and Site Geology as Determinants of Returns to Scale in Coal Mining," *The Review of Economics and Statistics* volume 69, number 1 (February), p. 18-23.

Brewer, Keith J., Gilles Bergevin and Louis P. Arseneau (1999) "Mineral Policy and Comparative Fiscal and Taxation Regimes for Mining," in Eugenio Figueroa B. ed., *Economic Rents and Environmental Management in Mining and Natural Resource Sectors*, University of Chile and University of Alberta, p. 245-271.

Brown, C. and J. Medoff (1978) "Trade Unions in the Production Process," *Journal of Political Economy* volume 86, number 4, p. 355-378.

Bureau of Labor Statistics (2003) *News*, USDL 03-490, Thursday, September 18.

Castrilli, Joseph F. (1999) "Environmental Regulation of the Mining Industry in Canada: An Update of Legal and Regulatory Requirements," Walter & Duncan Gordon Foundation, available at http://www.gordonfn.org/resources.cfm.

Centre for the Study of Living Standards (2003) "Productivity Trends in Natural Resources Industries in Canada," CSLS Research Report number 2003-01, February, available at www.csls.ca under Research Reports.

Centre for the Study of Living Standards (2004) "Report on Productivity Trends in Selected Natural Resource Industries in Canada," CSLS Research Report number 2004-06, October, available at www.csls.ca under Research Reports.

Chaykowski, Richard P. (1992) "Industrial Relations in the Canadian Mining Industry: Transition Under Pressure," in Richard P. Chaykowski and Anil Verma eds., *Industrial Relations in Canadian Industry*, (Toronto:Dryden), p. 141-185.

Chezum, Brian and John E. Garen (1998) "Are Union Productivity Effects Overestimated?: Evidence from Coal Mining," *Applied Economics* volume 30, p. 913-918.

Clement, Wallace (1983) *Class, Power and Property: Essays on Canadian Society*, (Toronto:Methuen).

Commonwealth Scientific and Industrial Research Organisation (1998) "Roof Bolting System for Coal Mine Safety, Productivity," Media Release ref 98/286, December 7. Available at www.csiro.au under Media.

Cranstone, Donald (2000) "Canada's Rank in World Mining," *Canadian Minerals Yearbook, 2000*, Natural Resources Canada, p.63.1-63.7.

Dahlby, Bev (1999) "Taxation of the Mining Sector in Canada," in Eugenio Figueroa B. ed., *Economic Rents and Environmental Management in Mining and Natural Resource Sectors*, University of Chile and University of Alberta, p. 273-298.

Darmstadter, Joel (1999) "Innovation and Productivity in U.S. Coal Mining," in R. David Simpson ed., *Productivity in Natural Resource Industries: Improvement Through Innovation*, (Washington, D.C.:Resources for the Future), p. 35-72.

Denison, Edward F. (1985) *Trends in American Economic Growth, 1929-1982*, (Washington, D.C.:Brookings Institution).

Ellerman, Danny, Thomas M. Stoker and Ernst R. Berndt (2001) "Sources of Productivity Growth in the American Coal Industry: 1972-95," in Charles R. Hulten, Edwin R. Dean and Michael J. Harper eds., *New Developments in Productivity Analysis*, (Chicago and London:University of Chicago Press).

Energy Information Administration (2002) *Annual Energy Review 2002*, Office of Integrated Analysis and Forecasting, U.S. Department of Energy. Available at http://tonto.eia.doe.gov/FTPROOT/multifuel/038402.pdf.

Flynn, Edward J. (2000) "Impact of Technological Change and Productivity on the Coal Market," *Issues in Midterm Analysis and Forecasting 2000*, Energy Information Administration, Department of Energy.

Global Economics (2001) *Mining Innovation: An Overview of Canada's Dynamic, Technologically Advanced Mining Industry*, prepared for the Mining Association of Canada, November.

