Labour Productivity in the British and South Wales Coal Industry, 1874–1914

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I

Naked to the waist, hot and grimy with labour, they squatted on their heels for a few minutes and talked, seeing each other dimly by the light of the safety lamps, while the black coal rose jutting around them, and the props of wood stood like little pillars in the low, black, very dark temple. . . . The day passed pleasantly enough. There was an ease, a go-as-you-please about the day underground, a delightful camaraderie of men shut off alone from the rest of the world, in a dangerous place, and a variety of labour, holing, loading, timbering, and a glamour of mystery and adventure in the atmosphere, . . .

D. H. Lawrence (1955)

The above quote from D. H. Lawrence, while perhaps over-emphasizing "glamour" and "adventure", illustrates one important aspect of colliery work: the intensity of a collier's effort was primarily self-imposed. It was the work intensity, combined with other factors, that determined labour productivity in the coal mines. A number of articles have addressed the problem of labour productivity in coalmining during the late nineteenth and early twentieth centuries, two of the most important being A. J. Taylor's (1961) examination of productivity and technological change in Britain and R. H. Walters' (1975) analysis of the same topic for South Wales.¹ In addition, there is a rich and growing literature on the broader problem of the existence of a "climacteric", a downward shift in the performance of the British economy in the late nineteenth century, often attributed to the "failure" of British entrepreneurs, as represented by their seeming unwillingness to adopt the best available techniques of production.²

The purpose of this paper is to specify and estimate an empirical model of labour productivity in coalmining, as well as to provide some suggestive evidence regarding the performance of entrepreneurs in this major industry.³ We believe our results provide added insight into the determination of labour productivity during this period, lending support to those who argue that the failure of British entrepreneurs has yet to be proved, while providing mixed evidence regarding conclusions drawn by economic historians.

II

Previous studies examining the rise and subsequent decline in labour productivity during this period have focused on a number of diverse factors. Although authors have differed in their emphasis, most have arrived at similar conclusions: labour productivity (as measured by annual output per worker)
was adversely affected in both the short and the long run by rising wages; coalmining exhibited diminishing returns in the long run owing to the necessity of working less productive and more inaccessible seams; and technological innovation partially, but not fully, offset the above two forces. In addition, such factors as the state of the business cycle, absenteeism, the number of inexperienced workers, the effects of maximum hours legislation, and strike activity have been considered.

In order to examine the determinants of labour productivity, we employ a somewhat ad hoc model reflecting the discussion by economic historians. We propose a model in which labour productivity, measured by the average product of labour, is a function of work effort, the business cycle or state of the coal trade, diminishing marginal returns in mining, and technological change. Empirical specification is determined in large part by data availability. Utilizing data provided primarily by Walters and Taylor, we estimate the following regression models for South Wales (SW) and Britain (B). The source and method of calculation for each of our variables are presented in the Appendix.

South Wales:  
\[
\ln \left( \frac{Q}{L} \right)_{SW} = a_0 + a_1 \ln (W)_{SW} + a_2 STRIKE_{SW} + a_3 HOURS_{SW} + a_4 \% \Delta TRADE_t + a_5 MINESIZE_{SW} + a_6 TIME + u_t 
\]
where we expect \( a_1, a_2, a_3, a_5 < 0 \) and \( a_4, a_6 > 0 \).

Britain:  
\[
\ln \left( \frac{Q}{L} \right)_B = b_0 + b_1 \ln (W)_B + b_2 STRIKE_B + b_3 HOURS_{SW} + b_4 \% \Delta TRADE_t + b_5 TIME + v_t 
\]
where we expect \( b_1, b_2, b_3 < 0, b_4 > 0, \) and \( b_5 \geq 0 \). Here

\[
\ln (Q/L) = \text{labour productivity as measured by the natural log of tons of output per worker above and below ground;}
\]
\[
\ln (W) = \text{natural log of a wage rate index;}
\]
\[
STRIKE = \text{a dummy variable, 1 for strike years, 0 otherwise;}
\]
\[
HOURS = \text{a dummy variable, 1 for years after 1908, 0 otherwise;}
\]
\[
\% \Delta TRADE = \text{percentage change in the value of British trade (domestic exports plus imports);}
\]
\[
MINESIZE = \text{average annual output per mine in South Wales (a proxy for diminishing returns); and}
\]
\[
TIME = \text{a linear time trend (intended to capture technological change).}
\]

For much of this period, wages (generally piece rates) were determined by a sliding scale relating wages to the price of coal, though there did exist some variation across mines depending on local conditions. Thus, we are able to specify the following wage equations for South Wales and Britain:

\[
\ln (W)_{SW} = \alpha_0 + \alpha_1 \ln (P)_{SW} + \alpha_2 \ln (P)_{SW} + w_i 
\]
\[
\ln (W)_B = \beta_0 + \beta_1 \ln (P)_B + \beta_2 \ln (P)_B + z_i 
\]
where \( \ln (P) \) is the natural log of the price of coal for South Wales and Britain.
respectively and all coefficients are expected to be positive. As specified, the system is recursive (price determines wages, which in turn affect productivity), enabling the labour productivity equations to be estimated by single-equation techniques as long as the error terms across equations are not correlated. We examine whether the error terms are correlated and compare single-equation results with those using a systems approach.

