NOTES

Technical Change in the Mid-Nineteenth Century British Cotton Industry: A Note

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That relative labour scarcity played a telling role in the different histories of British and American industry in the nineteenth century is one of the standard arguments of the 'new economic history'. Usually traced back to Rothbarth (1946) it has been restated and refined by Habakkuk (1962), Temin (1966), Ames and Rosenberg (1968) David (1975) and others.[1] The argument comes in two parts. The first suggests that higher American wages influenced the choice of technique, by giving business there an incentive to mechanize. But if American business economized on factory hands and on unskilled farm labour, the relative wastefulness of its machines insofar as resource-based unputs and skilled labour were concerned is also emphasized. American workers had less need, in wielding their lathes and drills, of economizing on plentiful supplies of timber and coal (Ames and Rosenberg, 1968). The second part of the argument asserts that labour scarcity prompted the Americans to produce better machines over time, thereby adding a relative bias to the process of technological change. The ultimate supremacy of the American way adds point to this latter claim: the 'correct' factor-price configuration, inducing techniques which were to became the wave of the future, was a key to the Americans' success. By the same token British industrial decline could be attributed, at least in part, to mere 'bad luck'.

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[1] A useful survey is David (1975, pp. 19–44).

Though a change in the relative price of a factor may well generate biased technical change against that input (Ahmad, 1966), this is not guaranteed. In theory, laboratory or technological constraints at the research stage could so increase the costs of, say, labour-saving methods as to rule them out. As Binswanger (1974 a) has shown, both the relative productivity of alternative research lines and total factor costs — not just factor prices — govern the direction of induced innovation. Theory, then, does not fully support the historians' intuition, however plausible, about technological innovation bias. Ironically, the only empirical study so far to estimate relative factor bias in America and Britain, that by Ephraim Asher (1975), finds the bias greater in the latter, " in contrast with what one might have expected from the Rothbarth-Habakkuk implications ", as its author ruefully concedes.

For the economic historian, establishing the direction of bias is a useful exercise in its own right, and Asher's study is an important milestone in that respect. He focused on the textile sector in both countries rather than on the economy as a whole. This is appropriate since global bias against any factor might simply reflect changes in consumption away from commodities intensive in that factor. The periods selected for analysis were 1820-1880 for British cotton and 1850-1900 for British wool and American cotton and wool. Unfortunately, however, Asher's results are suspect for several reasons. Most serious, perhaps, are their shaky statistical base: the fitted production functions rely on decennial data, so that saving even a single degree of freedom becomes a crucial matter. The quality of the data used in the study also leaves something to be desired. An authority on British textile history has dismissed its British data base as " hopelessly astray "; some pitfalls in its American source, the published censal statistics on manufacturing, have been highlighted in recent studies (Von Tunzelmann, 1978, p. 285; Atack, Bateman, and Weiss, 1979; Bateman and Weiss, 1981, pp. 169-71). A second limitation, recognized by Asher, is the study's two-factor framework: all regressions include only labour and a somewhat arbitrary index of capital input. This requires that the production function be separable between included and excluded inputs — that is, that the marginal rate of substitution between capital and labour be independent of the quantities of all other factors used in production. Third, the constant elasticity of substitution formulation used by Asher is perhaps unnecessarily restrictive.

Unfortunately, the data required to estimate the relative bias on both sides of the Atlantic are still unavailable. In the case of the United States, excellent work on the economics of cotton production and on individual cotton enterprises has failed to produce the needed series on aggregate output and inputs (see Wright, 1978; McGouldrick, 1968). However, von Tunzelmann (1978) has recently provided detailed and carefully-supported data on the mid-nineteenth century British cotton textile sector which, combined with other data series, permit a preliminary analysis of trends on that side of the Atlantic at least. These same data also help answer some other questions about the economics of mid-nineteenth century cotton production.

