The relationship between openness and growth in the United Kingdom: a summary of the Bank of England Openness and Growth Project[(1)]

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This article summarises the results of the Bank's Openness and Growth Project. The empirical findings suggest that openness is closely associated with growth in productivity both across countries and across sectors within the United Kingdom. Between 1970 and 1992, some 15% of the initial gap in productivity between the United Kingdom and the United States was closed. Of this, roughly half was attributable to the rise in international openness.

Introduction

Between 1970–90, value added per worker in the United Kingdom grew at an average annual rate of 1.9%.[(2)] But this aggregate figure conceals considerable variation across sectors and time. Value added per worker in services rose at an average annual rate of 0.5%, whereas in manufacturing the corresponding figure was 3.0%. From 1973–79—the peak-to-peak of the business cycle—the average annual rate of growth of value added per worker was 1.7% in manufacturing and 0.7% in services. In contrast, in the second peak-to-peak business cycle period from 1979–89, these figures rose to 3.7% and 0.8% respectively.

This differing growth was associated with considerable variation in the size of trade flows, trade barriers, foreign direct investment (FDI) and international expenditure on research and development (R&D). For example, between 1970–90, the ratio of exports to domestic output in manufacturing rose from 17.7% to 30.0%, within manufacturing, the average share of exports ranged from 5.4% in paper and printing to 79.8% in computing.[(3)]

The Openness and Growth Project examined how far these variations in economic growth rates related to differences in the degree of international openness, where openness is defined as the extent of impediments to international flows of goods and services, factors of production and ideas. The project resulted in a series of research papers, each of which focused on a particular aspect of the relationship. This summary paper draws together the detailed research.

The second section reviews theoretical relationship between international openness and rates of economic growth. Most of our research has been empirical, based on a detailed, disaggregated analysis of the links between openness and growth in the United Kingdom. To place this analysis in a wider context, the third section considers the relationship between openness and growth across 109 economies in the period 1970–89.

The rest of the project analyses the relationship between openness and growth at the sectoral level. The fourth section discusses the characteristics of the the United Kingdom's economic growth experience, and the fifth addresses the problem of moving from the conceptual definition of international openness to quantitative measures. Clearly, one of the main factors underlying a research project of this kind is the availability and quality of data. Where possible, we consider the relationship between rates of economic growth and international openness across the whole economy. But the quality of data for the service sector on domestic variables (such as output and the capital stock) is poor, and there is relatively little information on measures of international openness in services. So some of the detailed research has necessarily been restricted to manufacturing, where more and better data are available. Where enough data do exist, we find that the results for the whole economy are broadly similar to those for manufacturing alone.

The sixth section considers the empirical relationship between openness and growth at the sectoral level in the United Kingdom. First, we analyse the simple cross-section relationship between estimated rates of productivity growth and measures of international openness. Second, we consider a more formal econometric analysis, using a theoretical model in which an industry's productivity growth rate depends on the difference between the level of productivity and the level attained in the technologically most advanced economy. In this framework, international openness facilitates the transfer of technology from the most advanced economy. Using our econometric results, we estimate implicit long-run levels of productivity in the

(1) The Openness and Growth Project was reviewed at an academic conference held at the Bank in mid September. The conference proceedings, including the research papers and the comments of conference participants, will be published by the Bank in spring 1998. The project consists of six research papers. Details are provided in the Annex. The individual papers are available on request from the authors. One of the papers was written jointly with Marco Bianchi and three were written jointly with Gavin Cameron (Nuffield College, Oxford) whose research was funded by the ESRC. We are very grateful to them for their collaboration. Space prevents us from thanking all those from whose comments and suggestions we have benefited enormously, but we are particularly indebted to Steve Bond, Nigel Jenkinson, John Muellbauer, Danny Quah, Jon Temple and Peter Westaway for their invaluable help and advice.
(2) Source: OECD International Sectoral Database.
(3) Source: ONS Data.

United Kingdom relative to the United States, and relate changes in these levels to those in the main explanatory variables.

We conclude that though the relationship between openness and growth is complex, openness has raised the rate of productivity growth in the United Kingdom by increasing the speed of convergence with the technological leader.

Theoretical links between international openness and economic growth

The first research paper[(1)] surveys the theoretical literature on the relationship between international openness and economic growth. The recent literature on endogenous growth provides a useful framework.

In the long run, the rate of technological progress in an economy is endogenously determined by the profit-seeking choices of economic agents and is the prime determinant of *per capita* income growth. A range of formal econometric evidence suggests that the accumulation of physical and human capital is subject to diminishing returns: successive units of these factors of production yield ever-smaller increments in output. So even if physical and human capital accumulate at a constant rate, an economy's rate of growth of output will fall in time, in the absence of further technological progress.

But technological change can sustain long-run *per capita* growth. Technological innovation directly increases the flow of output from given stocks of physical and human capital and (by raising the marginal product of each factor of production) indirectly increases output by encouraging additional investment in physical and human capital. To assess informally the role of technological change in driving long-run growth, consider how manufacturing would proceed without electricity, the internal combustion engine and the computer.

In the endogenous growth literature, the process determining long-run growth rates is represented as either an increase in the variety or an improvement in the quality of the goods produced by an economy. The rate of output growth is determined by the rate of introduction of new designs for goods discovered in the research sector. The pace of innovation itself is a function of the amount of skilled labour employed in research and the productivity of that research.

In a world with many economies at different stages of economic development, it is also likely that technologically less advanced economies grow more rapidly by adopting technologies discovered in their more advanced counterparts.

