Path Dependence, Fragmented Property Rights, and the Slow Diffusion of High Throughput Technologies in Interwar British Coal Mining

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The rise and decline of the coal industry occupies a central place in Britain’s industrial history. At its peak, immediately before and after the First World War, it constituted the largest industrial employer of male labour, around one in twelve of the population being directly dependent on it, while providing a key input to other industries and an important contribution to exports. Yet during the interwar years the industry witnessed a dramatic decline. By 1937 its employment and tonnage exported had fallen to only 63.1 per cent and 66.3 per cent of their 1924 values.¹ This was the product of a number of developments, including adverse movements in the demand for coal and the growth of international protectionism. Yet a major factor behind the British industry’s declining international competitiveness was its poor productivity growth. This, in turn, appears to have been closely associated with the slow diffusion of mechanization and associated production techniques.

One major strand of research into the industry’s performance has focused on the substantial regional differences among the British coalfields in work organization, geology, and other mining conditions. Such analysis, drawing principally on wide regional differences in the diffusion of mechanical coal-cutting, has suggested that Britain’s poor aggregate productivity performance was due, at least in part, to certain ‘problem regions’ where specific conditions inhibited mechanization.² Indeed, if government intervention, most notably through the 1930 Coal Mines Act, had not limited industrial restructuring, it has been argued, the increased concentration of the industry in the newer and more environmentally-favoured coalfields of Yorkshire and the North Midlands would have increased productivity growth towards the European average.³
This article demonstrates that, while major geological differences did exist between the British coalfields, their interwar productivity growth was bunched towards the bottom of the European league table. This was largely due to the fact that they faced a common problem, of over-riding importance in inhibiting the development of mechanised mining throughout the British industry – the inability to mechanize main haulage (haulage on roadways delivering coal directly to the shaft). As the most authoritative contemporary technical appraisal of the pre-nationalisation coal industry, the 1945 Reid Committee Report, emphasised, unmechanized main haulage placed a key bottleneck on throughput, which both inhibited mechanization further ‘upstream’ and imposed a productivity ceiling on the mechanised technology that was introduced.4

Britain’s coal industry had become ‘locked-in’ to sub-optimal technology, via processes which have been illuminated in the literature on path dependence. Path dependence refers to dynamical, stochastic, systems in which local positive feedbacks provide self-reinforcing mechanisms directing the system towards particular outcomes, typically selected by the persisting consequences of transient conditions prevailing during the early history of the process.5 As time progresses an industry’s installed base of technology selected to meet these transient conditions will become increasingly important in determining current choices regarding interrelated capital investment, inhibiting the introduction of superior new technology that is not compatible with existing plant.6 Charles Kindleberger identified two forms of interrelatedness; technical interrelatedness - the need to modify various stages of a production process to accommodate a new technology; and institutional interrelatedness - the additional obstacles to modification arising from fragmented ownership of that process.7 Fragmentation can impede technical change either due to coordination and transactions cost problems and/or as
a result of a-symmetries in the costs and benefits faced by the different parties.\textsuperscript{8}

The following section compares Britain’s interwar productivity experience with that of other European coalfields, demonstrating that all British coalfields had poor productivity growth compared to the European average, while their productivity levels fell below those of coalfields where the inherent difficulties of coal extraction were regarded as being on a par with Britain. Poor productivity growth is shown to have stemmed from the inability to mechanise haulage on main and secondary underground roadways, that both placed a ceiling on the potential productivity of mechanization further upstream and prevented the development of fully-mechanized mining. This, in turn, stemmed from institutional interrelatedness between British mine development practice and its unique system of fragmented mineral royalties.

II

In contrast to Britain, the major European coal producers enjoyed rapid interwar productivity growth. Between 1913 and 1936 the Netherlands increased output per man-shift (O/S) by 117.20 per cent, while increases of 81.34 per cent were recorded in the Ruhr; 72.46 per cent in Polish Upper Silesia; 50.57 per cent in Belgium; 50.31 per cent in Czechoslovakia, 22.40 per cent in France (Pas de Calais); but only 9.63 per cent in the UK.\textsuperscript{9} While in 1913 Britain’s O/S was only exceeded by the USA and Polish Upper Silesia (both of which had exceptionally good geological conditions), by 1936 it had also been overtaken by the Ruhr, Netherlands, and Czechoslovakia.

To what extent is Britain’s poor productivity growth due to certain problem regions, which mask the more respectable record of its other coalfields? Table 1 compares O/S for all
British and European coalfields for which data are available, ranked according to their 1913-37 O/S growth. No British coalfield other than Lancashire, North Staffordshire and Cheshire (LNC) manages to beat the growth performance of any continental coalfield, while even this region fails to match the European average. The British `1913’ data are based on a single month (June 1914) and a sample covering only two thirds of collieries. A comparison was therefore also made using the earliest interwar base year for which data are available for most coalfields, 1923. The British coalfields are again grouped at the bottom of the growth league, even LNC ranking above only a single continental producer – France. Finally, growth over the period 1923-29 is examined, as this excludes any suppression of British productivity growth arising from output restrictions under the 1930 Coal Mines Act. It also shows British O/S growth in a particularly favourable light, since it includes a significant increase in working hours following the British miners’ defeat in the 1926 strike. Yet even on this basis all British coalfields for which data are available have growth substantially below the European average.

International comparison of mining productivity is complicated by the importance of natural conditions in determining potential productivity. Contemporary expert opinion, both in the UK and overseas, identified the USA and Upper Silesian coalfield as having superior conditions to Britain, though Britain was ranked ahead of most European coalfields and at least on a par with Holland and the Ruhr, which were viewed as the best comparators for assessing Britain’s mining productivity record. In 1927 Holland and the Ruhr had roughly similar O/S to Britain, 1.02 and 1.13 metric tons respectively compared to Britain’s 1.05 metric tons (and values for individual coalfields ranging from 0.84-1.16 metric tons). However, by 1937 they had increased O/S to 1.77 and 1.63 metric tons respectively, compared to Britain’s 1.19 metric tons (with even the best coalfield achieving only 1.34 metric tons).
Comparing productivity in terms of output per hour (O/H) would portray Britain in an even less favourable light. Greasley estimated that hours worked per shift by hewers declined from 8.65 for most British coalfields immediately prior to the First World War to around 8.15 during the 1930s.\textsuperscript{13} Meanwhile most continental coalfields had experienced larger falls in working hours; between 1913 and the mid-1930s shift lengths had declined from 9-10.5 hours to 8 hours 2 minutes in Poland, from 9.5 hours to 7 hours 20-28 minutes in Czechoslovakia; from 9 hours to 8 hours 10 minutes in the Netherlands; from 9 to 7.75-8.25 hours in France; and from 9 hours to 7 hours 50-55 minutes in Belgium. In the Ruhr the shift length fell from 8.5 hours in 1913 to 8 hours in the mid-late 1920s, and 8 hours exclusive of winding time by the mid-1930s.\textsuperscript{14}