This note reports the results of using annual data to estimate a production function and technological bias for the British cotton industry over the period 1835-1856. The period was one of massive expansion for the industry: by mid century it accounted for about one-tenth of national income, and almost one half of all merchandise exports. Its success was achieved, as textbooks document, in a context of regional concentration, innovation, and massive structural change, and it has recently been proposed that one-sixth of all productivity growth in the British economy during the Industrial Revolution — and hence more in the period examined here — was due to the cotton industry alone (Farnie, 1978; McCloskey, 1981). Data are available on four inputs: raw cotton, labour, energy, and machinery. The labour series is due to Wood, while the capital series is the value of looms and spindles aggregated by their 1860 prices as reported by Feinstein (1978). The raw energy series is given by von Tunzelmann; to calculate energy's share it was assumed that price dropped exponentially from £ 22.1 to £ 10.6 per unit over the period. This latter assumption is admittedly somewhat arbitrary. Wood's series (Wood, 1910, pp. 598-9), too, is certainly not the last word on labour input: it is used here *faute de mieux*.[2]

It is assumed that technological possibilities in the industry are captured by a transcendental logarithmic production function. The translog places no restriction on the elasticity of substitution between inputs, and generates estimates of the direction of factor-bias in straightforward fashion (see e.g. Binswanger, 1974 b; Cain and Paterson, 1981). Output is related to the quantities of the inputs (X_i) by:

$$\ln Q = a_0 + \sum_i a_i \ln X_i + \tfrac{1}{2} \sum_i \sum_j b_{ij} \ln X_i \ln X_j + c_0 \ln t +$$
$$+ c_1 (\ln t)^2 + \sum_i c_{ij} \ln X_i \ln t$$

where Q = output
X_i = quantity of input i
t = time

and a_i, b_{ij}, c_{ij} are parameters to be estimated. b_{ij} is set equal to b_{ji}.

[2] Wood (1910, pp. 598-9): see von Tunzelmann's criticisms (Von Tunzelmann, 1978, pp. 238-9). Other data used come from variety of sources. The value of output and cotton input series are taken from von Tunzelmann. as are the energy series (Von Tunzelmann, 1978, Appendix 7.1). The figures of or looms and spindles are based, with interpolation, on those given in Blaug (1961). The loom and spindle prices are those given in Table XII of C.H. Feinstein (1978). In calculating labour's share it was assumed that operatives worked a fifty-week year; the prices used to estimate energy's share are interpolations on the figures given in von Tunzelmann (1978, pp. 74, 150).

Whence,

$$S_i = a_i + \sum_i b_{ij} \ln X_i + \sum_i c_{ij} \ln t$$

where S_i is the share of factor i. Linear homogeneity in inputs implies

$$\Sigma a_i = 1$$
$$\Sigma b_{ij} = 0$$
$$\Sigma c_{it} = 0$$

Linear homogeneity does not seem an over-restrictive assumption in the circumstances. Recent research has stressed both the wide range of output over which firms could successfully produce and the highly competitive character of the industry (Farnie, 1978; Gatrell, 1977).[3]

Maximum likelihood estimates of the parameters of the translog function are reported in Table I. If $c_{it} > 0$, then the period analyzed was on average one of i-saving technical change; $c_{it} < 0$ would imply that the bias was i-using.

TABLE 1

PARAMETER ESTIMATES OF THE TRANSLOG PRODUCTION FUNCTION (STANDARD ERRORS IN PARENTHESES)

a_C	0.5646 (0.4213)	b_{EE}	0.0176 (0.0040)
a_E	0.2264 (0.0401)	b_{KK}	−0.2119 (0.1200)
a_L	0.4473 (0.1463)	b_{CK}	0.1458 (0.1141)
a_K	−0.2383 (0.4836)	b_{LK}	0.0541 (0.0370)
b_{CC}	−0.0082 (0.1043)	b_{EK}	0.0121 (0.0067)
b_{CL}	−0.1023 (0.0161)	c_{Ct}	−0.0020 (0.0292)
b_{CE}	−0.0352 (0.0030)	c_{Et}	0.0034 (0.0014)
b_{LL}	0.0426 (0.0304)	c_{Lt}	0.0142 (0.0058)
b_{LE}	0.0056 (0.0058)	c_{Kt}	−0.0156 (0.0320)

[3] The simple "survivor test" of industrial organization theory (see Stigler, 1968, pp. 71-94), applied to Gatrell's 1835 and 1841 data (Gatrell, 1977), suggests that economies of scale were absent over a wide range of output at that time.