So international openness may affect an economy's growth rate by influencing either the rate of innovation or the rate of adoption of existing technologies. Grossman and Helpman (1991), for example, examine the relationship between international openness and the rate of innovation in advanced economies. Openness will raise an economy's rate of innovation insofar as it increases the incentive to engage in R&D activities (for example, by increasing market size), raises the productivity of those activities (for example, by facilitating the diffusion of ideas among research communities) or reallocates resources between final goods sectors with different rates of innovation. Parente and Prescott (1994) consider how openness may also make it easier to adopt existing technologies in other economies and use them in final goods production, which not only increases an economy's growth rate in the medium term, but also raises its long-run level of productivity.

In this project, we consider the effect of openness in a framework that allows for levels of productivity to converge towards the technological leader, assumed throughout to be the United States.

The association between openness and growth at the international level[(2)]

The academic literature (Quah 1993a, 1996) provides evidence that the world is evolving into two distinct 'convergence clubs': a group of high-income, fast-growing economies and a group of low-income, slow-growing economies. In this section, we consider how far this trend in the evolution of *per capita* income is associated with international openness, where openness is defined in terms of a variety of measures of the average stance of trade policy in the period and the degree of exchange control.[(3)] To do so, we first use the statistical technique of discriminant analysis to sort the countries into groups of relatively open and relatively closed economies. This technique selects groups by emphasising both the similarities of the trade characteristics of the data within the same group and the differences between the representative properties of the groups.[(4)] We then examine how the distributions of countries' income *per capita* relative to the United States have evolved, for open and closed economies separately. In particular, we analyse how countries move within this distribution.

The results are briefly summarised in Table A, which gives estimates of the percentages of each group that would eventually converge into one of five bands of relative incomes.[(5)] For example, it is estimated that only just over 1% of the group of closed economies would tend towards an eventual steady-state income level of between about 50% and 100% of the US level, compared with 90% of the group of open economies.

(1) *Openness and Growth: theoretical links and empirical estimation*, by Stephen Redding (July 1996).
(2) *Is international openness associated with faster economic growth*? by James Proudman, Stephen Redding and Marco Bianchi (June 1997).
(3) These are the most informative openness variables available for such a large cross-section of countries for the sample period.
(4) Formally, we choose linear combinations of the openness variables to maximise the ratio of between-group to within-group sums of squares.
(5) These proportions are independent of the initial distribution across states.

International openness appears to be associated with convergence with a higher relative income *per capita*, even after taking into account different investment levels. But it is difficult to make the stronger claim that increased international openness causes higher growth. In particular, there may be an endogeneity problem: lower trade barriers could themselves result from membership of the high-income convergence club. We consider this endogeneity problem more fully below.

Table A
Estimated steady-state distribution for groups of open and closed economies, 108 countries, 1970–89

Group (a)	0.9%–5.9%	5.9%–11.4%	11.4%–21.2%	21.2%–47.2%	47.2%–100%
Open	0.0	0.0	0.0	10.0	90.0
Closed	38.8	24.9	18.1	16.7	1.4

(a) Boundaries of bands are income *per capita* relative to the United States (entries in percentages). The boundaries between the five bands are chosen so that the observed sample is divided into categories with an approximately equal number of observations.

UK economic growth

In this section, we look at the characteristics of economic growth in the United Kingdom.(1) The rate of output growth can be decomposed into the contributions from increased hours worked, physical capital accumulation and a residual. This residual encompasses the effect of influences on how efficiently existing quantities of capital and labour are used. It includes, for example, the influence of technology, and the extent of competition, training and unionisation. In practice, empirical evidence suggests that the residual is largely determined by technological change, and it provides a widely used empirical measure, known as Total Factor Productivity (TFP) growth, of the rate of technological progress.

The decomposition of UK output growth between 1970–90 is summarised in Table B. These results are derived from internationally comparable data provided in the OECD's International Sectoral Database, disaggregated into nine industrial sectors. Unfortunately, the accuracy of the data—particularly for service industries—is poor. For instance, the estimated negative TFP growth in financial services is difficult to reconcile with informal evidence of financial liberalisation and innovation. It seems likely that this partly reflects the difficulties of measuring service sector output and capital.

Table B
Sources of UK output growth, 1970–90 (annual percentage change)

Sector	ISIC code (a)	Output	Labour	Capital	TFP
Agriculture	1	2.07	-0.90	0.53	2.43
Mining	2	3.20	-1.13	3.02	1.31
Manufacturing	3	0.84	-1.77	0.33	2.27
Utilities	4	5.18	-0.73	0.50	5.42
Construction	5	0.74	0.30	0.42	0.03
Wholesale and retail	6	2.00	1.05	0.86	0.08
Transport	7	2.71	-0.30	0.37	2.64
Financial services	8	3.37	2.23	1.88	-0.74
Social services	9	3.98	2.25	0.86	0.87
Whole economy					
of which:	0	2.28	0.17	0.85	1.26
Government services	0	1.09	0.76	0.23	0.10

Source: OECD International Sectoral Database.

(a) International Standard Industrial Classification.

But we are able to make use of a much more detailed and accurate ONS dataset, extended by Cameron (1997). This only covers manufacturing, disaggregated into the 19 subsectors shown in Table C. We use both datasets in this paper.

