PROBLEMS

The Economic Performance of Late Victorian Britain: Traditional Historians and Growth

William H. Phillips
University of South Carolina

When the techniques of the "new" economic history were initially applied by Profs. McCloskey and Sandberg to judge the Victorian British entrepreneur, the verdict was generally one of "not guilty" [2]. This conclusion is backed up by several sets of empirical discoveries. First, although British failure supposedly began in the 1870s, productivity growth — on a total factor basis — in a critical British industry such as iron and steel was not surpassed by the "modern" American industry until the 1890s or 1900s.[3] Secondly, on an absolute basis, efficiency in the British coal, iron, and steel sectors was still essentially second-to-none late in the decade of 1900.[4] Therefore, even when British productivity growth started to lag, this merely reflected a catching-up process by previously inferior competitors in the United States or the rapidly emerging German economy. A third area of research involves demonstrating that British failure to rapidly adopt certain industrial techniques such as the Thomas-Gilchrist process in steel or ring spinning in textiles was in fact rational given the factor prices faced by British producers. Nor can the loss of specific overseas markets be blamed on British technological stagnation, due

[1] Gratitude for their patience and guidance is extended to my thesis supervisors, Profs. Charles P. Kindleberger and Peter Temin. Thanks are also due to Roderick Floud, William Kennedy, Richard Vedder, and the members of the Research Triangle Economic History Workshop. The usual disclaimers apply.

[2] D.N. McCloskey, "Did Victorian Britain Fail?", *Economic History Review*, 2nd ser. XXIII (1970), 446-59; McCloskey and L.G. Sandberg, "From Damnation to Redemption: Judgements on the Late Victorian Entrepreneur", *Explorations in Economic History*, IX (1971-2), 89-108.

[3] McCloskey, *Economic Maturity and Entrepreneurial Decline: British Iron and Steel, 1870-1913* (Cambridge, Mass., 1973), chapter 5.

[4] Ibid., chapter 7, and "International Differences in Productivity? Coal and Steel in America and Britain before World War I", in McCloskey, ed., *Essays on a Mature Economy: Britain after 1840* (Princeton, 1971), pp. 285-309.

to the maturing of competing nations more ideally located for servicing such areas.[5] Finally, through simple counterfactual exercises, it is shown that the few occasional inefficiencies that did or could conceivably have existed (e.g. an artificially low British savings rate or a 2 or 3 percent efficiency edge for American steel in 1907) are unable to account for any major effect on the growth rate of the British economy.[6]

Many of these calculations have recently been challenged, and the Victorian entrepreneur controversy appears to be re-opening.[7] The purpose of this paper is to propose a new approach to viewing the concept of economic failure. Much of the present new economic history work on this topic, both in the McCloskey-Sandberg tradition and in the subsequent rebuttals, deals with an "objective" definition of failure. That is, failure is defined by differences in absolute productivity, productivity growth rates, or measured costs in using different techniques. The problem is that such an approach implicitly makes technology exogenous to the model. If overall British efficiency or a particular British technique is better than foreign achievements, no failure exists, since the best methods seen are the best available given the constraints of present technology. But if technology is in some sense responsive to internal incentives or efforts, is it not possible that Britain failed by losing a lead earlier than was necessary? Perhaps economic failure can consist of ignoring the clues to cost-saving of foreign innovations and not subsequently adapting them to local factor prices. Does relative economic growth solely depend on waiting for the "natural" advance of internal technology and only borrowing foreign innovations that can be plugged "as is" into domestic industry at a savings in costs?

I

From the point of view of what I will refer to as "traditional" historians of the Victorian British economy, technology is endogenous, and although direct comparisons of British and foreign technology are important, also important is the question of where British industry *should* have been. What improvements in technology could British entrepreneurs reasonably have been

[5] McCloskey, *Economic Maturity*, chapters 3 and 4; Sandberg, "American Rings and English Mules: The Role of Economic Rationality", *Quarterly Journal of Economics* LXXXIII (1969), 25-43.

[6] McCloskey, "Did Victorian Britian Fail?", and *Economic Maturity*, pp. 16-20.

[7] R.C. Allen, "The Peculiar Productivity History of American Blast Furnaces, 1840-1913", *Journal of Economic History*, XXXVII (1977), 605-33, and "International Competition in Iron and Steel, 1850-1913", *Jour. of Econ. Hist.* XXXIX (1979), 911-37; P. Berck, "Hard Driving and Efficiency: Iron Production in 1890", *Jour. of Econ. Hist.* XXXVIII (1978), 879-900; S.B. Webb, "Tariffs, Cartels, Technology, and Growth in the German Steel Industry, 1879 to 1914", *Jour. of Econ. Hist.*, XL (1980), 309-29; W. Lazonick, "Factor Costs and the Diffusion of Ring Spinning in Britain Prior to World War I", *Quar. Jour. of Econ.* XCVI (1981), 89-109.

expected to make, either on their own, or through modification of foreign improvements? The most recent example of this approach comes from Professor Kindleberger, who in his comparative survey of German and British growth in the nineteenth century gives the following definition to the late Victorian British problem: "there is no doubt that German economic growth after 1873 was fast, and faster than that of Great Britain. The question which is unsettled is whether the British economy slowed down, suffered a "climacteric", a maturing or aging process, and lost its capacity to adapt and to respond to economic signals".[8] As implied above, Kindleberger's most basic criticism of McCloskey and the other new economic historians lies in their assumption of exogenous technological limits.

> "But no consideration was given to the possible relevance of a model... in which among the ways to maximize profits were to alter technology so as to reduce costs, economize on a scarce resource, make more effective use of an abundant resource, or reorder institutions, such as substituting direct selling for the merchant, in an effort to overcome barriers to still higher profits".[9]
> "In a static model the problem is to maximize some function within given constraints. But [with] dynamic models... it is possible to break such constraints down... Bottlenecks can be limiting in a static model, or stimulating in a dynamic one".[10]

To Kindleberger and other traditional historians,[11] one of the major problems of the late Victorian British economy was that whereas previously the United Kingdom had initiated technical change and diffusion internally, it now let others invent and was then unable to modify these processes to British conditions. Therefore, in the following section we will construct an updated traditionalist's view of Victorian Britain and the more general economics of decline. The main task will be to model technology in an endogenous fashion. Obviously, given our knowledge of the processes of technological change, such an approach is likely to be much more subjective than the current focus of new economic history research on British growth. And just what model of technological progress should be used? The most empirically explicit fields of the economics of technology include those that focus on the embodiment of technical change in new capital equipment or on the influence

[8] C.P. KINDLEBERGER, "Germany's Overtaking of England, 1806-1914", *Weltwirtschafliches Archiv*, CXI (1975), 489.

[9] Ibid., 490.

[10] Ibid., 490-1.