As a measure of labour productivity, we follow convention and rely primarily on the annual average product per worker, measured in tons per worker.\(^6\) As a check on our results, we also present estimates using the marginal product of labour. As is true in most historical studies, our measure of productivity fails to reflect truly homogeneous labour units. Measured productivity is affected by labour quality and skill type (for instance, the ratio of hewers to oncost workers), hours of work per shift, absenteeism, strikes and work intensity. While we can account explicitly for strikes and mandated hours legislation, we do not have complete data on the other determinants of labour productivity.

A negative wage–productivity relationship is likely to reflect miners’ labour supply response to higher wages. As noted by historians, miners chose to take some of their higher potential income in the form of leisure: off the job through decreased regular hours or increased absenteeism, or on the job in the form of reduced work intensity. We use both a real and a money wage rate index to capture the expected negative effect of wages on productivity. The nominal index may be the preferred variable, since it has been argued that no completely satisfactory retail price index exists for this period (Walters, 1975, p. 292n.); thus the use of a real-wage index might introduce substantial measurement error in the variable, biasing the wage coefficient towards zero. We present results using both nominal and real variables.

A dummy variable, STRIKE is included to account for the reduced output per worker during years of major strikes. While some judgment is required in deciding what constitutes a major strike, we counted the years 1874, 1875, 1893, 1898, 1910, 1911 and 1912 as strike years in South Wales (Walters, 1975, p. 292n.). For Britain, only in the years 1893 and 1912 were there widespread strikes, even though there were numerous localized strikes throughout the period (Taylor, 1961, p. Sn.). Also included is a dummy variable, HOURS\(_{\text{LAW}}\), to account for the reduction in hours beginning in the latter part of 1909 resulting from the Eight Hour Act of 1908. The effect of the Eight Hour Act on labour productivity is expected to be greatest in South Wales, since prior to its enactment hours of work there were above both eight hours and the average for all of Britain (Walters, 1977).

We utilize %\(\Delta\)\(TRADE\)\(_{B}\) to measure the effects of the business cycle and the state of the coal trade on labour productivity in both South Wales and Britain. The total volume of trade should be a reasonable proxy for the state of the coal trade because of trade’s sensitivity to the business cycle and because the major use of steam coal was in transport (which is particularly true for South Wales). As an alternative measure of the state of the coal trade, we use %\(\Delta\)\(GDP\)\(_{B}\), representing the percentage change in British gross domestic product.\(^7\) As with the wage variable, we use both nominal and real \(TRADE\) and \(GDP\). We expect a positive relationship with these measures to reflect a changing capacity utilization rate at different points of the business cycle,
brought about partly by the practice of "short working", whereby owners reduced the number of days a colliery wound coal. However, hewers' output per shift might have increased in response to reduced hours of working in an attempt to mitigate the potential loss of earnings, thus partially offsetting any pro-cyclical effects.

Economic historians have long argued that diminishing marginal returns in mining were of crucial importance. Taylor (1961) concluded that labour-saving technology (primarily mechanical coal-cutters) might have offset diminishing returns and that slow adoption of such technology represented a "failure" of the late Victorian entrepreneur. Walters (1977) found that in South Wales the proportion of output coming from older pits increased over time. As the coal faces of these older pits retreated from the shaft, diseconomies tended to grow. Although mechanical coal-cutters could have had an offsetting effect, they were not adopted widely in South Wales, possibly because of the irregular nature of the seams.8

As a measure of diminishing marginal returns to mining in South Wales, we use, by necessity, the average mine size as presented in Walters (1975). While a negative relationship between \( \ln(Q/L)^{SW} \) and \( \text{MINESIZE}^{SW} \) is predicted, the coefficient should be biased in a positive direction. Since size is measured by output rather than area, increased output for any reason not accounted for in our model will increase both \( \ln(Q/L)^{SW} \) and \( \text{MINESIZE}^{SW} \), given any physical size of mines. No measure of diminishing returns is available for Britain. Thus, in the British model, diminishing returns will be reflected in the time trend variable. A time trend, \( \text{TIME} \), is included in both regression models. In the South Wales model, \( \text{TIME} \) is expected to measure any positive effects of technology on labour productivity, though these effects are not expected to be large. In the British model, \( \text{TIME} \) is expected to capture the opposing effects of technological change and diminishing returns; thus its coefficient is indeterminate a priori.