Table C
Sources of output growth in UK manufacturing 1970–92: annual percentage change

Sector (abbreviation)	ISIC Code	Output	Labour	Capital	TFP
Total	3	-0.18	-2.16	0.60	1.38
Food and drink (FBT)	31	-0.23	-1.16	1.19	-0.26
Textiles (TAT)	32	-1.49	-3.13	-0.12	1.76
Timber and furniture (WPP)	33	-0.71	-1.84	0.86	0.27
Paper and printing (PPP)	34	0.88	-1.43	0.99	1.32
Minerals (NMM)	36	-2.33	-2.11	0.84	-1.06
Chemicals (CHEM)	35	1.40	-1.11	0.98	1.52
of which:					
Chemicals nes (a) (CNES)	351..354–3522	-0.31	-1.62	0.82	1.10
Pharmaceuticals (DM)	3522	4.72	-0.65	1.52	3.85
Rubber and plastics (RPP)	355+356	1.24	-1.21	0.87	1.58
Basic metals (BMI)	37	-3.60	-5.43	0.09	1.73
of which:					
Iron and steel (IS)	371	-4.20	-6.46	0.04	2.22
Non-ferrous metals (NFM)	372	-1.93	-3.40	0.27	1.20
Fabricated metals (FMP)	38	-0.01	-2.56	0.48	2.07
of which:					
Metal goods (MNES)	381	-1.01	-2.71	0.31	1.39
Machinery (NEM)	382–3825	-1.54	-2.74	0.48	0.72
Computing (OCE)	3825	7.62	-1.17	3.12	5.67
Other electrical engineering (OEE)	383–3832	-0.31	-2.63	0.63	1.68
Electronics (RTV)	3832	1.91	-2.28	1.18	3.01
Motor vehicles (MV)	3843	-1.22	-2.72	0.56	0.93
Aerospace (AERO)	3845	2.58	-1.52	-0.07	4.17
Instruments (PG)	385	2.16	-1.67	0.88	2.95
Other manufacturing (OM)	39	-1.38	-2.69	0.03	1.27

(a) Nes: not elsewhere specified.

Aggregate productivity growth can be broken down into the contributions made by productivity growth *within* individual sectors, and by transfers of factor resources *between* sectors with differing levels of productivity. This decomposition may be undertaken for either TFP or labour productivity. Table D presents this decomposition, first for the whole economy at the level of aggregation in Table B, and then at the disaggregated level within manufacturing.

Table D
Decomposition of UK productivity growth, 1970–92

Shares of total growth (per cent)		Between	Within	Total
TFP growth	Whole economy	17.1	82.9	100.0
	Manufacturing	9.2	90.8	100.0
Labour productivity growth:	Whole economy	4.4	95.6	100.0
	Manufacturing	3.0	97.0	100.0

Analysis of the productivity data suggests a number of stylised facts about the UK growth performance:

- Technological change was estimated to be the major source of output growth, both within manufacturing

(1) *Deconstructing growth in UK manufacturing*, by Gavin Cameron, James Proudman and Stephen Redding (May 1997).

and for the whole economy. Between 1970–92, manufacturing output fell (by -0.2% per year). TFP and capital accumulation both made positive contributions to output growth, with the contribution of TFP (+1.4% per year) much higher than that of capital accumulation (+0.6% per year). Labour utilisation fell sharply, accounting for the overall decline in output.

- Average growth rates of TFP (and labour productivity) varied across sectors. Within manufacturing, TFP annual growth ranged from 5.7% in computing—and was more than 3.5% in pharmaceuticals and aerospace—to negative numbers in food and minerals. The level of total factor productivity across sectors also varied considerably.

- The share of output growth accounted for by TFP growth relative to that accounted for by capital accumulation was higher during the 1980s' business cycle (1979–89) than during the 1970s' cycle (1973–79).

- The average growth rate of TFP (and labour productivity) was higher in the 1980s than in the 1970s. In manufacturing as a whole, TFP fell at an average annual rate of 1.9% between 1973–79, but rose at 3.3% per year between 1979–89.

- Most of the growth in aggregate TFP and labour productivity was generated by growth within sectors, rather than by shifts in resources from low to high productivity sectors. This is true for both manufacturing and the whole economy.

Quantifying international openness in the United Kingdom

In this section, we try to quantify the degree of international openness in terms of the size of impediments to flows of goods, factors of production and ideas. We draw upon two research papers. The first analyses changes in the UK pattern of specialisation in trade in manufactured goods;[1] the second assesses the extent of international openness and examines the partial correlation between the latter and economic growth rates.[2] Some of the analysis is restricted to manufacturing, because of the absence of comprehensive and compatible service sector data.

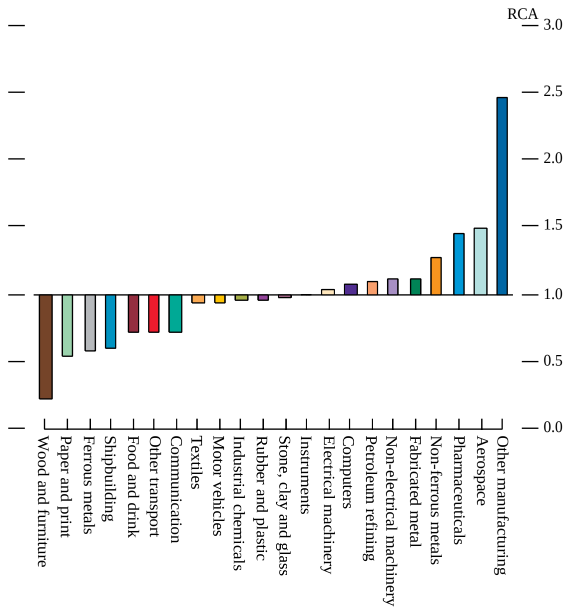
Trade in goods and services

International trade affects growth through two main channels. First, specialisation according to comparative advantage changes the allocation of resources across industrial sectors. Suppose that sectors exhibit different equilibrium rates of growth. Then an economy's aggregate rate of growth may either increase or decrease, depending on which sectors the economy specialises in as a result of changes in its comparative advantage.[3]

These changes in patterns of international trade specialisation have received relatively little attention in the empirical literature. To assess their importance in the sample period, this section examines the dynamics of international trade in manufactured goods in the United Kingdom between 1970–93.