[11] For example, see D.H. ALDCROFT and H.W. RICHARDSON, *The British Economy, 1870-1939* (New York, 1970); H.J. HABAKKUK, *American and British Technology in the Nineteenth Century: The Search for Labour-Saving Inventions* (Cambridge, 1962); D. LANDES, "Technical Change and Development in Western Europe, 1750-1914", in H.J. HABAKKUK and M.M. POSTAN, eds. *Cambridge Economic History of Europe*, VI, pt. 1, *The Industrial Revolution and After* (Cambridge, 1965), 553-84.

of full time research and development.[12] In these cases, it is such things as profits, expected payoffs, growth of the market, and depreciation which can influence productivity growth. Although promising, such treatments appear much more suited to modern firms with institutionalized research departments.[13]

The model of endogenous technical change that appears most relevant for our study of Victorian Britain is that of induced innovation. The basic induced innovation hypothesis is simply that technical change is biased towards the saving of expensive factors of production.[14] From this, it is only a short step before one tries to explain specific technological developments by the scarcity of certain factors of production. For example, there is the role of dwindling wood supplies in stimulating the development of coke-smelting of iron or of abundant wood supplies in stimulating American machine tool developments.[15] Furthermore, in the work of Habakkuk, factor prices not only induce specific innovations, they also spur the overall rate of technical change.[16] Presumably it is entrepreneurs who are responding to these price signals and implementing the appropriate technologies. Therefore, if the rate of technological change is enhanced by changing factor prices, given the responsiveness of entrepreneurs, cannot efficiency growth slow down if, as Kindleberger argues, the economy loses its capacity to respond to the factor-price signals? The major theoretical obstacle is that of distinguishing between an "induced" innovation and the ordinary substitution of factors that takes place when factor prices change. The diagrammatic treatment of the next section seeks to do this, as well as to show how induced innovation can explain relative economic growth and in turn be used to search for economic failure.

II

From a strictly neoclassical point of view, a firm that pays each factor the value of its marginal product cannot possibly consider the price of any input

[12] E. MANSFIELD, *Industrial Research and Technological Innovation: An Econometric Analysis* (New York, 1968); JACOB SCHMOOKLER, *Invention and Economic Growth* (Cambridge, Mass., 1966); ZVI GRILICHES, "Hybrid Corn: An Exploration in the Economics of Technological Change", *Econometrica* XXV (1957), 501-22.

[13] Note however the following uses of embodiment models in history: P. TEMIN, "The Relative Decline of the British Steel Industry, 1880-1913", in H. ROSOVSKY, ed. *Industrialization in Two Systems* (New York, 1966), chapter 5; J. WILLIAMSON, "Embodiment, Disembodiment, Learning by Doing, and Returns to Scale in Nineteenth-Century Cotton Textiles", *Jour. of Econ. Hist.* XXXII (1972), 691-705.

[14] J. HICKS, *The Theory of Wages* (New York, 1932), pp. 124-5.

[15] LANDES, loc. cit. 320-25; N. ROSENBERG, "Technological Change in the Machine Tool Industry, 1840-1910", *Jour. of Econ. Hist.* XXIII (1963), 414-43.

[16] HABAKKUK, op. cit.

as relatively "high" or "low" and so be induced to innovate. Reactions to factor prices within the bounds of technological knowledge by definition involve merely factor substitution. Nevertheless, Profs. Atkinson and Stiglitz have challenged the prevailing treatment of technical change because of the increasing emphasis given to the role of numerous individual techniques in the rigorous construction of a production function.[17]

> "The different points on the [isoquant] curve represent different processes of production, and associated with each of these processes there will be certain technical knowledge specific to that technique... If one brings about a technological improvement in one of the blueprints this may have little or no effect on the other blueprints"[18]

Once one accepts this point of view, the distinction between factor substitution and innovation in history can then be questioned for its realism, as for example by Nathan Rosenberg.

> "... where only a small range of alternative techniques is known, what becomes of the fundamental distinction between factor substitution and technological change? If, in response to a change in factor prices, a firm has to commit resources to establishing new optimal input mixes, should not the activity leading to the new knowledge be described as technological change and not factor substitution?".[19]

What is needed is a concept that can differentiate between the "ordinary" substitution of factors among known techniques of production and the "original" induced innovation for adapting to new factor-price relationships. Such a concept has been introduced by Profs. Hayami and Ruttan, who refer to a "metaproduction function".

> "The metaproduction function can be regarded as the envelope of commonly conceived neoclassical production functions. In the *short-run*, in which substitution among inputs is circumscribed by the rigidity of existing capital and equipment, production relationships can best be described by an activity with relatively fixed factor-factor and factor-product ratios. In the *long-run*, in which the constraints exercised by existing capital disappear and are replaced by the fund of available technical knowledge, including all alternative feasible factor-factor and factor-product combinations, production relationships can be adequately described by the neoclassical production function. In the *secular period* of production, in which the constraints given by the available fund of technical knowledge are further relaxed to admit all potentially discoverable possibilities, production relationships can be described

[17] A.B. Atkinson and J.E. Stiglitz, "A New View of Technological Change", *Economic Journal*, LXXIX (1969), 573-8.

[18] Ibid., 573.

[19] N. Rosenberg, "Problems in the Economist's Conception of Technological Innovation", *History of Political Economy*, VII (1975), 459.

by a meta-production function which describes all conceivable technical alternatives that might be discovered".[20]

Let us now diagrammatically see how such a perspective on invention might be applicable to a traditionalist view of growth. In the isoquant diagram of figure 1, an economy is said to begin at point A, using a fixed factor-coefficient technique of production (T_0). This process minimizes the costs of production at relative factor prices P_0, lying along the smooth and continuous metaproduction function (MF), which allows for potential induced innovations. For industrializing economies of the late Victorian era (Britain, Germany, and the United States), we will accept the Hicksian "stylized fact" that the relative price of capital to labour falls over time. It can then be argued that a great deal of technological innovation goes hand-in-hand with traditional factor substitution and involves the continuous working out of new more capital-intensive techniques like T_1, in response to ever steeper price lines such as P_1. However, from a historical perspective, this working out is never as smooth and automatic as one would like. In harmony with Kindleberger's thought, moving from point A to point Z requires breaking the static constraint of the present technique. Therefore, a dynamic economy will use technological flexibility to quickly move from A to Z and act as if MF was its real neoclassical production function (i.e., take full advantage of its potential adaptive capabilities). On the other hand, the stagnant or fossilized nation will remain at A when relative factor prices move from P_0 to P_1. And other things equal, this nation will inevitably lose its relative income position at the new factor prices, since it cannot produce its output at the same cost (note the parallel isocost lines of the two economies formed when the new P_1 price lines run through points Z and A respectively).

Of course, this picture of the wholly dynamic nation versus the completely static economy is overdrawn and lacks any story about the movement from T_0 to T_1. In the isoquant diagram of figure 2, the severe non-substitutability of factors in the availability of techniques is relaxed so that any economy, dynamic or static, will substitute factors as prices change, and move along a regular production function (PF) from A to M (T_0 to T_1). From this point, the realization of the untapped scientific knowledge contained in the metaproduction function will generate a localized search for improved techniques of production. We can visualize a random sequence of small discrete improvements in techniques that are inevitably closely related to the starting point M. Each localized step can imply any change in factor ratios or absolute factor usage as long as the new technique installed costs less at prices P_1 (note the parallel price or isocost lines). In the long run, this evolutionary profit search would seek out point Z (T_2), the new optimum along the metaproduction function.[21]

[20] Y. Hayami and V.W. Ruttan, *Agricultural Development: An International Perspective* (Baltimore, 1971), pp. 82-3.