### III

Despite data limitations, regression results from the model are found to be useful in explaining changes in labour productivity. Table 1 presents regression results of the labour productivity model for South Wales. Specifications shown include both nominal and real wage, trade and GDP variables. We utilize a maximum likelihood iterative estimation technique (AR1) developed by Beach and MacKinnon (1978) to deal with first-order serial correlation. Autoregression was not serious in the South Wales model, and the AR1 results are quite similar to those obtained by OLS. For purposes of comparison, column (1) presents OLS results for one of the specifications.

The hypothesis that labour productivity declines in response to higher wage rates is strongly supported by our results, showing that there exists a significant negative relationship between wages (nominal or real) and output per worker after accounting for other measurable determinants of labour productivity. Our point estimates indicate that a 10 per cent increase in wage rates was associated with approximately a 21.3 per cent decrease in output per worker. This empirical finding is consistent with both the casual empiricism
LABOUR PRODUCTIVITY IN THE COAL INDUSTRY

<table>
<thead>
<tr>
<th>Variable</th>
<th>OLS</th>
<th>AR1</th>
<th>AR1</th>
<th>AR1</th>
<th>AR1</th>
</tr>
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<tr>
<td>( \ln (W)^{SW} ) (nominal)</td>
<td>-0.301</td>
<td>-0.287</td>
<td>-0.261</td>
<td>-0.276</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(-3.35)</td>
<td>(-2.86)</td>
<td>(-2.36)</td>
<td>(-2.24)</td>
<td></td>
</tr>
<tr>
<td>( \ln (W)^{SW} ) (real)</td>
<td>—</td>
<td>—</td>
<td>-0.258</td>
<td>—</td>
<td>-0.276</td>
</tr>
<tr>
<td></td>
<td>—</td>
<td>(2.18)</td>
<td>—</td>
<td>(2.24)</td>
<td></td>
</tr>
<tr>
<td>STRIKE(^{SW})</td>
<td>-0.157</td>
<td>-0.162</td>
<td>-0.164</td>
<td>-0.161</td>
<td>-0.169</td>
</tr>
<tr>
<td></td>
<td>(-5.66)</td>
<td>(-6.16)</td>
<td>(-6.11)</td>
<td>(-6.02)</td>
<td>(-6.19)</td>
</tr>
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<td>HOURS(^{LAB})</td>
<td>-0.071</td>
<td>-0.064</td>
<td>-0.091</td>
<td>-0.073</td>
<td>-0.094</td>
</tr>
<tr>
<td></td>
<td>(-1.68)</td>
<td>(-1.38)</td>
<td>(-1.73)</td>
<td>(1.55)</td>
<td>(-1.69)</td>
</tr>
<tr>
<td>( % \Delta TRADE(^{B})) (nominal)</td>
<td>0.0026</td>
<td>0.0023</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td></td>
<td>(1.53)</td>
<td>(1.45)</td>
<td>—</td>
<td>—</td>
<td>—</td>
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<tr>
<td>( % \Delta TRADE(^{B})) (real)</td>
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<td>—</td>
<td>0.0037</td>
<td>—</td>
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<tr>
<td></td>
<td>—</td>
<td>—</td>
<td>(1.71)</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>( % \Delta GDP(^{B})) (nominal)</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>0.0041</td>
<td>—</td>
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<td></td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>(1.14)</td>
<td>—</td>
</tr>
<tr>
<td>( % \Delta GDP(^{B})) (real)</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>0.0035</td>
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<td></td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>(0.90)</td>
</tr>
<tr>
<td>MINESIZE</td>
<td>-0.022</td>
<td>-0.019</td>
<td>-0.011</td>
<td>-0.022</td>
<td>-0.010</td>
</tr>
<tr>
<td></td>
<td>(-1.94)</td>
<td>(-1.44)</td>
<td>(-0.78)</td>
<td>(-1.62)</td>
<td>(-0.65)</td>
</tr>
<tr>
<td>TIME</td>
<td>0.0082</td>
<td>0.0067</td>
<td>0.0055</td>
<td>0.0074</td>
<td>0.0050</td>
</tr>
<tr>
<td></td>
<td>(1.78)</td>
<td>(1.31)</td>
<td>(1.00)</td>
<td>(1.43)</td>
<td>(0.87)</td>
</tr>
<tr>
<td>Constant</td>
<td>7.156</td>
<td>7.076</td>
<td>6.889</td>
<td>6.967</td>
<td>6.975</td>
</tr>
</tbody>
</table>

\( R^2 \) 0.699 0.922 0.948 0.912 0.952
s.e. 0.058 0.056 0.058 0.057 0.059
D-W 1.47 2.03 2.06 1.98 1.99
\( \hat{\rho} \) 0.26 0.36 0.25 0.40