Productivity comparisons would, of course, ideally be made in terms of total factor productivity (TFP) rather than labour productivity. Unfortunately no TFP estimates are available for continental coalfields (or for British coalfields – other than at the coalface).\textsuperscript{15} However, British coalfield-level data provide an indication of the relative impact of mechanization on labour and other costs. Table Two compares the growth of mechanization in six British coalfields (ranked according to the increase in the proportion of coal mechanically conveyed), together with changes in costs per ton of coal mined, from 1927-37. The two areas that exceed the national average for the growth in mechanical conveyance (the best available proxy for overall mechanization, as discussed below) over this period, LNC and Yorkshire, also achieved the highest reductions in production costs. These mainly arose from labour cost savings, though other costs also fell. While differences in cost changes between coalfields were influenced by a number of factors, the Table does demonstrate that mechanisation (at least for upstream operations) was not associated with any significant increase in non-labour costs. Furthermore,
given that British collieries had considerably higher wages than their continental counterparts, labour-saving capital investment in mechanization should have had a greater relative impact on TFP in Britain, *other things being equal.*

[Table 2 near here]

Yet the mechanization of British coalfields lagged considerably behind their overseas rivals. While the United States was exceptional in mechanizing a high proportion of its bituminous coal production prior to the First World War, during the interwar years Britain’s major European competitors embarked on major mechanization programmes. Even when examined in terms of coal-cutting (which, as will be discussed below, portrays Britain in an unduly favourable light), Britain lagged well behind most major European producers. In 1930 31.1 per cent of British coal was mechanically cut, compared to 93.8 per cent in the Ruhr; 91.4 per cent in Belgium; 78.7 per cent in Czechoslovakia; over 72 per cent in France (Pas-de-Calais); and 32.1 per cent in Polish Upper Silesia. More importantly, while its principal competitors rapidly mechanized underground haulage, with locomotives becoming their standard main haulage technology, Britain failed to do so.

**III**

The heterogeneity of `natural conditions’ also greatly complicates the task of assessing the relative performance of different production technologies by means of contemporary evidence from individual collieries or trials. The thickness, hardness, friability, inclination, and faulting of coal seams, together with floor and roof conditions, can all have a significant bearing on productivity and vary not just between coalfields, but between collieries, or even different
seams of the same colliery. To minimise these difficulties, this paper uses results regarded by the British mining engineering community as broadly representative of typical colliery conditions. British mining engineers placed considerable emphasis on appraising alternative technologies via a process of ‘collective learning’, involving publishing data on experiments and experience with new methods, which were then submitted to verbal and written peer discussion. Both the papers and their discussion at regional meetings of mining engineers (together with subsequent written comments) were reproduced in a national Transactions of the federated regional mining engineering institutes. Papers ranged from the experience of single mines to major exercises, such as an examination of underground conveying that drew data from 25 collieries. Research for this paper has involved a comprehensive review of all articles included in the Federation’s Transactions from its establishment to 1939 (together with their appraisal by the engineering community), plus other technical publications such as Colliery Engineering and The Colliery Guardian. Results reported below are selected to represent the consensus among mining engineers regarding both the potential of mechanized technology and the barriers to its introduction.

The diffusion of mechanized undercutting of coal seams (sometimes supplemented by mechanised conveying of coal at the coalface) has been widely used as the yardstick for judging Britain’s coal mechanization record and regional variations in mechanization. However, there are severe drawbacks in using these as proxies for the growth of mechanized mining. Mechanized mining was defined, even during this period, as the introduction of high throughput systems involving the entire cycle of getting the coal, conveying it to the loading road, transporting it by auxiliary haulage and then main haulage to the shaft, winding it to the surface and returning the empty tubs. As the Colliery Yearbook noted in 1923, these ‘various stages are
interdependent and must therefore be properly synchronised. The rate of the flow of coal from
the face to the surface and the return of the empty trams is restricted by the slowest process in
the cycle’. 21

Coal-cutters and, to a lesser extent, face conveyors, were often adopted in Britain for
reasons not connected with throughput. Mechanized cutting offered three major advantages.
First, it represented a ‘niche’ technology for very thin or hard seams, where manually
undercutting the coal with a pick proved difficult (face conveyors also initially represented a
niche technology - for thin seams where it was difficult to bring wagons along the face). 22
Secondly, mechanized cutting was a quality-enhancing technology, as it produced a larger
proportion of round coal, particularly in thin seams. This was more highly valued (where coal
was not carbonized) on account of its greater thermal efficiency. Finally, coal-cutters offered
substantial increases in throughput.

The salience of mechanized cutting as a component in a mechanized mining system
cconcerned only this final factor. However, especially during the early diffusion of coal-cutters in
British mines, the first two factors generally proved the main motivations. 23 Taking coal-cutting
as the yardstick for mechanization greatly exaggerates regional differences in the overall
mechanization process. Coalfields had varying incentives to adopt cutters, depending on the
thinness and hardness of their seams and the proportion of their coal that was carbonized. An
extreme example was South Wales, where coal was particularly easy to bring down using hand-
methods and mechanization was therefore often led by face conveying rather than coal-cutting.
Regional differences in the diffusion of cutting are consequently poorly correlated with those for
downstream mechanization. Regressing county-level data for the proportion of coal face-
conveyed against the proportion mechanically-cut in 1936 produces an adjusted $R^2$ of only
The relationship with mechanization further downstream is even weaker. For example by 1931 Scotland, which had pioneered cutters in thin seams, had 67 per cent of its coal mechanically cut, compared to a national average of 35 per cent. Yet only 12 per cent of coal was conveyed at the loading gate, a mere 3.6 percentage points above the British average.\textsuperscript{25}