[21] In addition to the previous references in this section, the analysis is also heavily

In a traditionalist's world, a technologically responsive country will pursue the search for point Z quickly and efficiently, perhaps undertaking several paths at once, so as to maximize the possibility of finding the shortest route. The fossilized nation will instead complain about the higher price of labour, only haltingly financing one search path, perhaps withdrawing support should this path reach an apparent impasse. Eventually, the nation dynamic will reach the economically feasible limit of the frontier of pure knowledge, while the nation static has only slightly progressed beyond M. Should the two idealized nations possess MFs and PFs of approximately the same elasticity of substitution, the dynamic nation will appear to have the higher elasticity, due to its ability to respond to factor scarcities. Moreover, when factor prices differ between countries, we may get the paradox of the 'progressive' technique not being rational in a static economy despite free access to the blueprints. As shown below, it could then be said that perhaps Britain began to suffer once she became a borrower and poor adapter, rather than continuing to produce inventions geared to her own price structure.

Figure 3 applies our induced innovation framework to the case of the late Victorian United Kingdom. New economic historians such as McCloskey have disputed the old accusations of British entrepreneurial failure in this period by computing the costs of progressive German and American techniques if applied in England, and finding them no cheaper than the supposedly static local methods. The reason is that the new techniques are geared to different factor proportions. But more traditional historians would not consider this neglect of techniques therefore rational, but rather would consider this a symptom of British failure to adapt the latest methods to local conditions. When the German and American isoquant techniques at points G and A are evaluated at British prices P_{UK} through the use of isocost lines, they appear inferior to the English production method at point B. But in fact, the traditional argument implies that the British are no longer successfully inducing new techniques from the latest scientific knowledge, creating a gap between actual practice and the metaproduction function. In the course of development, the ability of entrepreneurs to adapt to changing factor prices has fallen, and the distance between point B and the optimum point O is indicative of the relative British decline. The resulting conclusion is that much of the economics of relative decline is closely related to induced innovational ability and the consequent substitutability (read 'flexibility', 'adaptability', 'responsiveness') present in a society.

indebted to the work of PAUL DAVID, RICHARD NELSON and SIDNEY WINTER: P. DAVID, "Labor Scarcity and the Problem of Technological Practice and Progress in Nineteenth-Century America", in P. DAVID, *Technical Choice, Innovation and Economic Growth* (Cambridge, 1975), pp. 19-91; R.R. NELSON and S.G. WINTER, "Factor Price Changes and Substitution in an Evolutionary Model", *Bell Journal of Economics* VI (1975), 466-86.