The extent of specialisation is measured by a slightly modified version of Balassa's (1965) index of Revealed Comparative Advantage (RCA).[4] A value greater than one indicates an industry in which an economy's share of world exports exceeds its share of total world exports across all industries—in other words, an industry in which an economy specialises. Charts 1–3 show the evolution of patterns of international specialisation in the United Kingdom across industries. In Chart 1, industries are ordered in terms of increasing RCA for the period 1970–74. The same ordering is preserved in Charts 2 and 3, which show the pattern of RCA for two further five-year periods, with a gap of five years between them.

Chart 1
United Kingdom RCA[(a)] 1970–74



(a) Disaggregated data compiled from the OECD's Bilateral Trade Database.

If the nature of international specialisation stayed relatively constant, the pattern of RCA in Charts 2 and 3 would resemble that in Chart 1. But considerable changes in international specialisation are observed—a finding confirmed using more formal indices of mobility. The

(1) *Persistence and mobility in international trade*, by James Proudman and Stephen Redding (June 1997).
(2) *Openness and its association with productivity growth in UK manufacturing*, by Gavin Cameron, James Proudman and Stephen Redding (June 1997).
(3) Note that even if this mechanism reduces an economy's own aggregate rate of growth, economic welfare may still rise because the economy benefits (through an improvement in the terms of trade) from output growth in its trade partners. Nonetheless, it is theoretically possible (though this is unlikely to be important in the United Kingdom) for trade to have a negative effect on economic welfare through this mechanism.
(4) This index is given by an economy's export share in an industry divided by its average export share across all industries.

previous section, however, showed that transfers of resources between sectors contributed relatively little to the growth in aggregate TFP and labour productivity. Overall, the analysis suggests that changes in international specialisation have not been a channel through which international openness has substantially affected UK productivity growth in the sample period.

Chart 2
United Kingdom RCA 1980–84

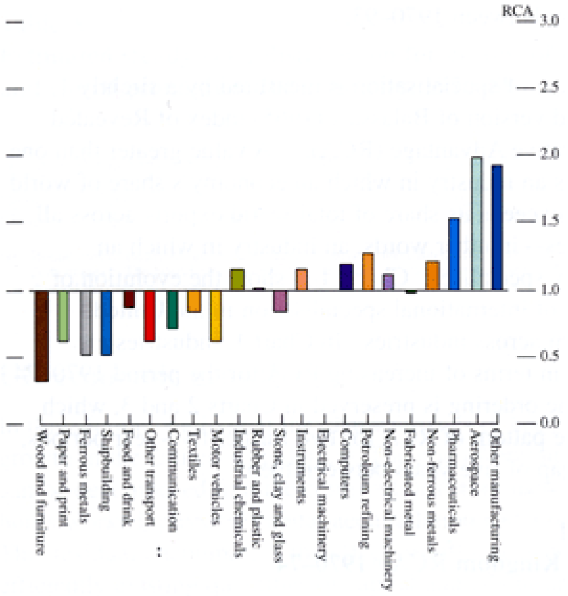
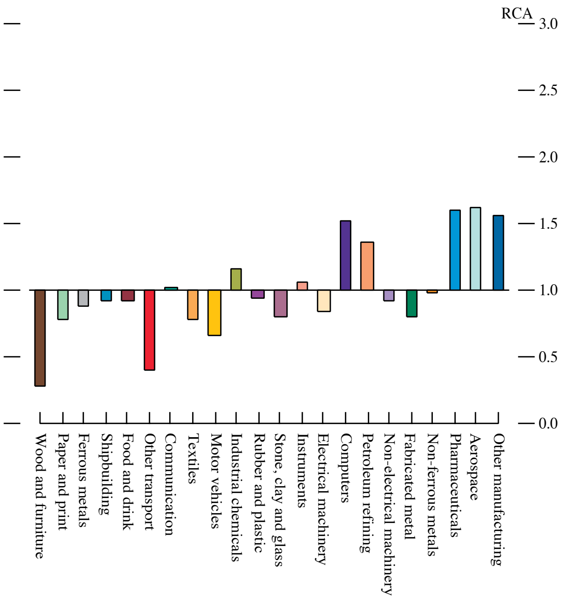


Chart 3
United Kingdom RCA 1990–93



Having discounted this channel, we consider the effects of trade within individual sectors. In this context, there are five interrelated ways in which international trade may affect rates of productivity growth. The first four would increase growth; the effect of the fifth is uncertain:

- Trade may be directly responsible for the transfer of technology between countries with differing productivity levels. That is, trade enables sectors to catch up to the productivity levels of technologically more advanced economies more quickly than otherwise. For example, trade may allow firms to 'reverse engineer' their foreign rivals' products.

- Trade may be directly responsible for the spillover of ideas, thereby generating a larger pool of knowledge to assist future innovation, raising the productivity of research and boosting long-run growth rates.

- Trade eliminates incentives for duplication in innovation. The integration of countries' product markets through openness to trade places innovators in different countries in competition with one another, giving them the incentive to pursue new ideas in the world economy. So trade tends to reduce duplication of research effort, increasing the aggregate productivity of resources employed in innovation.

- Trade increases the market size available to successful researchers, increasing the incentive to engage in research.

- Trade enhances the intensity of product market competition. Increased competition reduces the equilibrium profits to be derived from successful research, which in turn may either increase or decrease the incentive to engage in research.[(1)]

In practice, it seems plausible that the effects of trade on growth will be largely positive. Before estimating the strength of this link, we examine the time-series and cross-section behaviour of two quantitative measures of openness to trade at the sectoral level (the exports/output ratio and imports/domestic sales ratio).