The productivity advantages of mechanized coal-cutting and face conveying were, of course, considerable, but only where subsequent haulage arrangements allowed them to reach their potential throughput. From the early years of mechanization it became apparent that this was to be a major problem for British collieries. As one commentator noted in 1906, in thicker seams cutter output was restricted by the ability to clear coal from the face; only in thin seams did filling keep pace with cutting.\textsuperscript{26} Face conveyors merely moved this problem one step further downstream. As the coal machinery manufacturer and consultant Sam Mavor noted, poor haulage was, `the rock on which ambitious schemes of face-conveying have not infrequently been wrecked… it is futile to install face machinery [producing an output] ... in excess of the capacity to transport it'.\textsuperscript{27}

\textbf{Table 3 near here}

As Table 3 shows, the proportion of coal conveyed beyond the face did not exceed a third of total output until 1938. Meanwhile locomotive or conveyor haulage further downstream, on secondary and main roadways, represented a negligible proportion of output throughout the interwar period. As a paper presented to the South Staffordshire and Warwickshire Institute of Mining Engineers noted, `Practically every machine-mining lay-out is determined by one limiting factor - haulage - and in very few cases can coal-face machinery work at maximum efficiency owing to this limiting factor'.\textsuperscript{28}

While in continental Europe and the USA locomotives rapidly became standard, on the
By the 1920s locomotives offered considerable advantages over the rope systems generally used in British collieries, on account of their much higher throughput and other important savings in power consumption, labour, flexibility in the locations served (which greatly reduced production losses from mining equipment breakdowns) and their ability to deal with temporary increases in throughput beyond their designated capacity. Contemporary British studies indicated savings of up to 80 per cent from the replacement of endless-rope haulage by locomotives. The locomotive’s crucial throughput advantage was the ability to haul large wagons. Rope haulage could only deal with low capacity ‘tubs’, as it was difficult to clip a large wagon onto a moving rope. During the interwar years British tubs were only a fraction of the size typically used in Europe and the U.S. (where large wagons were successfully employed.
even for thin seams). The most extensive contemporary investigation, encompassing 22 pits in England and Scotland, found that 45 per cent of tubs were below 0.60 long tons [hereafter tons] capacity, while the average tub capacity of the pits surveyed was 0.65 tons. While mechanized cutting and conveying expanded substantially during the following decade, tub capacity showed little change. Despite the observation of a 1927 paper by L. J. Barraclough (based on research visits to British and overseas coalfields), that tubs of 0.5 tons or less, `should be seen only in museums exhibiting mining antiquities`, a follow-up survey in 1937 indicated an average load per tub of only 0.58 tons.

Small tubs proved inefficient in a number of important respects. They constrained the capacity of conveyors that fed them, owing to congestion and the need to frequently switch between tubs. As one mining engineer stated, in discussion of Barraclough’s paper, ‘We found ... that the tub capacity was nothing like sufficient to make the conveyor a paying proposition, so we took it out. It was standing idle half its time, because we had filled all the tubs we could get hold of’. This problem became particularly severe under intensive mining, where conveyors delivered coal to central loading points at the rate of 1,000 tons or more per shift in many cases; during peak rushes one ton could arrive in 20 seconds. Small tubs were not practicable for such throughput; Barraclough estimated the optimum operation of modern conveyor systems required tubs holding at least two tons.

Small tubs also incurred substantial efficiency losses in their direct haulage operations. It was estimated in a 1915 discussion at the North of England Institute of Mining and Mechanical Engineers that using 0.5 ton tubs increased the laden weight of wagons carrying four tons of coal by 19.9 per cent and their unladen weight by 79.2 per cent compared to a single 4 ton wagon. Friction added to the efficiency gap; each 4 tons of coal entailed the friction of four large wheels
(with efficient roller-bearings) with 4 ton wagons, as against 32 small wheels (with bearings generally of a very crude character) with 0.5 ton tubs. The overall impact of savings in friction and weight was thus considerable, it being estimated that the drawing power required to move 80 tons of coal would be roughly halved by the move from 0.5 to 4 ton wagons.\textsuperscript{41} One colliery estimated that the adoption of 5 ton wagons, together with associated changes in the pit’s rail gauge and winding system, would reduce combined underground and surface haulage costs by about 80 per cent compared to its 0.35 ton tubs.\textsuperscript{42}

An extensive review of contemporary engineering papers and discussions indicates a 50 per cent saving from the use of locomotives in combination with large tubs to be a lower-bound estimate. Poor British haulage productivity was reflected in high labour requirements: the proportion of British mineworkers engaged on haulage during the 1930s remained roughly constant at just over 20 per cent, while in the USA it was less than 5 per cent and in the Netherlands – which instituted an intensive programme of mechanization - it declined from 26.96 per cent in 1926 to 12.41 per cent in 1937, with each haulage worker handling around 4-5 times the tonnage of coal moved by his British counterpart.\textsuperscript{43} Meanwhile the failure to mechanize haulage also increased the costs of delivering men, equipment, and materials to and from the face. A frequent grievance of miners was the long distances they had to travel underground on foot, walking over an hour each way in extreme cases. Yet rope-haulage usually made man-riding impractical.\textsuperscript{44}

Yet the most important impact of retaining rope haulage was the creation of bottlenecks, that limited the efficiency of mechanization further up-stream and blocked the full development of intensive mining. Concentrating extraction in a small area of coalface that was intensively worked proved key to achieving the potential productivity advantages of mechanisation.
Without such concentration, and the high throughput it produced, the heavy fixed costs of mechanized technology negated at least some of its potential savings.\textsuperscript{45} For example a 1929 analysis of 22 collieries using face conveyors revealed that the `intensively-mined' collieries had an O/S to the main haulage that was 45.9 per cent greater than that for the other collieries in the sample.\textsuperscript{46} An essential pre-requisite for truly intensive mining was a haulage system capable of dealing with the high throughput. Small wagons restricted concentration both by being unsuitable for centralised loading stations and by congesting underground roadways. The average haul from the shaft to loading points in British mines during the late 1930s was about one mile. Given a daily output of 1,000 tons, traffic density would be 400 tub-miles with five ton tubs, but rose to 2,000 tub-miles with one ton tubs, and 4,000 tub-miles with 0.5 ton tubs.\textsuperscript{47}

\textbf{IV}

Despite the considerable potential savings and higher throughput from a move to large wagons hauled by locomotives, interrelatedness with underground mining layouts and roadway development systems prohibited their introduction. This is reflected in contemporary mine engineering reports, which identified large potential savings, but found that these were outweighed by the costs of modification. It was not the costs of scrapping and replacing the haulage system, tubs, and tracks that were identified as being prohibitive, but rather the much greater costs of straightening or replacing underground roadways.\textsuperscript{48} As an official report noted, there was `great difficulty in making major alterations to the main lines of underground operations already at an advanced stage. Roadways …in a middle aged mine … often represent a sum of money far in excess of the whole of the company’s share capital'.\textsuperscript{49}

Britain’s seams were relatively flat compared to some European coalfields and should,
therefore, have been more suitable for locomotives – which required reasonably level gradients.