Figure 1

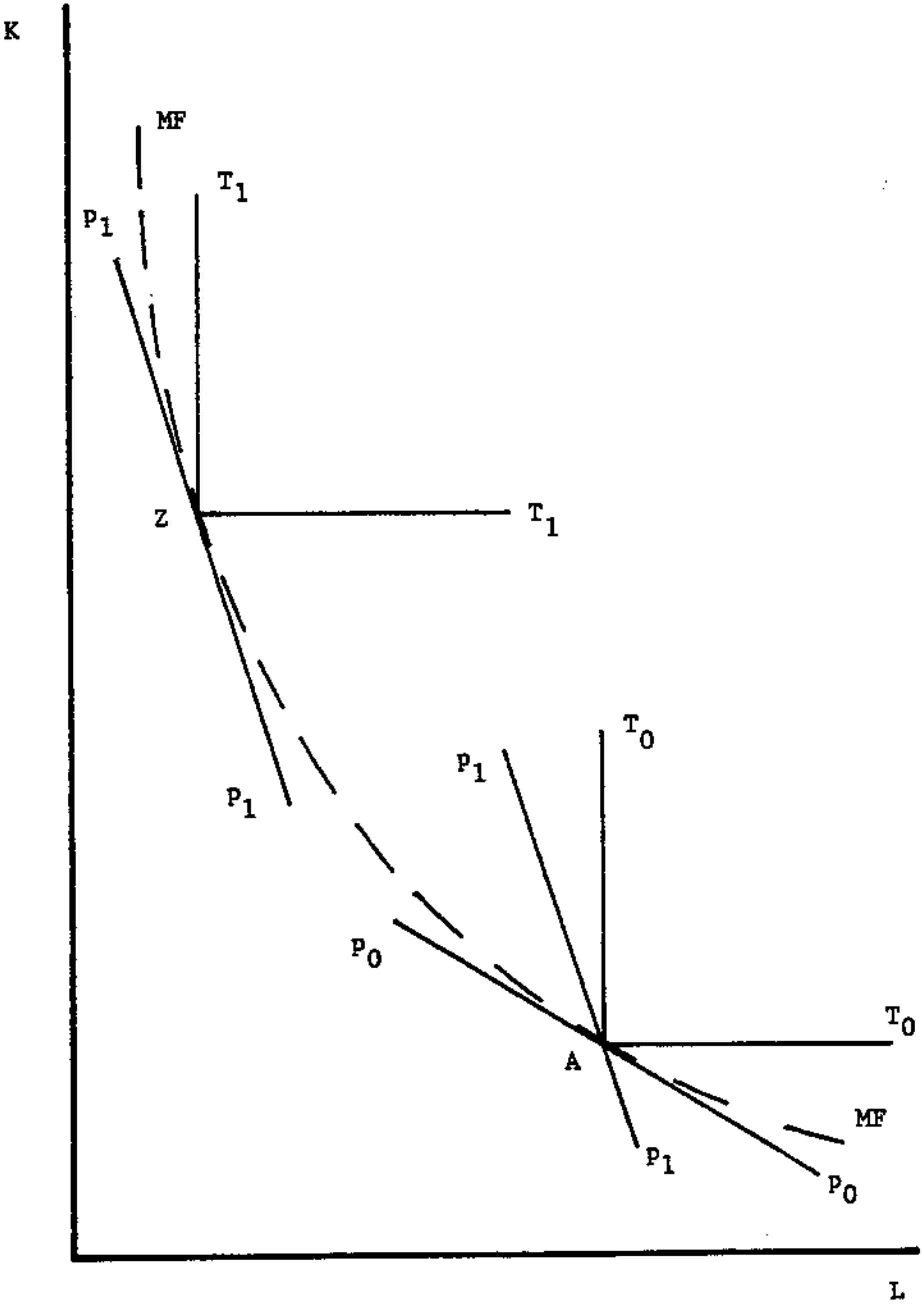


Figure 2

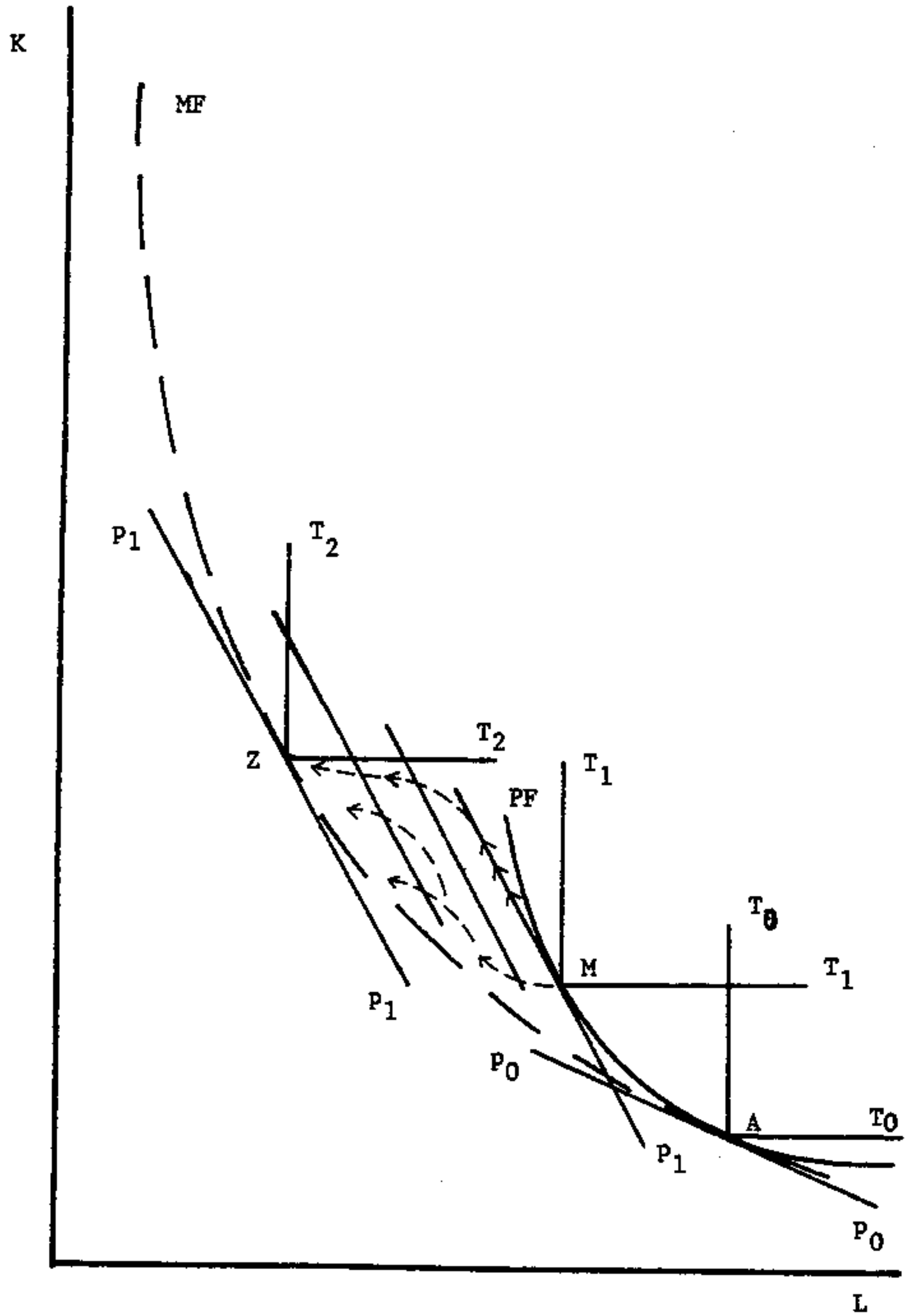
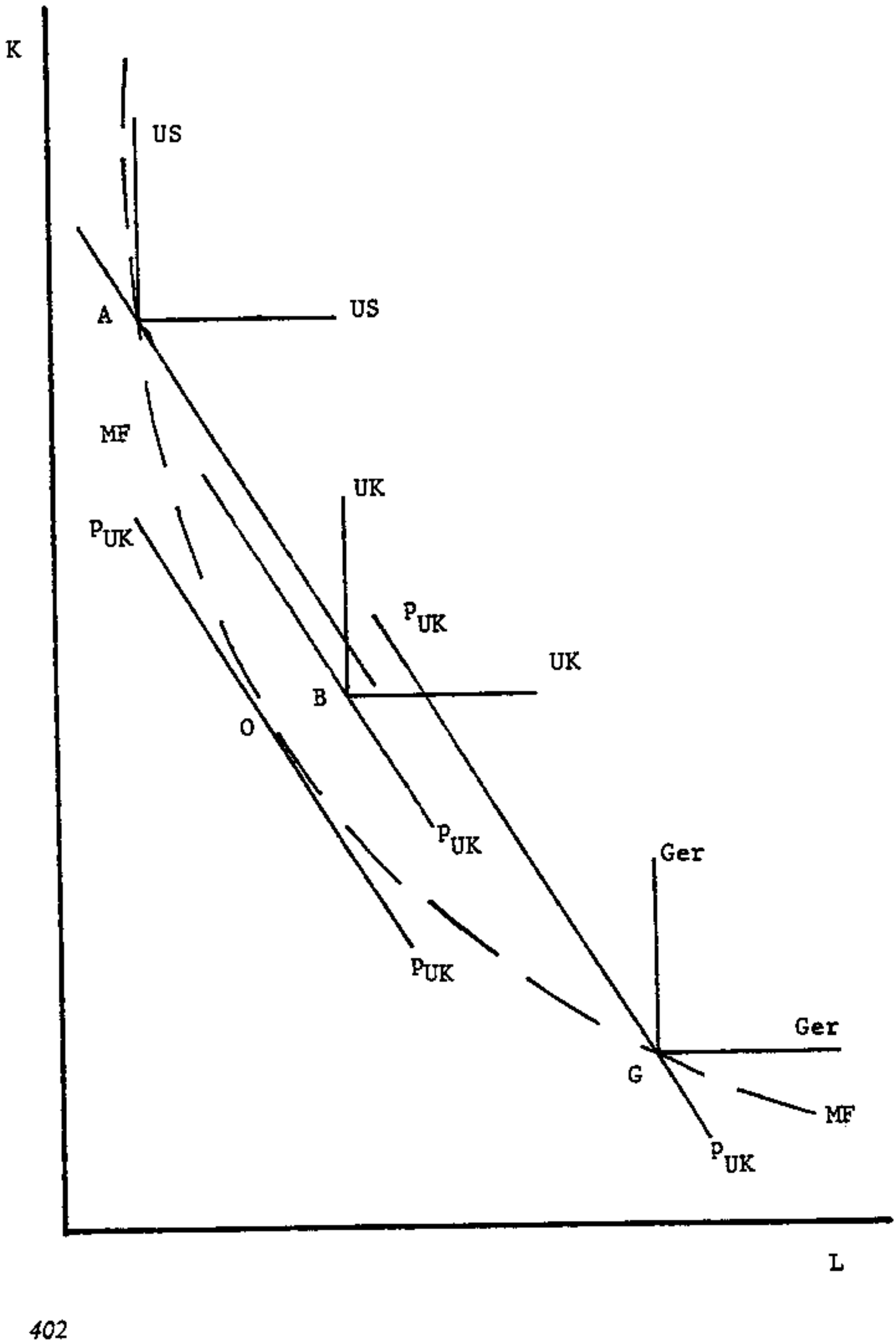


Figure 3



III

The traditional historian's opinion of late Victorian Britain has now been conceptually tied to induced innovation. Through the use of this model, we have demonstrated how a decline in the ability of entrepreneurs to induce innovations successfully can result in unnecessarily high costs of production. Also shown is how a growing reliance on borrowing foreign technology can backfire. If new innovations are specific to the factor prices where the new techniques are conceived, modern technology can appear more costly than backward technology in the borrowing nation. British industry may not have been able to lower costs with foreign techniques as used abroad, but still may have been passing up opportunities for cost-cutting by selective adaptation. Alternatively, why did British entrepreneurs not develop the new technologies themselves, originally geared to British conditions?