Table 2

ESTIMATED ELASTICITIES OF SUBSTITUTION
(STANDARD ERRORS IN PARENTHESES)

	z_{KK}	z_{KK}	ν_{KK}	z_{KK}	z_{KK}	z_{KK}	z_{KK}	z_{KK}	z_{KK}	z_{KK}
1835	— 2.4340	— 2.1367	— 2.7656	— 12.086	— 0.4746	— 2.9399	2.0287	1.9650	1.5876	2.0174
	(0.6959)	(0.9760)	(0.6748)	(5.3458)	(0.2314)	(0.3385)	(0.8050)	(1.0100)	(0.4016)	(0.5687)
1845	— 2.1574	— 2.0429	— 3.2375	— 7.0757	— 0.6830	— 3.9459	1.9372	2.4699	1.6496	2.2345
	(0.6218)	(0.9198)	(0.9364)	(8.9383)	(0.2647)	(0.4249)	(0.7334)	(1.5389)	(0.4440)	(0.6900)
1855	— 1.9816	— 2.1295	— 3.4152	— 5.4865	— 0.8415	— 6.3218	1.9220	2.6351	1.6607	2.2372
	(0.5615)	(0.9716)	(1.0571)	(9.7970)	(0.2890)	(0.4572)	(0.7215)	(1.7118)	(0.4515)	(0.6915)

Our results support the standard view that technical change in the British cotton industry at this time was labour-saving. This does not exclude the possibility — cogently urged by Von Tunzelmann (1981) — of no such bias on average over a longer period. Table I also implies an energy-saving bias. By definition bias must therefore have been capital and/or cotton-using, though the size of the (asymptotic) standard errors prohibit inference about the relative strength of these biases.

The Allen-Uzawa own- and cross-elasticities of substitution implied by the production function are presented for selected years in Table 2. The results imply that the basic conditions for a well-behaved production function were met in the cotton textiles sector. In most cases the cross-elasticities are positive, indicating that imputs were generally substitutable in cotton manufacturing. The negative values of α_{CE} and α_{CL} are worth noting, however. Finally, the price elasticities of demand for the four inputs are reported in Table 3, again for selected years. The results support Marshall's contention about the importance of being unimportant: the lower a factor's share in total costs, the lower its reported elasticity turned out to be (see Marshall, 1920, p. 385). Yet while it may seem reassuring to find negative elasticities, and in general, small standard errors in Table 3, the results must be handled with care. A search for yardsticks in the literature produces no standard robust estimates, modern or historical, at aggregate or sectoral level. Here it is noted simply that the estimated demand elasticity for cotton as an input is close to that found in a different context by Gavin Wright (1976, pp. 92-3), and the labour estimates about midway along the range suggested by modern empirical research.

TABLE 3

FACTOR DEMAND ELASTICITIES
(STANDARD ERRORS IN PARENTHESES)

Year	n_K	n_K	n_K	n_K
1835	— 1.0552	— 0.6983	— 0.5870	— 0.3308
	(0.3017)	(0.3190)	(0.1432)	(0.1463)
1845	— 0.9967	— 0.6878	— 0.5833	— 0.1489
	(0.2831)	(0.3097)	(0.1684)	(0.1892)
1855	— 0.9564	— 0.6975	— 0.5792	— 0.1109
	(0.2710)	(0.3183)	(0.1793)	(0.1981)

[4] Compare Cain and Paterson (1981, pp. 351-2).

REFERENCES

S. Ahmad, (1966), " On the Theory of Induced Innovation ", *Economic Journal*, Vol. 76, No. 302, pp. 344-57.

E. Asher, (1972), " Industrial Efficiency and Biased Technical Change in American and British Manufacturing: The Case of Textiles in the Nineteenth Century ", *Journal of Economic History*, Vol. 32, No. 2, pp. 431-42.