Yet the problem was not one of level seams but of level underground roadways. As an early post-war study by a National Coal Board official noted, `The most efficient method of main-road haulage both for men and materials is by diesel or electric locomotive, but few pits in this country are designed for such working’.  

British underground roadways followed the coal seams in often undulating and tortuous paths, along which locomotives could not operate. Continental mines, by contrast, generally used the `horizon mining’ system of cutting level roadways through the rock. Horizon mining was originally developed to cope with seams that were too steep for coal to be hauled along them. Yet as mine size grew during the late nineteenth and early twentieth centuries it became the standard European mining technique even for relatively flat seams, as it offered various advantages over in-seam mining - improved ventilation, cost savings regarding roadway repairs and `ripping’, and, of crucial and growing importance, suitability for mechanized haulage.

By the twentieth century horizon mining had developed into a system of concentrated face workings, reached by carefully-engineered roadways cut through the rock at a steady slight upward incline from the shaft bottom (typically 1 in 400 to 1 in 500 in the Ruhr and 1 in 300 in the Netherlands, where roller bearings were used). These roadways enabled even low horsepower locomotives to move large tonnages over considerable distances at high speeds, with sufficient throughput to meet the haulage requirements of mechanized, concentrated, mining.

In Britain, by contrast, roadways continued to be developed along the seam, due to institutional interrelatedness between mine development systems and fragmented mineral rights (discussed below). Despite the growth in mine size over the nineteenth century, prior to mechanization the problems arising from the British system did not impose a particularly heavy
efficiency penalty. However, the system entailed much greater costs for mechanized mining, which relied on two key features of horizon mining, concentrated workings – that allowed coal-cutting and other coal-face machinery to be employed at capacity - and straight, level, roadways, suitable for locomotive or conveyor haulage of that capacity output. Even those collieries that embarked on ‘integrated’ mechanization programmes were generally forced to restrict haulage improvements to the deployment of slightly larger wagons, compatible with rope haulage and existing layouts. For example in 1925 the Nostell Colliery in West Yorkshire embarked on a major programme of mechanization, encompassing the complete cycle of mining operations. Yet, despite spending £33,000 on wagons, the average weight of coal per tub only experienced a modest increase from 0.39 tons in 1927 to 0.55 tons in 1936.\footnote{55} Collieries found it more profitable to follow the second-best solution of working mechanised cutters and conveyors below capacity. Extensive time-studies conducted by the Ashington Coal Co. revealed that its endless rope systems created main haulage bottlenecks, limiting effective conveyor running time to only 72-73 per cent of its potential. Yet their replacement by locomotives would have required the driving of new roadways, which would have both incurred considerable expense and interfered with current mining operations.\footnote{56}

Interwar British ‘mechanized mines’ thus constituted a technological compromise, aimed at achieving the maximum benefits from upstream mechanization within the capacity constraints of low throughput haulage systems. Between 1928 and 1936 the proportion of output mechanically cut and conveyed rose from 26 to 55 per cent and 12 to 48 per cent respectively. Yet O/S only increased by 10.6 per cent.\footnote{57} Furthermore, according to estimates by David Greasley, regions such as Durham and Northumberland - with the longest underground roadways (and, therefore, the greatest cost penalty from the rope haulage systems common to all
British coalfields) - achieved the lowest face multifactor productivity growth (despite their very
different coalface mechanization records). Adaption of mechanized techniques in British mines
represented a rational 'second-best' solution - maximising the returns from mechanisation within
the constraints imposed by technological lock-in into extensive in-seam mining. The degree to
which British collieries optimized mechanisation even within these constraints is itself a subject
of vigorous debate – though one that is beyond the scope of this article.

Why had Britain become locked-in to a system of developing underground roadways
along the line of the seam, despite the fact that it prevented the introduction of mechanised main
haulage and, therefore, truly mechanised mining? For older pits, part of the answer lay in their
great age and extensive legacy of previous workings. Britain’s interwar colliery stock was
considerably older than that of any other major coal-producing nation, reflecting its growth peak
in the mid-nineteenth century. In 1925 51.1 per cent of British miners were employed in
collieries over 50 years old and only 26.9 per cent in mines opened since 1895. Very old mines
were often extremely difficult to mechanize. In addition to inappropriate underground layouts
they often had shafts of too narrow diameter to accommodate high throughput; these could not
generally be widened without temporarily closing the mine and incurring considerable costs.

Yet this still left a substantial proportion of more recent mines, developed over the period
when European coalfields had adopted horizon-mining. These should have been much more
suitable for conversion to mechanisation and mass throughput. Shaft capacity for newer mines,
while often less than optimal for mechanized mining, but was normally sufficient for such
systems to be introduced, as shown by the example of the post-nationalisation coal industry. Despite the further development of high throughput mining techniques, as late as the early 1980s the average diameter of British mine shafts, 5.7 metres, was not greatly in excess of that at the time of nationalisation, (typically ranging from 4.9 metres (or less) for older shafts to 6.4 metres for the best modern collieries). The highly-mechanised interwar Dutch industry had shafts of 5.8 metres. Meanwhile the Ruhr’s transition to mechanized mining involved existing shafts, that were considered relatively narrow by American standards. In some cases skip winding was introduced, though often simpler modifications were made – such as fitting additional decks to cages or fitting four cages into the same shaft. Mechanized haulage increased effective shaft capacity. For example, one British colliery found that each new one ton tub occupied the same space in its winding cage as two existing 7 cwt. tubs, enabling its daily output to be drawn in one shift rather than two. Meanwhile, replacement of the shaft’s cage winding system with skip winding enabled the colliery to employ 5 ton tubs, without widening the shaft.