A well-known problem with all possible measures of openness is their potential endogeneity. To help mitigate the effects of the simultaneity problem in our empirical analysis, we use a number of econometric techniques—in particular, instrumental variables and lagged values of openness measures—and try to show that our results are generally robust.

The exports/output and imports/domestic sales ratios in selected manufacturing sectors are shown in Charts 4–7, and in selected non-manufacturing sectors in Charts 8–9. In almost all manufacturing sectors, both measures increase significantly in the sample period. Non-manufacturing sectors also display high rates of growth, particularly for the exports/output ratio. But the rates of change of openness vary considerably between sectors.

The flow of capital

Another measure of openness that may affect rates of productivity growth is foreign direct investment (FDI).

(1) See for example, Grossman and Helpman (1991), Aghion, Dewatripont and Rey (1996) and Aghion, Harris and Vickers (1996).

Chart 4
Exports/output ratio for selected manufacturing sectors with above-average export and import ratios

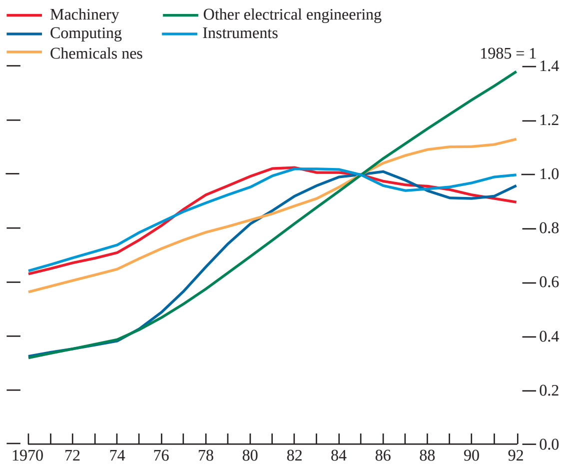


Chart 5
Exports/output ratio for selected manufacturing sectors with below-average export and import ratios

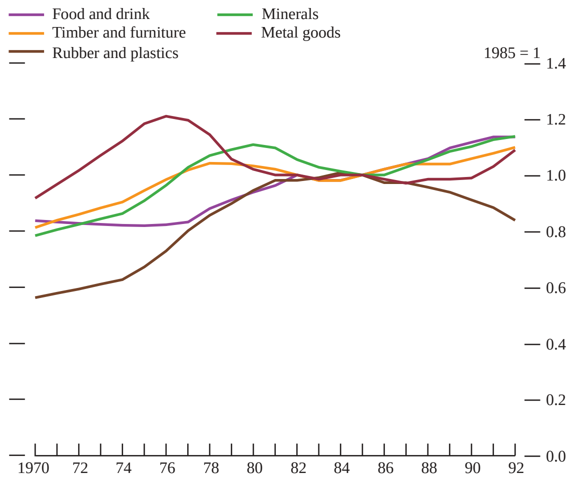


Chart 6
Imports/sales ratio for selected manufacturing sectors with above-average export and import ratios

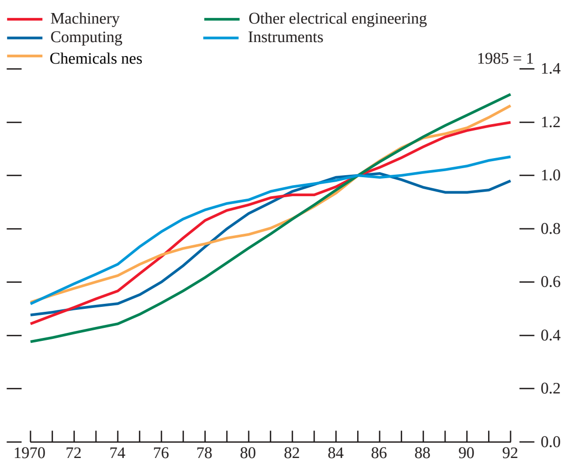


Chart 7
Imports/sales ratio for selected manufacturing sectors with below-average export and import ratios