However, an insistence that economic failure is possible is no substitute for proving that such a failure did in fact happen. The traditional arguments about British decline are not new, but new economic historians have often faulted them for not having an empirically testable basis. It is hoped that by putting the traditional approach into the induced innovation framework, one can open up a new research agenda for direct testing of the hypothesis of economic failure. General questions to be raised include: 1) is technical change actually biased by factor prices? That is, does induced innovation actually exist? 2) if induced innovation does exist, can it be empirically connected with the overall rate of technical progress or with economic growth and development? To date, the most serious attempt at approaching these issues comes from the work of Hans Binswanger and his colleagues, and to be frank, the results are at best ambiguous.[22] Induced innovation is still just a hypothesis, and an unproven one at that.

Nevertheless, if induced innovation does exist, and can be shown vital to the economic well-being of a nation, what is necessary to explain the British climacteric with this approach? First, one must show that induced innovation was at work at one point in the British economy, but that during the time of the climacteric, induced innovation activity disappeared or was sharply reduced. Secondly, it is then imperative to be able to demonstrate that any decline or disappearance of induced innovation can account for a substantial injury to the British economy, either through an increase in costs, loss in efficiency or markets, or a reduction in economic growth or welfare. Given the breadth of the research programme, the remainder of this paper will deal exclusively with the issue of a decline in induced innovations in the late nineteenth-century British economy. Two empirical tests for the existence of induced innovations will be tried in the following sections. One is based on aggregated

[22] H.P. Binswanger, V.W. Ruttan et. al., *Induced Innovation: Technology, Institutions and Development* (Baltimore, 1971).

data on British factor use and factor prices, whereas the second concentrates on the British coal sector. With the measurement errors inherent in the data, it is encouraging that the separate results are quite consistent with each other, and so strengthen our confidence in their meaning.

IV

In the discussion of figure 2 above, it was noted that the ability of dynamic nations to adjust their techniques of production rapidly would lead to the appearance of having a greater overall elasticity of substitution. Our first test for induced innovation essentially attempts to measure these elasticities over the 'secular' period of production as defined previously by Hayami and Ruttan. Through the documentation of drastic changes in factor use in agriculture for various nations, Hayami, Ruttan, and Binswanger have argued that factor substitution alone cannot historically explain the apparently high elasticities of substitution in agricultural production.[23] Induced innovation must be at work. For the British and German economies, we are therefore seeking to measure:

$$\sigma = \frac{\text{percentage change in capital-labour ratio}}{\text{percentage change in labour price-capital price ratio}}$$

$$= \frac{(K/L)_{i+1} - (K/L)_i}{(P_L/P_K)_i - (P_L/P_K)_{i+1}} \times \sqrt{\frac{(P_L/P_K)_{i+1}\,(P_L/P_K)_i}{(K/L)_{i+1}\,(K/L)_i}}$$

where i and i+1 are the time periods defining the secular period of production, and geometric means are used in calculating the percentage changes in capital-labor use (K/L) in response to percentage changes in the wage-rental ratio (P_L/P_K).

Within the framework of the British climacteric, we are asking whether or not the apparent elasticity of substitution in production declined at some crucial point late in the nineteenth century. If so, one could use the analysis of figure 2 to claim that such a decline was the result of reduced induced innovative activity by British entrepreneurs. For comparison purposes, our test is also applied to the German economy. Five-year moving averages of the capital-labour ratio and the wage-rental ratio were calculated for the United Kingdom from 1855 to 1914, using the aggregate data of Professor Feinstein. The wage-rental ratio was based on a weekly wage earnings index divided by

[23] HAYAMI and RUTTAN, "Factor Prices and Technical Change in Agricultural Development: The United States and Japan, 1880-1960", *Journal of Political Economy*, LXXVIII (1970), 1115-41; RUTTAN, BINSWANGER, HAYAMI et. al., "Factor Productivity and Growth: A Historical Interpretation", in Binswanger, Ruttan et. al., op. cit. 44-87.

the gross capital stock deflator. Professor Hoffmann's benchmark estimates for Germany were used through 1875, after which time moving averages could be created with the annual data running to 1913. This German wage-rental ratio was based on an index of worker's income relative to a gross capital stock price deflator. A selected sequence of the estimates for σ are presented in table 1.

Table 1
NECESSARY ELASTICITY OF SUBSTITUTION TO EXPLAIN CHANGES IN CAPITAL-LABOUR RATIOS BY PRICE EFFECTS (σ)
UNITED KINGDOM 1855-1914 – GERMANY 1852-1913

United Kingdom		Germany	
Ten-year periods			
1862-1872	−0.29	1852-1861	−0.69
1872-1882	−1.06	1861-1875	−0.78
1882-1892	−0.14	1875-1886	−0.78
1892-1902	−3.83	1886-1896	−1.01
1902-1912	−6.82	1896-1906	−3.20
Fifteen-year periods			
1862-1877	−0.65	1855-1867	−0.51
1877-1892	−0.23	1867-1881	−0.64
1892-1907	−2.18	1881-1896	−1.21
		1896-1911	−1.74

Source: C.H. Feinstein, *National Income, Expenditure and Output of the United Kingdom, 1855-1965* (Cambridge, 1972), tables 20, 43, 46, and 65; W.G. Hoffmann, *Das Wachstum der Deutschen Wirtschaft* (Berlin, 1965), tables 20, 39, 40, and 119.

In the British sequence of ten-year periods, the pattern is one of very low elasticities of substitution in the 1860s and 1880s, with an intervening period of moderation in the 1870s. From 1892 on, the adaptability of the British economy seems to make a great surge forward. Analysis of the fifteen-year periods confirms a pattern of a moderate elasticity until the late 1870s, an extreme lack of substitution capability until the early 1890s, with the ensuing acquisition of flexibility thereafter. Proponents of a British climacteric would then need to point to the 1880s as a time in which the British economy was seemingly unable to adjust to factor-price signals. But if there is evidence of a fall in the United Kingdom's technological responsiveness at this time, one might argue that this is dominated by the evidence of an even more substantial revival going into the twentieth century. For this reason, we turn to the German results, where a similar rise in elasticities also takes place. However, there is no indication in the German economy of the extremely low elasticities in the middle of the sample.