Britain’s retention of in-seam mining during this period can be traced to its unique system of fragmented mineral royalties. European royalty practice generally developed from a tradition of crown mineral ownership, modified from the late eighteenth century to overcome the problems that would otherwise arise from the considerable subdivision of land in most European nations. Under this system the state owned mineral royalties and granted concessions to mining concerns. Britain, by contrast, already had a well-established coal mining industry, together with a commercialised agricultural sector with relatively large land-holdings. It therefore maintained its system of vesting mineral ownership with the owners of the surface land. Most of Britain's current and former colonies followed British practice, but as land was generally held in very large estates this imposed few problems regarding fragmentation.
Ben Fine has argued that the relationship between landowners and mineowners in Britain originally facilitated the rapid expansion of mines and high rates of extraction. Similarly, Britain’s practice of developing underground roadways along the line of the seam had originally been efficient, given that its seams were mainly of moderate inclination and, for small pits using manual technology, it was cheaper to mine through coal than rock. However, from the late nineteenth century - as mine size expanded to encompass several royalties and technological change made horizon mining increasingly attractive – private royalties impeded the introduction of new technology and associated mining systems. The 1925 Royal Commission on the Coal Industry (Samuel Commission) found that the average British mine worked the coal of five mineral owners. Meanwhile the seams worked from any particular pit were not necessarily determined by efficiency considerations, but by the success of the mine-owner in obtaining leases. This problem was compounded for large collieries, where as many as 20 royalty owners might be involved.

Horizon mining involved concentrating workings and conveying coal from those workings to the shaft via a single, straight, high capacity underground roadway. Developing a straight roadway from the shaft to the coalface required access to the intervening land; a roadway that meandered to conform with surface land boundaries would not be suitable for the high throughput haulage systems required to deal with mechanised, concentrated, extraction. Any significant break in the straight line and uniform gradient would have a substantial impact on speed, load, and, therefore, throughput.

Would this problem have been solved by efficient bargaining between mine and royalty owners? Coase’s seminal 1960 article, ‘The problem of Social cost’, shows that, given complete information and no transactions costs, negotiation between parties to an initially inefficient
market outcome, such as that produced by fragmented British royalties, will produce Pareto-efficient solutions. Coase explicitly assumed zero transactions costs; indeed he subsequently stated that the chief significance of the ‘Coase theorem’ is in emphasising the importance of positive transactions costs in modifying the predictions of his theorem and the standard economic theory from which it is derived. Yet this theorem has been interpreted by some commentators as asserting that however property rights are assigned we should observe only outcomes that are constrained efficient in the sense that all potential gains from trade (net of transactions costs) are exploited.

The dangers of extending the Coase theorem to a world of positive transaction costs have been illustrated by Anderlini and Felli. Modelling bargaining in the presence of transactions costs, they found that, even assuming complete information, the theorem no longer holds, as an efficient (or even Pareto-improving) outcome is no longer guaranteed. Renegotiating mineral leases involved particularly heavy transactions costs, given the complexity of the agreements they represented between landowners and mineowners regarding access to, and removal of, coal. For example, in evidence to the 1919 Royal Commission on the Coal Industry (Sankey Commission), the Chief Inspector of Mines, R. A. S. Redmayne, noted that transactions costs for renegotiating access to small plots of land often formed a high proportion of the overall cost of the leases in question, citing one case where access to mineral royalties valued at £350 involved negotiation costs of £84, despite it being a relatively straightforward transaction.

Gains from trade through negotiation were further inhibited by the absence of another critical assumption of the Coase theorem – complete information. The literature on ‘non-cooperative’ bargaining models (as opposed to ‘cooperative’ bargaining theory, one of the axioms of which is that outcomes are efficient) indicates that bargaining is typically inefficient
in situations where each party holds relevant information unknown to the other party, such as their payoff from a successful agreement. This can lead to a failure to make mutually advantageous bargains, excessive delay, and other direct bargaining costs, as each bargainer incurs and imposes real costs to change the expected price to their advantage.\textsuperscript{76}

As noted above, assessing the expected profitability of mining investment projects was an extremely complex task, many key factors being dependent on conditions in the colliery, or even seam, in question. Colliery owners, despite themselves facing incomplete information, were nevertheless much better placed to assess the expected impact of rationalization projects on colliery profitability than were royalty owners. Meanwhile royalty owners were often in a powerful bargaining position in that they held an effective veto over modifications to existing workings that violated current leases. Developing straight underground roadways from the shaft to the face would, under the British royalty system, typically involve crossing several royalties from which no coal would be mined. Leases would have to be obtained for each area crossed and charges paid for `wayleave’ – the right to transport coal through the royalty. Landlords sought to limit wayleave rights as much as possible in order to ensure the maximum working of their own coal, sometimes limiting the amount of coal that could be transported via the wayleave to a certain percentage of the colliery’s output.\textsuperscript{77} If royalties were to be leased purely for haulage purposes it was in the financial interests of each landlord to seek wayleave charges which both compensated them for their lost potential income from coal extraction and reflected the monopoly value of their land’s intervening position between the shaft and coal-face.

This gave royalty owners with sites in key locations great scope for `strategic hold-up’ to extract as much of the perceived likely increased profits from the scheme in question as they felt they could get away with; a practice noted by contemporary industry observers. For example,
the Chief Inspector of Mines informed the Sankey Commission that he had frequently come across cases where a strategically-placed royalty owner sought `to extract extortionate terms, either of wayleave or by unduly inflating the price.' This continued to be reported as a serious problem during the 1920s and 1930s. The cost penalties facing a royalty owner from the failure to secure agreement to a mine rationalization project were relatively slight. Most leases extant during the interwar period had been agreed during the era of relatively high coal prices prior to 1921 and, as they were set relative to the output, rather than value, of the coal produced, were inelastic to variations in colliery profits so long as the royalty continued to be worked. Thus, while colliery profits declined from more than twice the value of royalties during the five years prior to the First World War to about two thirds of their value during 1930-34, the average royalty had experienced only a slight absolute fall, from 5.64 d to 5.34 d per ton. Even if the colliery ceased working that particular royalty, the owner still received income, so long as the mine stayed in operation, due to a system of `minimum rents', payable regardless of output, which again reflected market conditions at the time leases were taken out and appreciated relative to mining revenues during the interwar depression.