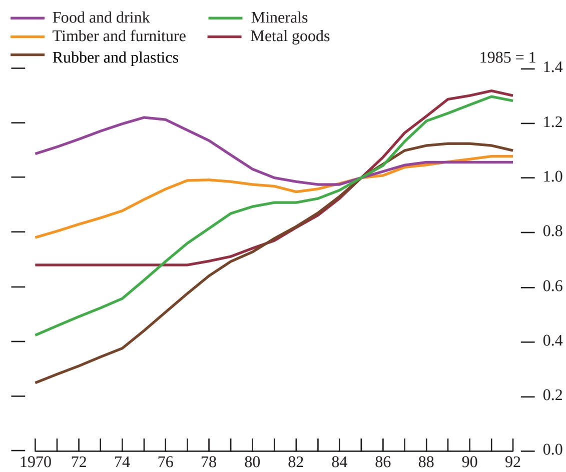


Chart 8
Exports/output ratio for selected non-manufacturing sectors

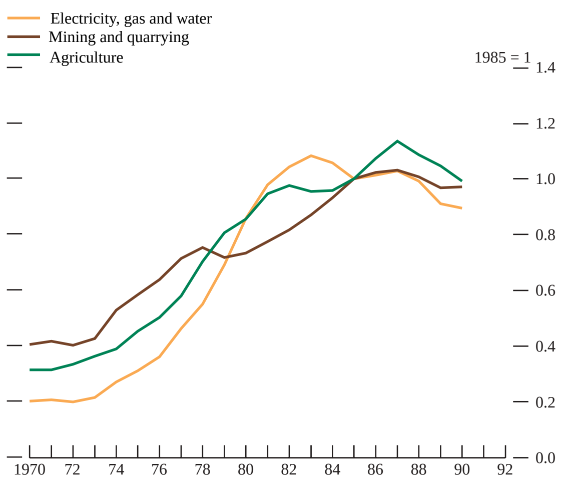
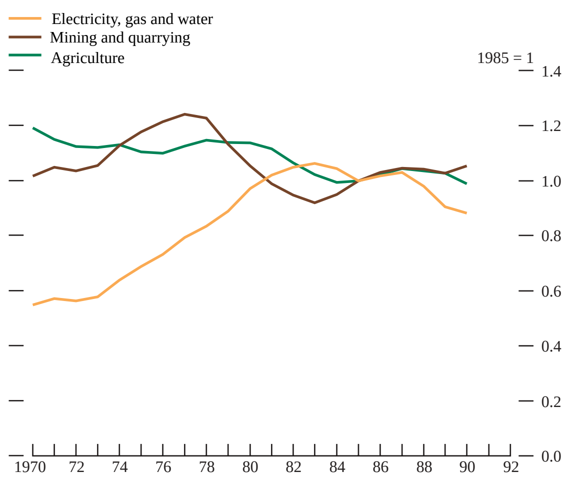


Chart 9
Imports/sales ratio for selected non-manufacturing sectors



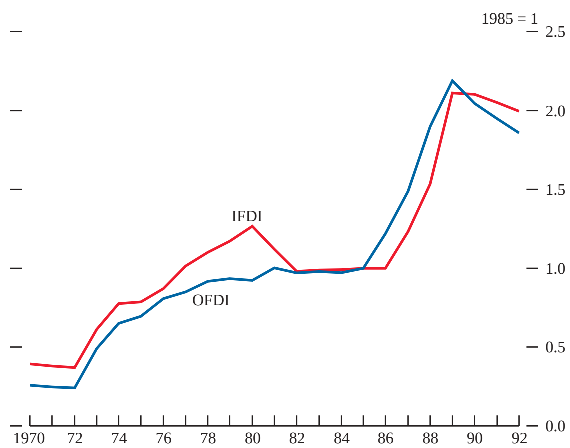
Inward FDI may be a determinant of TFP growth because it facilitates the transfer of technology into the United Kingdom from abroad. FDI allows foreign firms to exploit superior technology when they are unable to do so from, for example, the international licensing of patents. This may occur both because the technology is somehow specific to the production processes of the individual firm, and because potential purchasers of the patent are, by definition, unable to obtain full information on its value. At the same time, FDI may result in positive externalities to the host economy, in the form of spillovers of technology or better business organisation. For example, the introduction of superior technology or production processes can be emulated by other firms and spread by workers who may transfer their skills elsewhere.

Outward FDI may also be an important factor in determining domestic productivity growth rates. For example, outward FDI may act as a means of appropriating foreign technology. Through FDI in a more advanced economy, the investor may acquire information on superior technology in companies or skills possessed by the foreign labour force.

Before examining the strength of this relationship between FDI and productivity growth in Section 6, we therefore also constructed disaggregated measures of inward and outward FDI stocks. To construct FDI stocks, we cumulated ONS data on real FDI flows, imposing a common rate of depreciation and imputing an initial value of the stock in each sector.(1)

An estimate of the stock of inward FDI in manufacturing—expressed as a ratio to the domestic capital stock—is shown in Chart 10. The stock of inward FDI rose during the period in most manufacturing and non-manufacturing sectors, with a particularly pronounced increase in the second half of the 1980s. The estimated stock of outward FDI in manufacturing is also shown in Chart 10. As for inward FDI, there was an increase in the period, with a particularly marked rise in the late 1980s.

Chart 10
Inward and outward FDI stocks/total domestic capital stock ratio in UK manufacturing



The international spillover of ideas

A domestic economy's rate of growth may also be affected by spillovers of ideas from other economies. These may occur directly or through flows of goods and services and FDI.

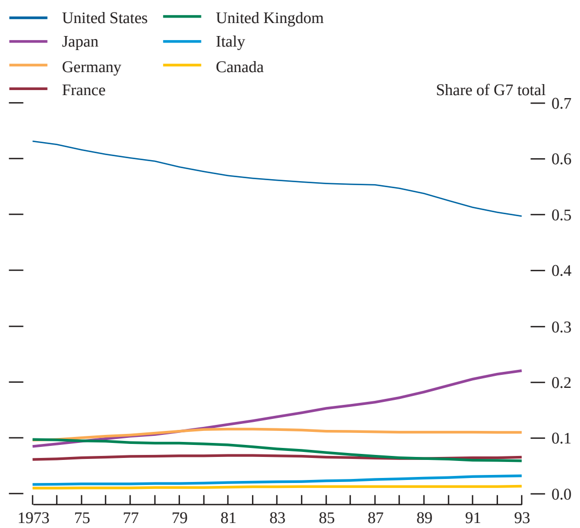
Spillovers of ideas across economies may be proxied using expenditure on R&D, as in Coe and Helpman (1995). There is well-documented evidence at the sectoral and firm level that firms' own expenditure on R&D and that of their near rivals are both significantly correlated with productivity.(2) There is also evidence at the economy-wide level that foreign R&D affects domestic productivity (though the spillovers are generally found to be far from complete). For example, Coe and Helpman (1995) estimate that the elasticity of UK TFP with respect to foreign R&D stocks was between 0.06% and 0.08% between 1970–90.(3)

R&D stocks for manufacturing enterprises in the OECD have been derived from the OECD's ANBERD(4) database (see Chart 11). Preliminary analysis suggests that:

- By the end of the period, nearly 75% of the OECD's R&D expenditure in manufacturing was undertaken in the United States and Japan, the two countries one would expect to be most technologically advanced and for whom technology transfer is least likely to be a major source of growth. The UK share amounts to some 6%.