The conclusion from this test must be cautious. The yeoman work of Feinstein and Hoffmann cannot eliminate the wide margin of error in the figures, relative to what they are being asked to do. Particularly dangerous is the temptation to compare the German and British elasticities on an absolute basis. These data sets are not that comparable, so only the pattern of these elasticities over time should be used. In Germany, the pattern is one of an increasing amount of flexibility over time. In the United Kingdom, on the other hand, there are definite setbacks. Relative to Germany, the aggregate production function of the United Kingdom does display the characteristics of a static economy around the time of the 1880s.

V

Our second study of the late Victorian British economy involves a direct econometric test for the existence of induced innovation in the British coal industry. That is, we are seeking to estimate the production function of the British coal sector, to measure any bias in the technical progression of this function over time, and finally to see if this bias is responsive to factor prices in a manner consistent with the induced innovation hypothesis. The estimation procedure is built around a translog cost function as used by Binswanger and subsequently, Rodney Stevenson.[24] Through the use of logarithmic derivatives (see Appendix A), one can write an expression for the share of output paid to any factor of production:

$$S_i = \nu_i + \sum_j \gamma_{ij} \ln W_j + \beta_i \ln Y + \omega_i T + \sum_j \omega_{ij} T \ln W_j + \Theta_i T \ln Y$$

where S_i = factor share i
$\ln W_j$ = natural log of factor price j
$\ln Y$ = natural log of output
T = time

In this equation, the γ_{ij} coefficients determine the partial elasticities of substitution for the production function (Appendix A). β_i provides a test for whether this function is homothetic or not, while ω_i measures the exogenous bias of technological change, Q_i, as determined by the behavior of factor shares over time:

$$Q_i = \alpha S_i/\alpha T = \omega_i \begin{array}{ll} < 0 & \text{i - saving} \\ > 0 & \text{i - using} \end{array}$$

The cross-term coefficients, ω_{ij}, and Θ_i, allow for endogenous technological effects by charting how the bias of technical change responds to either factor

[24] BINSWANGER, "Measured Biases of Technical Change: The United States", in Binswanger, Ruttan, et.al., op. cit. 215-42; RODNEY STEVENSON, "Measuring Technological Bias", *American Economic Review* LXX (1980), 162-73.

prices or output. In our study, ω_{ij} now gives us a direct test of the induced innovation hypothesis, since it represents the change in factor shares over time — due to bias — in response to factor prices:

$$\alpha^2 S_i / \alpha T \alpha \ 1n \ W_j = \omega_{ij}$$

As described below and in Appendix B, the aggregate data of the British coal sector can only be separated into two factor shares, namely 'labor' and 'other'. Therefore, the coal industry production function is described by the following two factor share equations:

$$S_L = v_L + \gamma_{LL} \ 1n \ W_L + \gamma_{Lo} \ 1n \ W_0 + \beta_L \ 1n \ Y + \omega_L \ T + \omega_{LL} \ (T \cdot 1n \ W_L) + \omega_{Lo} (T \cdot 1n \ W_0) + \Theta_L (T \cdot 1n \ Y)$$

$$S_0 = v_0 + \gamma_{0L} \ 1n \ W_L + \gamma_{00} \ 1n \ W_0 + \beta_0 \ 1n \ Y + \omega_0 \ T + \omega_{0L} \ (T \cdot 1n \ W_L) + \omega_{00} (T \cdot 1n \ W_0) + \Theta_0 (T \cdot 1n \ Y)$$

In all of the regression work, symmetry was imposed: $\gamma_{OL} = \gamma_{Lo}$ and $\omega_{OL} = \omega_{LO}$. Tests were applied to see if the production function was homogeneous, in which case $\sum_i \gamma_{ij} = \sum_j \gamma_{ij} = \sum_i \sum_j \gamma_{ij} = 0$, $\sum_i \omega_{ij} = \sum_j \omega_{ij} = \sum_i \sum_j \omega_{ij} = 0$, $\sum_i \upsilon_i = 0$, $\sum_i \beta_i = 0$, $\sum_i \omega_i = 0$, and $\sum_i \Theta_i = 0$. Tests were also applied to see if the production function was homothetic: $\beta_L = 0$, $\beta_0 = 0$, $\Theta_L = 0$, and $\Theta_0 = 0$.

If induced innovation is active, one would expect that if labour costs (W_L) were to rise, then over time the bias of technical change should act to reduce labour's share of output (S_L). In other words, we expect to find a negative coefficient for ω_{LL}. Similarly, one would look for $\omega_{00} < 0$. Cross-coefficients should be positive — $\omega_{Lo} = \omega_{0L} > 0$ — if innovations are induced. However, caution must be exercised in that the factor prices must be exogenous to the coal industry for the expected patterns to follow.[25] If the coal sector can reasonably be assumed to be tapped into a national labour market, then the labour-saving innovations induced by rising relative wages should have negligible effect on these wages. However, as noted below, the 'other' factor includes the rents to coal land. Should a rise in the price of this land induce a profound land-saving innovation — a decrease in unrecovered coal dust — then it may cause the price of the land to go back down and cover up the 'inducement' of induced innovation. For this reason, even though all of the ω_{ij} coefficients will be looked at in our test, ω_{LL} must be considered our best guide to determining whether there is evidence of induced innovation.

Again the question arises of how to apply our induced innovation tests to the study of supposed British economic failure. Earlier analysis in the paper implies that dynamic economies behave according to the induced innovation hypothesis, while static economies do not. We need to apply our two-

[25] Binswanger, loc. cit. 216.

equation model over a long enough period of time — in this case 1864 to 1914 — to permit the British coal sector to demonstrate dynamic behaviour over some parts of the sample; static behaviour over others. The 51 years of data can at most be broken into three separate periods and yet permit adequate degrees of freedom in the regressions. The model therefore was run repeatedly over varying samples of the data set of between 15 and 19 years in duration. The partition of the data into the periods 1864-79, 1880-97, and 1898-1914 generated the greatest reduction in the residual sum-of-squares compared to a regression run over the entire 51-year period.[26] Therefore, the results presented below and in Appendix C are based on this division. A traditional historian is looking for the following evidence of a climacteric: 1) a rejection of the induced innovation hypothesis during the 1880-97 sample, consistent with the low British estimate for σ from 1877 to 1892 in table 1; 2) acceptance of the induced innovation hypothesis during the 1898-1914 sample, consistent with the high British estimate for σ from 1892 to 1907; 3) a result somewhere in between for the 1864-1879 sample, consistent with the moderate estimate for σ from 1862 to 1877.

The data needed for the model consists of real indexes of the factor prices for labour and other (W_L and W_0), coal output (Y), and the shares of revenue paid to labor and other (S_L and S_0). An index of nominal wages is available in the *Abstract of British Historical Statistics* (see Appendix B) from 1880 onwards, with occasional benchmark estimates beforehand. Interpolations using Feinstein's weekly wage rate series fill in the gaps. The nominal wages are made 'real' in the production sense through division by the price of coal output. An adjustment is also made based on the Eight Hours Bill of 1909. The price index for the 'other' factor is a weighted average of various components, as determined by McCloskey's analysis of factor shares, using the 1919 *Reports of the Coal Industry Commission*.[27] The result of this process is also put into a real form when divided by the coal price index. Coal output (Y) is directly available from the *Abstract*.