A review by the author of archival evidence on interwar coal-field rationalisation projects highlights the obstacles that fragmented royalties placed in the path of concentrated workings. The Mining Association, the South Yorkshire collieries (in a scheme for a holding company for the coalfield), a leading mining engineer (presenting a provisional scheme for amalgamating collieries in south-west Lancashire), and the Chairman of Amalgamated Anthracite Collieries, all drew attention to current royalty patterns and difficulties in renegotiating them as key factors impeding rationalisation. A technical report to the Coal Mines Reorganisation Commission, concerning a proposed colliery amalgamation for the Fife
area of Scotland, emphasised the barriers to the project imposed by current fragmented leases. A simultaneous merger of royalties covered by the scheme was suggested, via the formation of a royalties company in which each royalty owner would hold shares and which would charge the merged colliery company a flat royalty rate per ton. Yet the report acknowledged that difficulties in reaching agreement with all royalty owners would probably block such an initiative, despite its obvious efficiency advantages.  

The same difficulty arose at the level of the individual colliery, even in the relatively new coalfields where new mine development had been concentrated during the early twentieth century. For example a large colliery in South Yorkshire, one of Britain’s more recently-developed coalfields, wished to concentrate extraction in a particular area, producing a tonnage on which royalties would greatly exceed minimum rents. However, the £11,000 that it would have to pay each year in minimum rents on its un-worked leases constituted a powerful disincentive. Such calculations faced many collieries; as a 1938 article on mechanized mining noted, ‘Where feasible, the aim is to work a quota of tonnage from each leasehold to cover the minimum rent. Where the dead rent is allowed to accumulate, the charge is apt to become onerous particularly if the property is extensive’.  

No comprehensive information is available on the locations of the 16 locomotives operating in British mines by 1938. Yet fragmentary documentary evidence indicates that most recorded cases of successful and sustained adoption of locomotives were in Scotland, where royalties were substantially more concentrated than in England. These included the Gilmerton Colliery; the Coltness Iron Co.’s Kingshill and Douglas collieries; and the Alloa Coal Co.’s Devon Colliery. The Kingshill Colliery was a new pit, sinking of the first shaft having been completed in 1918. Following the introduction of locomotive haulage as part of an integrated
cycle of concentrated mechanized mining, it achieved an output of two tons per man-shift in around 1928 (compared to an average of 1.18 tons for Scottish, and 1.06 tons for all British, mines) from a relatively narrow seam. The Devon Colliery, by contrast, was an extremely old mine, yet despite its great age an electric locomotive was successfully introduced there by the Alloa Coal Co., which had adopted a policy of owning the royalties it mined. One successful instance of an English mine adopting locomotives occurred in Cumberland following the acquisition of Whitehaven Collieries by the Coltness Iron Co. in 1937. However, in this case royalties did not pose a problem, as the seam was located under the Irish Sea.

VI

As the world’s main exporter of a bulk raw material, the British coal industry inevitably faced severe problems in adjusting to a new interwar economic environment of rising international competition, protectionism, and stagnant demand. Meanwhile the industry’s unusually high sunk costs and the long lifespan of its fixed capital delayed the exit of inefficient mines, while adversarial industrial relations, flawed government intervention, and, very probably, poor or indifferent entrepreneurship for many concerns, placed further barriers in the path of efficient restructuring. This article has not sought to dismiss or diminish the importance of these factors, but to demonstrate that there were also problems inherent in the technical and institutional systems of British coal mining, which, while originally rational, later came to constituted powerful barriers to modernization in their own right.

Problems of technical and institutional interrelatedness both considerably slowed mechanization and reduced the productivity impact of the mechanised technology that was introduced. Arguments that if the industry had been free from government intervention it could
have achieved productivity growth close to the European average by concentrating production in more environmentally-favoured coalfields are, therefore, incorrect. For example a major feature of the Ruhr’s rationalization programme was the concentration of mining operations in a third of the number of coal faces previously worked. In Britain royalties constituted an effective barrier both to the concentration of extraction in particular faces and to the development of haulage facilities capable of removing coal from concentrated workings.

The problems of Britain’s interwar coal industry constitute an example of the more general phenomenon, identified by Veblen and Gerschenkron, of Britain paying the penalty during the early twentieth century for having earlier taken the lead in industrialisation. High degrees of technical and institutional interrelatedness were characteristic features of Britain’s staple industries. Further research into the impact of inherited production systems and institutional arrangements, through path dependence effects, might go some way towards providing a more general explanation of their rejection of the new technologies adopted by overseas producers encompassing a wide range of factor endowments and market opportunities.
## TABLE 1

OUTPUT PER MAN-SHIFT (O/S) IN THE MAIN COALFIELDS OF BRITAIN AND CONTINENTAL EUROPE, 1913-1937 (metric tons; ranked by growth is O/S, 1913-37)