Notes: dependent variable is \( \ln (Q/L)^{SW} \), mean \( \ln (Q/L)^{SW} = 5.582 \); \( t \)-ratios in parentheses; \( n = 41 \). All statistics from Beach–MacKinnon maximum likelihood autoregression procedure (AR1) are based on \( \rho \)-transformed data.

regarding that period and with the numerous current studies finding a backward-bending labour supply function for prime-age males.9

At this point it is worth distinguishing between the labour supply responses to wage differences across industries versus supply responses within coalmining. Throughout this period there were substantial increases in industry output and the number of workers. In South Wales output rose from 16.5 million tons in 1874 to 53.9 million in 1914, while employment increased from 73,000 to 234,000 persons (Walters, 1977, pp. 346–347, 353–354). Likewise, in Britain output rose from 126.6 million tons in 1874 to 287.4 millions in 1913, while employment increased from 515,000 to 1,107,000 persons (Taylor, 1961, pp. 68–69). In order to attract increasing numbers into coalmining, wages had to increase at rates equal to or greater than wages elsewhere (i.e. there had to exist a positive industry supply elasticity of workers). However, once in the industry, miners responded to higher wage levels with a decreased work effort, taking the form of decreased hours, greater absenteeism and possibly lessened work intensity (i.e. there existed a negative supply elasticity for work effort).10
As expected, output per worker decreased significantly during strike years. Results suggest that productivity in South Wales was approximately 15 per cent lower during strike years than non-strike years, ceteris paribus. We are unable to say to what extent this reduction resulted from fewer work days. It is quite possible that work days on average fell by more than 15 per cent during strike years, but that colliers and mineowners worked more intensely during the rest of the year in order partially to make up for losses in income.

The Eight Hour Act of 1908 also had the anticipated effect on labour productivity. We find that output per worker was approximately 6–9 per cent lower in South Wales from 1909 to 1914 than it would have been in the absence of the hours legislation. While the actual hours of work apparently decreased by more than this, it is likely that a compensating increase in work intensity mitigated the effect of the hours law.

The effect of the business cycle on labour productivity, as measured by the coefficients on nominal and real %ΔTRADE and %ΔGDP, is positive as predicted, but does not appear to be large after accounting for other determinants. Indeed, the standard errors are sufficiently large that one cannot reject the null hypothesis of no relationship. While "short working" would lead to a positive relationship between output per worker and the state of the coal trade, it appears likely that work intensity by colliers increased in response to shorter hours and lower prices, thus weakening the procyclical relationship. The weakness of this relationship may also reflect the fact that demand for coal during this period was relatively inelastic with respect to income and price.

MINESIZE, used as a proxy for diminishing returns in mining, is found as expected to be negatively, though usually not significantly, related to output per worker, in spite of the fact that its coefficient is likely to have a positive bias. In addition, strong collinearity between MINESIZE and TIME makes precise estimation difficult. It appears, however, that diminishing returns did play at least some role in bringing about declining labour productivity. Reinforcing this conclusion is the fact that labour costs per ton of coal rose faster than real wage rates, particularly during the latter part of this period. While real wages in South Wales coaling rose 35 per cent between 1887 and 1914, real labour costs per ton rose 134 per cent (Walters, 1977, p. 258), much of the increase being brought about by the greater need for oncost workers. While decreased work intensity and changes in labour quality might explain a part of this disparity, it is likely that diminishing returns is an important explanation.

Finally, we find a small, though generally insignificant, positive time trend in labour productivity of less than one per cent a year over the 1874–1914 period, after accounting for other determinants. We hypothesize that TIME primarily captures the modest effects of technological change in South Wales, where coaling did not easily lend itself to mechanical coal-cutting machines and other technological advances. TIME, of course, may also capture any unmeasured determinants of labour productivity that had a proportional effect over time. The positive coefficient on TIME provides additional support for McCloskey's position that there existed no entrepreneurial failure.

We also investigated the link between the price of coal, wage rates and labour productivity. Wage rates appeared to be primarily determined by coal prices, P, and in turn influenced output per worker. The recursive nature of
this system thus allows estimation by single-equation methods. If we relax the assumption of no cross-equation correlation of error terms and allow for autoregression ($\rho > 0$), we must estimate the wage and labour productivity equations jointly using a nonlinear systems approach. Using full information maximum likelihood (FIML) estimation, which utilizes an iterative procedure proposed by Berndt, Hall, Hall and Hausman (1974), we obtain the following results (asymptotic $t$ ratios in parentheses):

$$\ln (W)_{t}^{SW} = 3.102 + 0.632 \ln (P)_{t}^{SW} + 0.069 \ln (P)_{t-1}^{SW} \quad \hat{\rho} = 0.62 \tag{14.83}$$

$$\ln (Q/L)_{t}^{SW} = 7.760 - 0.433 \ln (W)_{t}^{SW} - 0.167 STRIKE_{t}^{SW} \quad (-1.91) \quad (-6.55)$$