The share of revenue given to labour is determined from the following equation:

$$S_L = (\hat{W}_L \cdot L) / (P_C \cdot Y)$$

where $\hat{W}_L$ represents the nominal wages paid to labour (L), and P_C represents the price paid for coal output (Y). The latter two variables can be retrie-

[26] All of the partitions tried were able to reject the hypothesis of a uniform production function over the entire data set. The F-statistics — 16 degrees of freedom in the numerator, 27 in the denominator — generated by these tests ranged from a low of 10.5 to a high of 20.7 for the 1864-79, 1880-97, 1898-1914 partition reported in the paper.

[27] McCloskey, "International Differences in Productivity? Coal and Steel in America and Britain before World War I", p. 301.

ved from the *Abstract,* but the estimates for labour employed in the coal fields had to be cut ten percent to yield reasonable labour share estimates. This is consistent with McCloskey's findings, where he also reduced the estimates by ten percent to correct for apparently normal absenteism and some non-coal mine coverage in the statistics.[28] To complete the equation, the nominal wage index described above must be translated into the actual amounts of money paid. An average annual wage of £ 51.4 was derived from the *Returns of Wages* for the North Staffordshire district during the year 1877. The nominal wage index was then applied to this benchmark. After the share of labour was computed, the share paid to the 'other' factor was the residual.

As should be apparent from the description of the data construction procedures, a margin of error is present. Therefore, we should bear in mind the tendency of measurement errors to bias regression coefficients towards zero. However, in 1919 the Coal Industry Commission estimated the share of coal revenue being paid to labour at 65 percent. This can be compared to the estimate of S_L one would derive for 1920 — the first one possible after World War I — through the use of our methods and assumptions, namely 66 percent. Given the constraints, the available data seems good enough to yield interesting analytical conclusions. Ordinary least squares analysis was applied, and the results are presented in table 2 and in Appendix C.[29]

Table 2 reveals the estimated coefficients and standard errors for the ω_{ij} parameters of our model. These are the coefficients that are crucial in the induced innovation tests, and so are separated for clarity from the full regression results (Appendix C). Homogeneity of the production function was rejected by the regression procedures. Neither is the production function homothetic in the last two partitions of the sample: 1880-97 and 1898-1914. On the other hand homotheticity cannot be rejected in the period 1864 to 1879. This appears to be due to a multicollinearity problem between coal output and time in the early part of the data set.[30] Tests for serial correlation were either rejected or inconclusive.

In an induced innovation model, the own-price bias of technical change should be negative, while the cross-price biases should be positive. By this guide, the induced innovation hypothesis is fully accepted during the 1898-1914 period, and fully rejected in the 1880-1897 period. All of these coeffi-

[28] Ibid., 291.

[29] It would be theoretically desirable to use a simultaneous-equation procedure since this model is an example of Zellner's seemingly-unrelated-regressions problem. Yet, since S_L and S_0 add up to one, one equation must be dropped to avoid a linear dependence problem. The system degenerates into ordinary least squares. See A. Zellner, "An Efficient Method of Estimating Seemingly Unrelated Regressions and Tests for Aggregation Bias", *Journal of the American Statistical Association,* LVII (1962), 348-68.

[30] The simple correlation coefficient between the two variables is 0.97 from 1864 to 1879.

Table 2

ESTIMATES FOR INDUCED INNOVATION COEFFICIENTS – BRITISH COAL SECTOR 1864-1914

1864-1879		1880-1897		1898-1914		Induced Innovation Hypothesis	
ω_{LL}	ω_{LO}	ω_{LL}	ω_{LO}	ω_{LL}	ω_{LO}	ω_{LL}	ω_{LO}
0.014	−0.072	0.019	−0.072	−0.072	0.050	−	+
(0.019)	(0.016)*	(0.010)*	(0.008)*	(0.013)*	(0.016)*		
ω_{OL}	ω_{OO}	ω_{OL}	ω_{OO}	ω_{OL}	ω_{OO}	ω_{OL}	ω_{OO}
−0.072	0.115	−0.072	0.093	0.050	−0.040	+	−
(0.016)*	(0.027)*	(0.008)*	(0.021)*	(0.016)*	(0.016)*		

* 10% significance (standard errors).

Source: Appendix C.

cients are of the proper sign to accept or reject, and they are all statistically significant. Despite the necessity of patching the data set together and of using an as yet unproven model of technical change, we are able to discern a sharp change in the pattern of technological innovation. British entrepreneurs were presumably very responsive to factor prices in the early twentieth century, in contrast to a total lack of response in the 1880s and early 1890s. Moreover, this pattern is consistent with our earlier test over the entire economy. Induced innovation activity corresponds to a high apparent elasticity of substitution. Lack of this activity corresponds to a low apparent elasticity of substitution.

The interpretation of our initial period (1864-1879) is more difficult. The pattern of signs is consistent with a rejection of the induced innovation hypothesis, and except for the ω_{LL} coefficient, the magnitude of all of the estimates are as large or larger than their corresponding coefficients in the 1880-1897 period. However, the ω_{LL} coefficient is smaller than its second-period mate and is no longer significant. And the importance of this fact must be placed out-of-proportion with the one-to-four weight of ω_{LL} in the model, because as discussed before, it is only with wages that we can be reasonably assured of exogeneity to the effects of localized technical innovation. Therefore, the test for induced innovation in the initial period should be considered inconclusive, although measurement error bias would lead one to believe that rejection is the more likely outcome. But again, the results correspond to our initial induced innovation test. The measured elasticity of substitution in Britain in the early part of the sample was either at a moderate level, or alternately low and then high, depending on the time period chosen (table 1). An intermediate result in one test with one set of data matches an intermediate result in another test with a different set of data.

VI

Did Victorian Britain fail? The questions raised in this article are too broad to be answered quickly. The purposes for raising them are threefold. First, the traditional view of the late Victorian British economy is based on a world in which technologies are responsive. Therefore, the traditional arguments cannot be summarily dismissed until such a view of the world has been tested and rejected. Secondly, an induced innovation model appears to most closely conform to the traditional view that the ability of an economy to be flexible and adaptive is crucial for long-term growth and development. Finally, preliminary tests for the existence of induced innovation in Britain show an absence or decline of the phenomenon in a period centred around the decade of 1880. A widespread failure of the Victorian British economy has not been proven yet, but neither has its complete success been proven. The traditional research agenda must be extended to other sectors of the economy,[31] and efforts must be made to quantify the effects of any British entrepreneurial failures found.