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Netherlands</td>
<td>0.82</td>
<td>0.70</td>
<td>1.25</td>
<td>1.77</td>
<td>116.3</td>
<td>153.1</td>
<td>77.9</td>
</tr>
<tr>
<td>Ruhr(a)</td>
<td>0.95</td>
<td>0.86</td>
<td>1.27</td>
<td>1.63</td>
<td>72.1</td>
<td>89.1</td>
<td>47.8</td>
</tr>
<tr>
<td>German Upper Silesia</td>
<td>1.15</td>
<td>0.63</td>
<td>1.38</td>
<td>1.93</td>
<td>68.0</td>
<td>208.8</td>
<td>120.3</td>
</tr>
<tr>
<td>Poland (excluding Karwin)</td>
<td>1.14</td>
<td>0.58</td>
<td>1.26</td>
<td>1.82</td>
<td>59.6</td>
<td>216.1</td>
<td>119.1</td>
</tr>
<tr>
<td>Aachen(a)</td>
<td>0.76</td>
<td>0.61</td>
<td>0.95</td>
<td>1.14</td>
<td>49.6</td>
<td>87.1</td>
<td>55.6</td>
</tr>
<tr>
<td>Czechoslovakia</td>
<td>0.97</td>
<td>0.74</td>
<td>1.04</td>
<td>1.45</td>
<td>49.2</td>
<td>95.3</td>
<td>40.5</td>
</tr>
<tr>
<td>German Lower Silesia(b)</td>
<td>0.67</td>
<td>0.43</td>
<td>0.84</td>
<td>0.98</td>
<td>45.9</td>
<td>128.0</td>
<td>97.2</td>
</tr>
<tr>
<td>Belgium</td>
<td>0.54</td>
<td>0.47</td>
<td>0.58</td>
<td>0.78</td>
<td>45.4</td>
<td>66.7</td>
<td>22.8</td>
</tr>
<tr>
<td><strong>Lancashire, North Staffs. &amp; Cheshire</strong></td>
<td><strong>0.79</strong></td>
<td><strong>0.68</strong></td>
<td><strong>0.90</strong></td>
<td><strong>1.06</strong></td>
<td><strong>33.5</strong></td>
<td><strong>55.2</strong></td>
<td><strong>31.7</strong></td>
</tr>
<tr>
<td>Saar</td>
<td>0.80</td>
<td>0.64</td>
<td>0.84</td>
<td>1.05</td>
<td>31.3</td>
<td>64.9</td>
<td>30.8</td>
</tr>
<tr>
<td>France (excluding Saar)</td>
<td>0.70</td>
<td>0.55</td>
<td>0.69</td>
<td>0.83</td>
<td>18.8</td>
<td>52.3</td>
<td>26.9</td>
</tr>
<tr>
<td>Saxony(a)</td>
<td>0.71</td>
<td>0.47</td>
<td>0.66</td>
<td>0.84</td>
<td>18.8</td>
<td>78.4</td>
<td>39.4</td>
</tr>
<tr>
<td><strong>South Wales &amp; Monmouthshire</strong>(c)</td>
<td><strong>0.89</strong></td>
<td><strong>0.76</strong></td>
<td><strong>1.04</strong></td>
<td><strong>1.05</strong></td>
<td><strong>17.8</strong></td>
<td><strong>36.8</strong></td>
<td><strong>35.9</strong></td>
</tr>
<tr>
<td><strong>North Derbyshire &amp; Nottinghamshire</strong></td>
<td><strong>1.28</strong></td>
<td>N/A</td>
<td>1.23</td>
<td>1.48</td>
<td>15.5</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Northumberland</td>
<td>1.02</td>
<td>0.79</td>
<td>1.15</td>
<td>1.18</td>
<td>15.5</td>
<td>49.1</td>
<td>44.4</td>
</tr>
<tr>
<td>Scotland</td>
<td>1.08</td>
<td>0.88</td>
<td>1.21</td>
<td>1.22</td>
<td>12.7</td>
<td>38.0</td>
<td>36.8</td>
</tr>
<tr>
<td><strong>South Derbyshire, Leicestershire,</strong></td>
<td><strong>1.09</strong></td>
<td>N/A</td>
<td>1.08</td>
<td>1.20</td>
<td>10.7</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td><strong>Cannock Chase &amp; Warwickshire</strong></td>
<td><strong>1.22</strong></td>
<td>N/A</td>
<td>1.19</td>
<td>1.34</td>
<td>9.5</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td><strong>Yorkshire</strong></td>
<td><strong>1.16</strong></td>
<td><strong>1.02</strong></td>
<td><strong>1.10</strong></td>
<td><strong>1.10</strong></td>
<td><strong>-4.6</strong></td>
<td><strong>34.7</strong></td>
<td><strong>34.1</strong></td>
</tr>
<tr>
<td>Average</td>
<td>0.93</td>
<td>0.66</td>
<td>1.03</td>
<td>1.26</td>
<td>36.07</td>
<td>90.85</td>
<td>53.82</td>
</tr>
<tr>
<td>Standard deviation (all areas)</td>
<td>0.21</td>
<td>0.14</td>
<td>0.23</td>
<td>0.34</td>
<td>29.07</td>
<td>57.54</td>
<td>32.00</td>
</tr>
<tr>
<td>Standard deviation (UK areas only)</td>
<td>0.16</td>
<td>0.07</td>
<td>0.11</td>
<td>0.15</td>
<td>10.55</td>
<td>8.94</td>
<td>4.79</td>
</tr>
</tbody>
</table>

**Notes:** \(a\) 1923 values are for 1924, as data for 1923 are not available. \(b\) 1913 figure includes East Upper Silesia. \(c\) Data are for February-January of each year. \(d\) 1913 values for UK regions are for June 1914.

**Sources:** United Kingdom, *Annual Report of H.M. Chief Inspector of Mines* (1914-38); *Statistical Tables Relating to British Foreign Trade and Industry* (1924-30), Part II: Principal Industries, Production and Trade (P.P. 1930-31, XXXI); NA, POWE22/174, Table, n.d., c.1944.
TABLE 2

CHANGES IN MECHANISATION AND PRODUCTION COSTS IN BRITISH COALFIELDS

1927 - 1937

<table>
<thead>
<tr>
<th>Coalfield</th>
<th>Increase in percentage of coal mechanically:</th>
<th>Change in cost per ton of coal produced (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Conveyed (^{a})</td>
<td>Cut</td>
</tr>
<tr>
<td>Lancashire, North Staffordshire &amp; Cheshire</td>
<td>61</td>
<td>51</td>
</tr>
<tr>
<td>Yorkshire</td>
<td>45</td>
<td>34</td>
</tr>
<tr>
<td>Northumberland</td>
<td>36</td>
<td>49</td>
</tr>
<tr>
<td>Scotland</td>
<td>32</td>
<td>23</td>
</tr>
<tr>
<td>South Wales &amp; Monmouthshire (^{b})</td>
<td>24</td>
<td>17</td>
</tr>
<tr>
<td>Durham</td>
<td>16</td>
<td>22</td>
</tr>
<tr>
<td>Great Britain</td>
<td>39</td>
<td>34</td>
</tr>
</tbody>
</table>

Notes: \(^{a}\) 1928-37 (coalfield-level data on mechanical conveyance are not available before 1928).

\(^{b}\) Data are for February-January of each year.