Humphris, Robert D. (1999) "The Future of Coal: Mining Costs & Productivity," in *The Future Role of Coal: Markets, Supply and the Environment: Coal Industry Advisory Board Members' Papers and Discussion at the 1998 CIAB Plenary*, (Paris and Washington, D.C.:Organisation for Economic Cooperation and Development and the International Energy Agency), p. 83-88.

International Energy Agency (2003) *Coal Information (2003 Edition)*, IEA and OECD.

International Labour Organization (2002) *The Evolution of Employment, Working Time and Training in the Mining Industry*, document TMMI/2002, (Geneva:International Labour Office).

Kissell, Fred N. (2000) "Insights on Technology Transfer from the Bureau of Mines," *Journal of Technology Transfer* volume 25, p. 5-8.

Kulshreshtha, Mudit and Jyoti Parikh (2002) "Study of Efficiency and Productivity Growth in Opencast and Underground Coal Mining in India: A DEA Analysis," *Energy Economics* volume 24, p. 439-453.

Lonmo, Charlene (2003) "Measuring Concentration of R&D Spending by Industry," *Innovation and Analysis Bulletin* (Statistics Canada catalogue number 88-003) vol. 5 no.3, October, p.16-19.

Mefford, R. N. (1986) "The Effect of Unions on Productivity in a Multinational Manufacturing Firm," *Industrial and Labor Relations Review* volume 40, number 1, p. 105-114.

Merrell, David R. (1999) "Productivity and Acquisitions in U.S. Coal Mining," Centre for Economic Studies Working Paper number CES 99-17, Bureau of the Census.

Mining Association of Canada (1999) *Innovation in the Canadian Mining Industry, 1999 Survey*, prepared by the Impact Group.

Mining Association of Canada (2003) *Environmental Progress Report 2003*.

Naples, Michele I. (1998) "Technical and Social Determinants of Productivity Growth in Bituminous Coal Mining, 1955-1980," *Eastern Economic Journal* volume 24, number 3 (Summer), p. 325-342.

Peterson, D. J., Tom La Tourrette and James T. Bartis (2001) *New Forces at Work in Mining: Industry Views of Critical Technologies*, RAND working paper number MR-1324-OSTP.

Pippenger, Jack (1995) "Competing with the Big Boys: Productivity and Innovation at the Freedom Lignite Mine," *Mining Engineering* (April), p. 333-345.

Richardson, P. R. (1976) *The Role of Innovation in the Mining and Mining Supply Industries*, report number MT 146, Department of Energy, Mines and Resources, Ottawa.

Romer, Paul (1987) "Crazy Explanations for the Productivity Slowdown," *NBER Macroeconomics Annual 1987*, p. 163-202.

Schaan, Susan (2002) *Innovation and the Use of Advanced Technologies in Canada's Mineral Sector: Metal Ore Mining*, Science, Innovation and Electronic Information Division working paper, Statistics Canada catalogue number 88F0006XIE No. 13, July.

Statistics Canada (2000) *Investment and Capital Stock: Main Changes in the Estimating Methodology Introduced in 2000*, non-catalogue publication provided by Flo Magmanlac of the Capital Stock Section of the Investment and Capital Stock Division at Statistics Canada. Updated version of the methodological introduction to *Fixed Capital Flows and Stocks, 1961-1994, Historical*, catalogue number 13-568.

Statistics Canada (2001) *Econnections: Linking the Environment and the Economy – Indicators and Detailed Statistics 2000*, catalogue number 16-200.

Uhrbach, Mark and Bryan van Tol (2004) "Information and Communication Technology Use: Are Small Firms Catching Up?" Statistics Canada Analytical Paper, catalogue number 11-621-MIE no. 009.

Winfield, Mark, Catherine Coumans, Joan Newman Kuyek, François Meloche, and Amy Taylor (2002) *Looking Beneath the Surface: An Assessment of the Value of Public Support for the Metal Mining Industry in Canada*, (Ottawa:MiningWatch Canada and the Pembina Institute), October.