$$-0.069 HOURS LAW_{t}^{B} \quad (-1.14)$$

$$+0.0020 \%\Delta TRADE_{t}^{B} - 0.0025 MINESIZE_{t}^{SW} \quad (0.71) \quad (-2.06)$$

$$+0.011 TIME \quad \hat{\rho} = 0.23 \quad (2.18)$$

log of likelihood function = 154.87

$n = 40$, $\ln (W)$ and $\%\Delta TRADE$ in nominal terms

These results, quite similar to those from single-equation estimation, provide support for the price-wage-productivity relationship outlined above. Wages moved with coal prices and in turn induced inverse labour supply responses. Indeed, the estimated wage coefficient from the FIML estimation ($-0.433$) is much larger than those presented in Table 1.

As further supporting evidence regarding the labour productivity-wage relationship we estimated a similar model for three individual South Wales coal companies for which productivity data were available for 20 of the years between 1888 and 1913. Regressing individual mine output per worker on the South Wales wage rate index, the hours law dummy and a time trend, we obtained the following OLS results:

J. Lancaster & Co. Ltd

$$\ln (Q/L)_{t} = 7.042 - 0.287 \ln (W)_{t}^{SW} - 0.123 HOURS LAW_{t}^{SW} \quad (-1.82) \quad (-2.37)$$

$$+0.001 TIME \quad (0.04)$$

$$\hat{R}^2 = 0.44 \quad s.e. = 0.075 \quad D-W = 1.31 \quad n = 20$$

Partridge, Jones & Co. Ltd

$$\ln (Q/L)_{t} = 6.780 - 0.350 \ln (W)_{t}^{SW} - 0.173 HOURS LAW_{t}^{B} \quad (-1.54) \quad (-2.30)$$

$$+0.021 TIME \quad (4.44)$$

$$\hat{R}^2 = 0.48 \quad s.e. = 0.108 \quad D-W = 2.06 \quad n = 20$$
Tredegar Iron & Coal Co. Ltd

\[
\ln (Q/L)_t = 7.892 - 0.450 \ln (W)_{tSW} - 0.109 \text{HOURS\textsubscript{L}} - 0.0004 \text{TIME} \\
(-4.86) \quad (-3.56) \quad (-0.23)
\]

\[
\bar{R} = 0.79 \quad \text{s.e.} = 0.044 \quad D-W = 1.66 \quad n = 20
\]

In each case we find a negative productivity–wage relationship at least as large as that estimated for all of South Wales. (A significant coefficient of \(-0.285\) was obtained in an identical regression for South Wales.) Interestingly, we again found no evidence of a significant negative trend in productivity in these three companies, after accounting for wages and hours legislation.

Regression results for the British model are presented in Table 2. Owing to serious autocorrelation, OLS estimation is not reliable; thus we concentrate on those estimates corrected for autoregressive residuals. Results are generally similar to those obtained for South Wales. However, no direct measure of diminishing returns was available, and the relationship between wage rates and labour productivity, while negative, is no longer statistically

<table>
<thead>
<tr>
<th>Variable</th>
<th>OLS</th>
<th>AR1</th>
<th>AR1</th>
<th>AR1</th>
<th>AR1</th>
</tr>
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<tbody>
<tr>
<td>(\ln (W)_{B}\text{(nominal)})</td>
<td>-0.395</td>
<td>-0.138</td>
<td>-0.091</td>
<td>-0.095</td>
<td></td>
</tr>
<tr>
<td>(\text{STRIKE}_{B})</td>
<td>-0.106</td>
<td>-0.085</td>
<td>-0.075</td>
<td>-0.081</td>
<td>-0.075</td>
</tr>
<tr>
<td>(\text{HOURS\textsubscript{L}}_{B})</td>
<td>-0.090</td>
<td>-0.068</td>
<td>-0.055</td>
<td>-0.065</td>
<td>-0.052</td>
</tr>
<tr>
<td>%\Delta \text{TRADE}_{B}\text{(nominal)}</td>
<td>0.0037</td>
<td>0.0028</td>
<td>-0.0025</td>
<td>0.0055</td>
<td></td>
</tr>
<tr>
<td>%\Delta \text{TRADE}_{B}\text{(real)}</td>
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<td>0.0025</td>
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<td></td>
</tr>
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<td>%\Delta \text{GDP}_{B}\text{(nominal)}</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>%\Delta \text{GDP}_{B}\text{(real)}</td>
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<td>0.0042</td>
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<td>\TEXT{TIME}</td>
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<td>0.0020</td>
<td>0.0021</td>
<td>0.0014</td>
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<td>(\text{CONSTANT})</td>
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</tr>
<tr>
<td>(R^2)</td>
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<td>0.988</td>
<td>0.985</td>
<td>0.988</td>
<td>0.984</td>
</tr>
<tr>
<td>s.e.</td>
<td>0.052</td>
<td>0.032</td>
<td>0.035</td>
<td>0.031</td>
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<tr>
<td>D-W</td>
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<td>1.69</td>
<td>1.57</td>
<td>1.54</td>
<td>1.50</td>
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<tr>
<td>(\hat{\rho})</td>
<td>-0.90</td>
<td>0.91</td>
<td>0.91</td>
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</tr>
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Notes: dependent variable is \(\ln (Q/L)_B\), mean \(\ln (Q/L)_B = 5.662\); \(t\)-ratios in parentheses; \(n = 40\). All statistics from Beach–MacKinnon maximum likelihood autoregression procedure (AR1) are based on \(p\)-transformed data.
significant. The apparent absence of a significant wage–productivity relationship may be due to an underlying labour supply function in which wage changes have only a small net effect on hours of work, intensity and absenteeism. Alternatively, the wage variable may contain sufficient measurement error that its estimated coefficient is biased significantly towards zero. Measurement error is likely both because it is based on data only from the principle coal districts and because we had to estimate the variable for the years 1874–1878.