Sources: N. K. Buxton, `Coalmining,’ 48-79 in N. K. Buxton and D. H. Aldcroft (eds), British Industry Between the Wars. Instability and Industrial Development 1919-1939 (1979), pp. 64-57;

TABLE 3
THE PERCENTAGE OF COAL MECHANICALLY CUT AND CONVEYED IN BRITAIN, 1903-1938

<table>
<thead>
<tr>
<th>Year</th>
<th>Mechanically cut</th>
<th>Face conveyed</th>
<th>Gate conveyed</th>
<th>Locomotive conveyed on main/secondary haulage ( \text{a} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>1903</td>
<td>2.3</td>
<td>N/A</td>
<td>N/A</td>
<td>0</td>
</tr>
<tr>
<td>1909</td>
<td>5.2</td>
<td>N/A</td>
<td>N/A</td>
<td>0</td>
</tr>
<tr>
<td>1913</td>
<td>8.5</td>
<td>N/A</td>
<td>N/A</td>
<td>0</td>
</tr>
<tr>
<td>1920</td>
<td>13.2</td>
<td>N/A</td>
<td>N/A</td>
<td>0</td>
</tr>
<tr>
<td>1924</td>
<td>18.7</td>
<td>N/A</td>
<td>N/A</td>
<td>0</td>
</tr>
<tr>
<td>1927</td>
<td>23.3</td>
<td>N/A</td>
<td>N/A</td>
<td>0</td>
</tr>
<tr>
<td>1928</td>
<td>25.9</td>
<td>11.8</td>
<td>N/A</td>
<td>0</td>
</tr>
<tr>
<td>1929</td>
<td>27.9</td>
<td>14.4</td>
<td>N/A</td>
<td>0</td>
</tr>
<tr>
<td>1930</td>
<td>31.1</td>
<td>17.4</td>
<td>5.8</td>
<td>0</td>
</tr>
<tr>
<td>1931</td>
<td>35.0</td>
<td>21.6</td>
<td>8.4</td>
<td>0</td>
</tr>
<tr>
<td>1932</td>
<td>38.5</td>
<td>25.2</td>
<td>10.5</td>
<td>0</td>
</tr>
<tr>
<td>1933</td>
<td>42.4</td>
<td>30.0</td>
<td>13.4</td>
<td>0</td>
</tr>
<tr>
<td>1934</td>
<td>47.0</td>
<td>36.9</td>
<td>19.1</td>
<td>0</td>
</tr>
<tr>
<td>1935</td>
<td>51.0</td>
<td>43.0</td>
<td>24.4</td>
<td>0</td>
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<tr>
<td>1936</td>
<td>55.0</td>
<td>47.9</td>
<td>29.5</td>
<td>0</td>
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<tr>
<td>1937</td>
<td>57.0</td>
<td>51.1</td>
<td>33.2</td>
<td>0</td>
</tr>
<tr>
<td>1938</td>
<td>59.5</td>
<td>54.1</td>
<td>36.2</td>
<td>0</td>
</tr>
</tbody>
</table>

Notes: N/A = not available.

\( \text{a} \) Derived from data on the number of locomotives in use in British mines, which stood at 16 in 1939, implying a percentage contribution to aggregate tonnage hauled that was not significantly different from zero.

Notes

This research was funded by ESRC grant no. R000223450. I am also grateful to the staff of the Durham Record Office, Industrial Railway Society, National Archive, National Archives of Scotland, Northumberland Record Office, and West Yorkshire Archive Service, for their generous assistance. Thanks are also due for comments on previous drafts, by Trevor Boyns, Tim Leunig, Teresa da Silva Lopes, Judith Wale, the participants of sessions at the Association of Business Historians conference, Portsmouth, Economic History Society Conference, Birmingham, and LSE Economic History Postgraduate Workshop, together with anonymous rapporteurs for my ESRC End of Award Report and three anonymous referees. Any errors or omissions are my own.


3 Greasley, 'Fifty Years’, p. 897.


10 Greasley, ‘Fifty Years, p. 892.


12 Beacham, ‘Efficiency and organisation’, p. 207.

exceptions were Durham and Northumberland, where Greasley estimates hours per shift at 6.82 and 7.32 respectively in 1914; however, these had moved into line with the national average by the 1930s.


15. For estimates of coalface TFP growth for British coalfields see Greasley, ‘Fifty Years’.

16. ‘Mechanisation in Collieries. Effect on Output in Different Countries’, Iron and Coal Trades Review, Vol. CXXVI (1933).p. 532. No data were available for France for 1930, values for 1929 and 1931 are 72 and 81 per cent respectively.


32


35. Barraclough, 'Some General Considerations', p.185.


37. Barraclough, 'Some General Considerations', p. 185.

38. Special Committee appointed by Midland Institute of Mining Engineers et. al., _Revised Report of a Further Investigation of the Underground Conveying and Loading of Coal by Mechanical Means_ (1937).


41. 'Discussion of Mr Samuel Dean's paper on "Modern coal-mining methods, with some comparisons"', Transactions of the Institution of Mining Engineers, Vol. LI (1915-1916), 35-60, p. 46 [contribution by S. Tate].

42. Swallow, 'Size of Pit Tubs'.


46. ‘Underground Conveying’, p. 256.

47. Swallow, ‘Size of Pit Tubs’.


52. Ripping involved cutting away the rock above the seam to increase the size of the roadway.


54. NA, POWE22/181, ‘Notes on locomotive haulage in the coalfields of the Ruhr and Holland,’ c. 1945.


64. Ministry of Fuel and Power, Coal Mining, p. 21.


66. Swallow, `Size of Pit Tubs’.


Anderlini and Felli, ‘Costly Bargaining’.


Royal Commission on the Coal Industry (Sankey), Minutes of Evidence (P.P. 1919, XII.), p. 1155.


NA, COAL 12/12, Interdepartmental committee on the organisation of the coal mining industry, draft report, 6 April 1934 [hereafter IC report] Appendix II.

National Archives of Scotland, CB14/1, Coal Mines Reorganisation Commission, mining engineers’
report on merger scheme for Fife collieries, November 1934.

84. NA, COAL 12/12, IC report, Appendix II.


86. Fine and Harris, Peculiarities, p. 295.

87. Smith and Etherington, National Coal Board Flameproof Locomotives, pp. 8-9; J. L. Carvel, One Hundred Years in Coal: The History of the Alloa Coal Co. (Edinburgh, 1944), pp. 82-129.

88. 'Mechanisation in Scotland’, Colliery Engineering (October 1928), pp. 385-93. O/S data cover all colliery personnel (including surface workers). The seam thickness varied from 2 feet 2 inches to 3 feet.

89. Carvel, One Hundred Years in Coal, pp. 82-129.