- The growth rate of aggregate R&D in UK manufacturing has been slower than in its G7 partners.

Chart 11
Shares of total R&D stocks in G7 manufacturing



(1) More specifically, we employ the same method as that used by Coe and Helpman (1995), among others, to construct R&D stocks.
(2) For a survey of this literature, see Cameron (1996).
(3) This is considerably lower than most estimates of the elasticity of TFP in the United Kingdom with respect to domestic R&D stocks [Cameron (1996)], though Coe and Helpman (1995) do not report their estimate for the latter.
(4) Analytical Business Enterprise Research and Development.

During the period, R&D stocks of UK manufacturing enterprises were overtaken by Japan, Germany and France.

Simple measures of foreign R&D stocks are unlikely on their own to be good proxies for the extent of knowledge spillovers. International knowledge is likely to flow between countries in proportion to the amount of contact between them, particularly resulting from trade, foreign investment and the flow of technological licences, but the precise mechanisms by which ideas flow across national borders are not well understood. In our empirical analysis, three alternative approaches to weighting R&D stocks were considered: import-weighted, inward FDI-weighted and outward FDI-weighted.(1) But the correlation between these measures is high and it is hard to distinguish between them: Section 6 reports the results for the import-weighted R&D stock.

An empirical analysis of the links between openness and growth

The earlier discussion suggested that international openness can affect growth in a number of ways and that quantifying the overall effect is not straightforward. Most channels imply a positive link, though one is ambiguous. In practice, as will be seen below, there is considerable empirical evidence that the net effect in the United Kingdom is positive.

A number of other factors are also likely to affect the rate of economic growth. For example, domestic rates of research and development, educational standards, the degree of unionisation and changes in capacity utilisation are frequently cited as important determinants of rates of productivity growth.(2) Because of this complexity, we take a two-stage approach to analysing the relationship between openness and growth. We begin by simply analysing partial correlations, which provide important stylised facts about the association between openness and growth.(3)

Having shown that there is a clear association, we move on to a more formal econometric analysis.(4) This draws on a theoretical model in which productivity in an industry may grow as a result of either innovation or technical transfer from the technologically most advanced economy. The difference between the initial level of productivity and that in the most advanced economy becomes an important determinant of rates of productivity growth. We therefore discuss the behaviour of TFP in UK manufacturing sectors relative to this standard, proxied throughout by the United States. International openness may affect either rates of innovation or rates of technological transfer, and we investigate the relative importance of these two channels with a variety of different measures of international openness. We also take into account the impact of the other potentially significant determinants of productivity growth cited above. Having estimated the econometric model, we briefly consider the effect of openness on the levels of long-run relative productivity and compare it with the effects of the other major explanatory variables.

The association between openness and growth

One problem in evaluating the relationship between openness and growth is that there are many different measures of international openness. We begin by trying to combine the information contained in the different measures to classify sectors as either relatively open or relatively closed. Drawing again on the technique of discriminant analysis, groups were selected that emphasise both the similarities of the openness characteristics of the sectors within the same group and the differences between the representative properties of the groups.

UK manufacturing sectors were divided into ‘relatively open’ and ‘relatively closed’ groups on the basis of five measures of openness: imports/sales (*M/S*), exports/output (*X/Y*), inward FDI flows/output (*IFDI/Y*), outward FDI flows/output (*OFDI/Y*) and trade-weighted foreign R&D stocks/output (*TWRD/Y*). Values of these variables in 1970 were chosen to try to address the endogeneity problem. The results are presented in Tables E and F.

Table E
Average growth characteristics for manufacturing industries classified as relatively closed using openness measures in 1970

Industry	*M/S*	*X/Y*	*IFDI/Y*	*OFDI/Y*	*TWRD/Y*	*ΔTFP*
Textiles	0.21	0.16	0.001	0.000	0.03	1.76
Timber and furniture	0.08	0.16	0.000	0.000	0.09	0.27
Minerals	0.11	0.06	0.000	0.000	0.06	-1.06
Iron and steel	0.12	0.07	0.000	0.019	0.08	2.22
Non-ferrous metals	0.21	0.37	0.000	0.057	0.19	1.20
Average closed	**0.15**	**0.16**	**0.000**	**0.015**	**0.09**	**0.88**

Table F
Average growth characteristics for manufacturing industries classified as relatively open using openness measures in 1970

Industry	*M/S*	*X/Y*	*IFDI/Y*	*OFDI/Y*	*TWRD/Y*	*ΔTFP*
Food and drink	0.09	0.19	0.014	0.037	0.02	-0.26
Paper and printing	0.03	0.23	0.003	0.008	0.03	1.32
Chemicals nes (a)	0.24	0.19	0.041	0.049	0.59	1.10
Pharmaceuticals	0.31	0.11	0.188	0.225	1.25	3.85
Rubber and plastics	0.13	0.06	0.019	0.000	0.20	1.58
Metal goods	0.12	0.09	0.016	0.031	0.09	1.39
Machinery	0.28	0.15	0.007	0.015	0.17	0.72
Computing	0.34	0.49	0.324	0.198	8.76	5.67
Other electrical engineering	0.19	0.24	0.066	0.041	2.56	1.68
Electronics	0.18	0.08	0.072	0.044	2.04	3.01
Motor vehicles	0.28	0.07	0.025	0.005	0.50	0.93
Aerospace	0.27	0.22	0.054	0.010	15.97	4.17
Instruments	0.35	0.29	0.285	0.174	2.75	2.95
Other manufacturing	0.32	0.19	0.076	0.245	0.86	1.27
Average open	**0.22**	**0.19**	**0.085**	**0.077**	**2.56**	**2.10**

(a) Nes: not elsewhere specified.