Results from the FIML system estimation shown below provide evidence of a relationship between wages and current prices, and of a wage–productivity relationship of similar magnitude as that estimated by single-equation methods:

\[
\ln(W)_t^B = 3.535 + 0.471 \ln(P)_t^B + 0.028 \ln(P)_{t-1}^B + \hat{\rho} = 0.93
\]
\[
(10.20) \quad (0.82)
\]

\[
\ln(Q/L)_t^B = 6.362 - 0.130 \ln(W)_t^B - 0.093 \text{STRIKE}_B^B
\]
\[
(-1.10) \quad (-5.67)
\]

\[
-0.052 \text{HOURS_LAW}_B^B
\]
\[
(-0.83)
\]

\[
+0.0025 \%\Delta\text{TRADE}_B^B - 0.0044 \text{TIME}^B
\]
\[
(3.92) \quad (-1.47)
\]

\[
\hat{\rho} = 0.76
\]

log of likelihood function = 169.27

\[n = 39, \ln(W) \text{ and } \%\Delta\text{TRADE} \text{ in normal terms.}\]

Both strikes and the Eight Hour Act of 1908 are found to have decreased labour productivity, but as expected the effect of each of these is less for Britain than for South Wales. The two general strikes of 1893 and 1912 are estimated to have decreased output per man throughout Britain by about 7–9 per cent (half the effect of strikes in South Wales). Likewise, the hours legislation is estimated to have reduced output per man in Britain by about 5–7 per cent (with a large standard error) as opposed to 6–9 per cent in South Wales, the difference possibly reflecting the fact that normal hours had already been reduced in much of Britain prior to the legislation. Labour productivity in Britain is found to be positively and significantly related to the state of the coal trade, possibly indicating that \%\Delta\text{TRADE} and \%\Delta\text{GDP} are better business cycle proxies for Britain than for South Wales. These estimates are, however, somewhat sensitive to specification.

The time trend, after adjusting for autocorrelated residuals, is found to be very close to zero and not statistically significant. We interpret the coefficient on \text{TIME} as the net effect of technology and diminishing returns. While mechanical coal-cutters were used more extensively in much of Britain than in South Wales, technology appears to have just offset diminishing returns in mining. Our results are not consistent with Taylor’s view that diminishing returns in mining was the primary explanation for Britain’s decrease in labour productivity, or with the view that entrepreneurs failed. Indeed, we observe no statistically significant trend in labour productivity, after accounting for wage rates, strikes, hours legislation and the business cycle.
As a further check on our results regarding a negative labour productivity-wage relationship, we estimate models identical to those shown above except that marginal products of labour, measured by $\ln (W/P)$, are used as the dependent variables (see McCloskey, 1971 for a defence of the use of marginal products). Presented below are the wage coefficients from these regressions. Estimation is by the Beach–MacKinnon autoregressive AR1 procedure ($t$ ratios in parentheses):

<table>
<thead>
<tr>
<th></th>
<th>South Wales</th>
<th>Britain</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\ln (W)$ (nominal)</td>
<td>$-0.456$</td>
<td>$-0.657$</td>
</tr>
<tr>
<td>$(-4.72)$</td>
<td>$(-4.75)$</td>
<td></td>
</tr>
<tr>
<td>$\ln (W)$ (real)</td>
<td>$-0.299$</td>
<td>$-0.596$</td>
</tr>
<tr>
<td>$(2.19)$</td>
<td>$(-2.80)$</td>
<td></td>
</tr>
</tbody>
</table>

These results provide further supporting evidence that miners' negative labour supply response to rising wage rates was an important reason for the downturn in measured labour productivity during this period both in South Wales and in Britain.