Appendix A

Derivation of Translog Factor Share Equation

The translog production function forms were developed by Professors Christensen, Jorgenson, and Lau, and are of great use for econometric estimation in a multifactor setting.[32] Unlike the CES function, these forms allow for non-restrictive estimation of all the relevant partial elasticities of substitution. Rodney Stevenson derives the direct test for induced innovation from a non-homothetic truncated 3rd-order Taylor-series expansion of a firm's cost function.[33] Our version takes the following form:

$$\ln C = v_0 + \sum_i v_i \ln W_i + 1/2 \sum_i \sum_j \gamma_{ij} \ln W_i \ln W_j + \beta_1 \ln Y + 1/2\, \beta_2 (\ln Y)^2 + \sum_i \beta_i \ln Y \ln W_i + \emptyset_1 T + 1/2\, \emptyset_2 (T)^2 + \sum_i \omega_i T \ln W_i + 1/2 \sum_i \sum_j \omega_{ij} T \ln W_i \ln W_j + \theta_1 T \ln Y + 1/2\, \theta_2 T (\ln Y)^2 + \sum_i \Theta_i T \ln Y \ln W_i$$

where the log of costs (C) are given as a function of factor prices (W), output (Y), and time (T).

Shephard's lemma states that $\alpha C/\alpha_i W_i = X_i$, where X_i is the amount used of a particular factor of production. By extension from this result a logarithmic derivative of a cost function yields factor shares:

$$\frac{\alpha \ln C}{\alpha \ln W_i} = \frac{W_i X_i}{C} = S_i$$

Application of such a derivative to the translog cost function given above yields the factor share equation used in the text. Finally, let us note the conversion formulas between the γ_{ij} coefficients and the partial elasticities of substitution:[34]

$$\sigma_{ii} = \frac{1}{S_i^2} (\gamma_{ii} + S_i^2 - S_i)$$

$$\sigma_{ij} = \frac{\gamma_{ij}}{S_i S_j} + 1$$

[31] W.H. Phillips, "Induced Innovation and Economic Performance in Late Victorian British Industry", *Journal of Economic History*, XLII (1982), 97-103.

[32] L.R. Christensen, D.W. Jorgenson, and L.J. Lau, "Transcendental Logarithmic Production Frontiers", *Review of Economics and Statistics* LV (1973), 28-45.

[33] R. Stevenson, op. cit., 164-65.

[34] Binswanger, loc. cit., 237.

Appendix B

Description of Coal Industry Data Set

1. Index of Real Wages (W_L)

From 1880 to 1914, Bowley's series is taken from the *Abstract* (pp. 350-51). Earlier benchmark estimates are due to Wood, and are also in the *Abstract* (p. 348). Wages in the remaining gaps are assumed to move with national wage levels, as determined by Feinstein's weekly wage rate series found in *National Income, Expenditure and Output of the United Kingdom, 1855-1965* (p. T140). Nominal wages are divided by an index of coal prices. From 1882 to 1914, coal prices are taken as the per unit value of coal output, implicit in the value and quantity series for coal found in the *Abstract* (pp. 115-16). Earlier coal prices are extrapolated based on movements in the export price of coal (*Abstract*, p. 483). The reason for this is that the stated values for coal given in the *Abstract* before 1882 are based on an arbitrarily selected price. The wage index was finally adjusted for a 1909 reduction in daily hours from ten to eight based on the *Coal Mines Bill* (P.P. 1908, I), 629-38.

2. Index of Real Price for Other Factors (W_O)

According to the *Reports of the Coal Industry Commission* (P.P. 1919, XI), p. iii, other inputs account for 35 percent of coal costs, of which 16 percent is for materials, 11 1/2 percent for capital and 7 1/2 percent for land. A weighted average index for "other" factor prices was prepared using the proportions implied above. Sauerbeck's raw materials index (*Abstract*, pp. 474-75) and Feinstein's capital goods index (*National Income*, p. T132) were used for the first two components. The price of coal land is assumed to be completely endogenous to the coal market, in which case the real price of coal land — nominal price divided by price of coal — would always be 100. The other two indexes were divided by the price of coal index described in (1).

3. Quantity of Coal Output (Y)

Directly available from the *Abstract* (pp. 115-116).

4. Share of Coal Revenue Paid to Labour [$S_L = (\hat{W}_L \cdot L)/(P_C \cdot Y)$]

The nominal wage index outlined in (1) above was converted into absolute wages ($\hat{W}_L$) based on an annual wage of £ 51.4 in 1877. This figure is from a report on wages in the North Staffordshire district in the *Returns of Wages* (P.P. 1887, LXXXIX), 138. The labour estimates (L) in the *Abstract* (pp. 118-19) were reduced by 10 percent to reflect absenteesm and other sources of overestimation. The price of coal and output series are detailed in Parts (1) and (3) respectively.

5. Share of Coal Revenue Paid to Other Factors (S_0)

The residual left over after labour's share is determined ($S_0 = 1 - S_L$).

Appendix C

Table 3
REGRESSION RESULTS - LABOUR AND OTHER FACTOR SHARE EQUATIONS (S_L AND S_0) BRITISH COAL INDUSTRY 1864-1914 (OLS)

Period I 1864-79

	ν_i	γ_{iL}	γ_{io}	β_i	ω_i	ω_{iL}	ω_{io}	Θ_i	R^2	D.W.
S_L	− 3.74	0.53	0.34	—	0.30	0.01	−0.07	—	0.97	2.29
	(0.52)*	(0.13)*	(0.12)*	(homothetic)	(0.05)*	(0.02)	(0.02)*	(homothetic)		
S_o	4.16	0.34	−1.06	—	−0.24	−0.07	0.11	—	0.72	0.82
	(1.34)*	(0.12)*	(0.26)*	(homothetic)	(0.14)	(0.02)*	(0.03)*	(homothetic)		

Period II 1880-97

	υ_i	γ_{iL}	γ_{io}	β_i	ω_i	ω_{iL}	ω_{io}	Θ_i	R^2	D.W.
S_L	−13.24	0.17	1.70	0.87	0.52	0.02	−0.07	−0.05	0.99	2.22
	(2.14)*	(0.25)	(0.22)*	(0.31)*	(0.07)*	(0.01)*	(0.01)*	(0.01)*		
S_o	20.27	1.70	−2.62	−2.89	−0.73	−0.07	0.09	0.12	0.94	1.48
	(5.87)*	(0.22)*	(0.58)*	(0.62)*	(0.20)*	(0.01)*	(0.02)*	(0.02)*		

Period III 1898-1914

	υ_i	γ_{iL}	γ_{io}	β_i	ω_i	ω_{iL}	ω_{io}	Θ_i	R^2	D.W.
S_L	− 9.68	3.56	−2.28	0.66	0.25	−0.07	0.05	−0.02	0.99	2.42
	(2.90)*	(0.55)*	(0.67)*	(0.35)*	(0.07)*	(0.01)*	(0.02)*	(0.01)*		
S_o	1.66	−2.28	1.54	0.53	−0.06	0.05	−0.04	−0.00	0.90	0.90
	(5.12)	(0.67)*	(0.63)*	(0.53)	(0.12)	(0.02)*	(0.02)*	(0.01)		

* 10% significance (standard errors in parentheses).