E. Ames, and Rosenberg, N. (1968), " The Enfield Arsenal in Theory and in History ", *Economic Journal*, Vol. 78, No. 4, pp. 827-42.

J. Atack, Bateman, F., and Weiss, T. (1979), " An Evaluation of Nineteenth-Censuses as Sources for Economic Statistics ", paper presented at the Cliometrics Conference, Chicago, June 8.

F. Bateman, and Weiss, T. (1981), *A Deplorable Scarcity: The Failure of Industrialization in the Slave Economy*, Chapel Hill, University of North Carolina Press.

H. Binswanger, (1974 a), " A Microeconomic Approach to Induced Innovation " *Economic Journal*, Vol. 84, No. 336, pp. 940-58.

H. Binswanger, (1974 b), " The Measurement of Technical Change Biases With Many Factors of Production ", *American Economic Review*, Vol. 64, No. 6, pp. 964-76.

M. Blaug, (1961), " The Productivity of Capital in the Lancashire Cotton Industry During the Nineteenth Century ", *Economic History Review*, Ser. 2, Vol. 13, pp. 358-81.

L.P. Cain, and Paterson, D.G. (1981), " Factor Biases and Technical Change in Manufacturing: The American System, 1850-1919 ", *Journal of Economic History*, Vol. 41, No. 2, pp. 341-60.

P.A. David, (1975), *Technical Choice, Innovation and Economic Growth*, Cambridge, Cambridge University Press.

D.A. Farnie, (1979), *The English Cotton Industry and the World Market 1815-1896*, Oxford, Clarendon Press.

C.H. Feinstein, (1978), " Capital Formation in Great Britian ", in P. Mathias and M.M. Postan, eds., *The Cambridge Economic History of Europe*, Vol. 7, Cambridge, Cambridge University Press, pp. 28-96.

V.A.C. Gatrell, (1977), " Labour, Power, and the Size of Firms in Lancashire Cotton in the Second Quarter of the Nineteenth Century ", *Economic History Review*, Ser. 2, Vol. 30, No. 1, pp. 95-139.

H.J. Habakkuk, (1962), *American and British Technology in the Nineteenth Century*, Cambridge, Cambridge University Press.

D.N. McCloskey, (1981), " The Industrial Revolution: A Survey " in R. Floud and D.N. McCloskey, eds., *The Economic History of Britain sice 1700* Vol. 1, Cambridge, Cambridge University Press, pp. 103-27.

P.F. McGouldrick, (1968), *New England Textiles in the Nineteenth Century: Profits and Investment*, Cambridge, Mass., Harvard University Press.

A. Marshall, (1920), *Principles of Economics*, London, Macmillan.

B.R. Mitchell, and P. Deane (1971), *Abstract of Historical Statistics*, Cambridge, Cambridge University Press.

E. Rothbarth, (1946), " Causes of the Superior Efficiency of U.S.A. Industry as Compared with British Industry ", *Economic Journal*, Vol. 56, No. 3, pp. 383-90.

G. Stigler, (1968), *The Organization of Industry*, Homewood 111., Richard D. Irwin.

P. Temin, " Labor Scarcity and the Problem of American Industrial Efficiency in the 1850's ", *Journal of Economic History*, Vol. 26, No. 3, pp. 361-79.

G.N. Von Tunzelmann, (1978), *Steam Power and British Industrialization to 1860*, Oxford, Oxford University Press.

G.N. Von Tunzelmann, (1981), " Technical Progress during the Industrial Revolution " in R. Floud and D.N. McCloskey, eds., *The Economic History of Britain since 1700*, Cambridge, Cambridge University Press, pp. 143-63.

G.T. Wood, (1910), " The Statistics of Wages in the United Kingdom during the Nineteenth Century: The Cotton Industry ", *Journal of the Royal Statistical Society*, Vol. 73, Part 3, pp. 585-626.

G. Wright, (1976), *The Political Economy of Cotton Production in the American South*, New York, Norton.