IV

Economic historians have stressed the long-term negative impact on labour productivity from increasing wages and diminishing marginal returns in mining. While many of their arguments were persuasive, they were far from conclusive, primarily because of the failure to control statistically for the effects of other variables. Fortunately, data presented by Taylor and Walters make it possible to submit these arguments to more rigorous statistical testing.

Our study has attempted to isolate the effects on productivity from rising wages after accounting for the effects of the business cycle, strikes, hours legislation, diminishing returns and technological change. We find that strikes and hours legislation significantly reduced average output per worker, and that productivity was pro-cyclical, though apparently to a lesser degree than previously believed. The effects of technological change appear to have been minor, though we could not measure this directly. We find strong support for the contention that rising wage rates played a major role in explaining decreased productivity, this decrease taking the form of greater absenteeism, fewer hours of work and a lessened intensity of effort. Our evidence supports the view that coal prices influenced miners' wage rates, which in turn induced inverse labour supply responses. A negative labour productivity-wage relationship was found using single-equation and systems estimation techniques, with either the average product or marginal product as a labour productivity measure, and with individual coal company as well as aggregate data.

Neither in South Wales nor in Britain did we find any evidence of a significant negative time trend in productivity, after accounting for other determinants. Labour productivity appears to have been determined by factors largely beyond the control of mineowners. Our results cast further doubt on the argument by Taylor and others that entrepeneurs “failed” during this
period. Moreover, our evidence with respect to the price–wage–productivity relationship helps explain what has appeared to some to be a paradox: that the era of falling productivity was also one of financial prosperity for mine-owners. Rising prices brought higher profits and higher wages, but measured productivity also fell, at least in part owing to negative labour supply responses by miners.

ACKNOWLEDGMENTS

The authors thank Terry Seaks, David Kemme, Larry Neal and an anonymous referee for helpful suggestions.

APPENDIX: DATA SOURCES

<table>
<thead>
<tr>
<th>Variable</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>ln ((Q/L)_{sw})</td>
<td>Walters (1975), Table 1, p. 300, col. (4).</td>
</tr>
<tr>
<td>ln ((W)_{sw}^{(nominal)})</td>
<td>Walters (1975), Table 1, p. 300, col. (9).</td>
</tr>
<tr>
<td>ln ((W)_{sw}^{(real)})</td>
<td>Walters (1975), Table 1, p. 300, col. (11).</td>
</tr>
<tr>
<td>MINESIZE(^{sw})</td>
<td>Walters (1977), Table 36, pp. 269–70, estimated for 1874–78 from linear combination of Glamorganshire and Monmouthshire colliery size ((R^2 = 0.992) for 1879–1913), and for 1914 by 10-year log-linear trend ((R^2 = 0.681)).</td>
</tr>
<tr>
<td>ln ((Q/L)_{B})</td>
<td>Taylor (1961), Appendix I, pp. 68–69, col. (5).</td>
</tr>
<tr>
<td>ln ((W)_{B}^{(nominal)})</td>
<td>Taylor (1961), Appendix I, pp. 68–69, col. (9), estimated for 1874–78 from regression on index of average weekly wage rate for Britain, taken from Feinstein (1972), Table 65, p. T140, col. (1), (R^2 = 0.907) for 1879–1913.</td>
</tr>
<tr>
<td>ln ((W)_{B}^{(real)})</td>
<td>Adjusted by retail price index from Feinstein (1972), Table 65, p. T140, col. (3), 1913 = 100.</td>
</tr>
<tr>
<td>%ΔTRADE(^{B}^{(nominal)})</td>
<td>Domestic exports and imports from Mitchell and Deane (1971), Ch. XI, Table 3, pp. 283–84.</td>
</tr>
<tr>
<td>%ΔTRADE(^{B}^{(real)})</td>
<td>Adjusted by Board of Trade WPI in Mitchell and Deane (1971), Ch. XVI, Table 5, p. 476, 1900 = 100.</td>
</tr>
<tr>
<td>%ΔGDP(^{B}^{(nominal)})</td>
<td>GDP at factor cost from Feinstein (1972), Table 1, pp. T4–T5, col. (9).</td>
</tr>
<tr>
<td>%ΔGDP(^{B}^{(real)})</td>
<td>GDP at constant factor cost from Feinstein (1972), Table 8, pp. T24–T25, col. (5), 1913 = 100.</td>
</tr>
<tr>
<td>HOURS(^{L}A)</td>
<td>1 for years 1909 and after; 0 otherwise.</td>
</tr>
</tbody>
</table>

NOTES

1. Walters’ article is based on Chapter V of his reprinted doctoral dissertation (Walters, 1977). See also Taylor (1968) and for a similar discussion of an earlier period, Blanchard (1978). For a discussion of how colliery work was actually organized see Daunton (1981).

2. For a summary of the debate see McCloskey and Sandberg (1971). Those who suggest that the entrepreneur failed include Aldcroft (1964), Crafts (1979), Phillips (1980) and Greasley (1982). The most ardent champion of the entrepreneur has been McCloskey (1970). For specific consideration of the coal industry during this period see McCloskey (1971), and for later periods, Rhodes (1945), Lomax (1950) and Buxton (1970).

3. While both the Taylor and Walters papers are noteworthy for their collection of data and richness of discussion, neither utilizes standard statistical procedures to test hypotheses.

4. An alternative approach would be to derive and estimate a production function for coal-mining. Unfortunately, absence of data on capital and homogeneous labour inputs makes such an approach of dubious value. However, if one assumes that coalmining is characterized by a CES
production function, that competitive maximization conditions hold and that technological change is disembodied and Hicks-neutral, an estimatable equation in which the log of the average product of labour is a function of the log of the wage rate divided by product price and of time can be obtained. The coefficient on log of the wage rate divided by product price is an estimate of the elasticity of substitution, while the sign of that on time indicates the direction of technological change. See, for example, Kalt (1978). Estimation of such equations for Britain and South Wales indicate that elasticities of substitution were quite low, suggesting a limited ability of mineowners to substitute capital and labour in response to changes in relative factor prices, while negative coefficients on time suggest a secular decline in factor productivity. For the reasons pointed out above, we do not pursue this approach.

5 For discussion of the sliding scale, see Walters (1977, pp. 214-24), Morris and Williams (1960) and Porter (1970).

6 An exception to this approach is McCloskey (1971), who uses wages divided by coal price as a measure of marginal product.

7 Alternatively, a variable measuring the percentage change in output could be used. While this variable might measure more precisely business conditions in the coal trade, any unmeasured determinants of labour productivity (e.g., work intensity) or determinants not measured precisely (e.g., technology, diminishing returns) would simultaneously increase or decrease both measured labour productivity and the percentage change in output. Thus, the coefficient on the variable would be biased upwards and would overstate the true effect of the state of the coal trade on productivity.

8 Use of coal-cutters in South Wales was extremely limited as late as the interwar period; see Rhodes (1945, p. 101).

9 For a reivew of this extensive literature see Addison and Siebert (1979). Borjas (1980) has recently cast doubt on the accuracy of the empirical results in many of these studies.

10 While we are unable to identify precisely the manner in which reduced labour productivity took place in response to higher wages, it undoubtedly consisted of some combination of reduced work intensity and greater absenteeism, combined with reduced regular hours of work. Taylor (1961, p. 170) does present evidence on absenteeism in the Durham coal district from 1879 to 1907. While we do not know how behaviour in Durham compares to behaviour elsewhere, absenteeism in Durham rose significantly as wages rose. Indeed, the simple correlation between wages and absenteeism in Durham was 0.81. Thus, it is likely that some of the reduced labour supply due to higher wages took the form of greater absenteeism.

11 The percentage effect of a dummy variable on the dependent variable in a semi-logarithmic equation is approximated by \[ \frac{\exp (c - \frac{1}{2} \text{var}(c)) - 1}{100} \] where \( c \) is the coefficient of the dummy variable. For small values of \( c \) the coefficient multiplied by 100 provides a very close approximation. See Kennedy (1981).

12 For an earlier period, 1700-1770, the price elasticity of demand for coal in London was found by Hausman (1980) to be between -0.52 and -0.74.

13 Evidence from the Powell Duffryn Steam Coal Company during this period (Walters, 1977, p. 258) indicates that their “getting” costs of coal per ton were relatively stable or falling as a percentage of total costs, while “oncost” labour costs rose. Powell Duffryn’s increased need for “unproductive” workers reflects the aging of their mines and an increased distance from coal face to shaft.

14 In the absence of autoregression, Zellner’s seemingly unrelated regression (SUR) technique would have produced efficient estimators. With autoregression, the system becomes nonlinear and FIML is the only known efficient estimator. The first observation had to be dropped in order to obtain estimates of \( p \). Both FIML and the Beach–MacKinnon AR1 procedure are available in the most recent version (3.5) of TSP.

15 Gaps in the sample necessitated the use of OLS rather than alternative autoregression procedures. A fourth mining company, Ebbw Vale Steel Iron and Coal Co., had to be excluded owing to high autocorrelation. The wage variable is in nominal terms. Similar regressions were run using real variables, as well as %STRIKE and %ΔTRADE. The trade and strike variables were generally insignificant. Results from the wage variables were similar regardless of specification. The source for the individual company data was Walters (1977, p. 357).

16 We were able to use two alternative dependent variables for Britain, the output per worker above and below ground (as shown), and output per worker below ground (results not shown). The two measures were almost perfectly correlated \( r = 0.998 \) and regression results are virtually identical. It is thus likely that the labour productivity variable for South Wales, which measures output per man above and below ground, is also an excellent proxy for output per man below ground (on which we have no data).

REFERENCES