(1) The Coe and Helpman (1995) method was used. For a critique of weighting foreign R&D stocks by trade shares, see Keller (1996).
(2) For a theoretical model in which R&D expenditures are an important determinant of growth, see Aghion and Howitt (1992). Benhabib and Spiegel (1994) emphasise human capital, and Ulph and Ulph (1994) consider the role of unionisation.
(3) *Openness and its association with productivity growth in UK manufacturing*, by Gavin Cameron, James Proudman and Stephen Redding (June 1997).
(4) *Productivity convergence and international openness* by Gavin Cameron, James Proudman and Stephen Redding (August 1997).

The average values of the openness measures are considerably higher for the group of 'relatively open' sectors than for the group of 'relatively closed'. At the same time, average annual productivity growth for the group of open sectors is 2.1% compared with 0.9% for the closed sectors, suggesting a striking degree of association between openness and rates of growth of TFP.(1) There is also a positive association between openness and levels of productivity.

Though discriminant analysis offers a simple way of illustrating that relatively open sectors tend to experience faster rates of productivity growth, it does not allow for differences in the degree of openness between members of the same group. Linear regression allows this restriction to be relaxed. In the next step of the analysis, we separately regress the average annual rate of growth in labour productivity, the rate of growth of TFP and the contribution to labour productivity growth from increases in the capital/labour ratio between 1970–92 against the 1970 value of each measure of openness.(2)

These cross-section regressions indicate that within manufacturing, the ratios of inward FDI to output (*IFDI/Y*), outward FDI to output (*OFDI/Y*) and trade-weighted R&D stocks to output (*TWRD/Y*) are positively and significantly correlated with labour productivity growth. All of these measures, and the exports to output ratio (*X/Y*) are significantly correlated with the rate of TFP growth. But none of the measures of openness is significantly correlated with that part of labour productivity growth explained by increases in the capital/labour ratio. This is consistent with the hypothesis that openness affects growth through rates of technical change, rather than through capital accumulation.

To address the endogeneity problem at least partly, the results reported in Table G are coefficients derived using 1970 values of openness. These results are in fact fairly robust to alternative specifications: for example, similar results were derived using an instrumental variables technique. The estimates are also robust to the exclusion of extreme values.

Table G also presents estimates for the whole economy as memo items. These were derived by extending the sample of 19 manufacturing sectors to include the eight non-manufacturing sectors listed in Table B. Estimation is undertaken using trade and foreign direct investment ratios only, since no consistent data on foreign R&D expenditures are available. The same general finding emerges: measures of openness are positively and significantly associated with rates of growth of TFP and labour productivity, but not with rates of growth of the capital/labour ratio.

Table G
Cross-section regressions of average TFP growth (1970–92) against initial (1970) measures of openness (standard errors in brackets)

Openness measures (logs)	β (labour productivity)	β (capital/ labour	β (TFP)
Exports/output (*X/Y*) (c)	0.0109	0.0010	0.0112 (a)
	(0.007)	(0.003)	(0.005)
Imports/sales (*M/S*) (c)	0.0069	0.0025	0.0094
	(0.007)	(0.003)	(0.006)
Inward FDI flows/output (*IFDI/Y*) (d)	0.0026 (a)	0.0004	0.0023 (a)
	(0.001)	(0.001)	(0.001)
Outward FDI flows/output (*OFDI/Y*) (d)	0.0022 (b)	0.0005	0.002 (a)
	(0.001)	(0.001)	(0.001)
Import-weighted R&D/output (e) (*TWRD/Y*)	0.0059 (a)	0.0004	0.0056 (a)
	(0.002)	(0.001)	(0.001)
memo items: whole-economy data			
Exports/output	0.0139 (a)	0.0028	0.0069 (a)
	(0.0052)	(0.0019)	(0.0033)
Imports/sales	0.0137 (a)	0.0013	0.0081 (a)
	(0.0036)	(0.0015)	(0.0026)
Inward FDI flows/output (*IFDI/Y*)	0.0031 (b)	0.0008	0.0024 (a)
	(0.0017)	(0.0006)	(0.0012)
Outward FDI flows/output (*OFDI/Y*)	0.0033 (b)	0.0008	0.0025 (a)
	(0.0019)	(0.0007)	(0.0012)

(a) Indicates significance at the 95% level.
(b) Indicates significance at the 90% level.
(c) Flow of goods.
(d) Flow of capital.
(e) Flow of ideas.

Productivity convergence and international openness

The empirical results presented in the previous section provide evidence that openness is associated with growth across sectors: sectors that were relatively open in 1970 tended to have higher rates of productivity growth between 1970–92. But this association reflects a partial correlation. This cannot be interpreted as a structural relationship, since no allowance has been made for interactions with and between other economic variables. In this section, we therefore move on to consider the effect of openness on growth in a more formal econometric framework, derived from an underlying theoretical model.(3) As discussed in the second section, one of the most important ways in which international openness may affect rates of economic growth is by facilitating technological transfer from a more technologically advanced economy. Based on a theoretical model of the determinants of productivity growth, in which international openness may affect the rate of technological transfer or the rate of innovation, a simple mathematical expression for the rate of growth of TFP in each manufacturing sector can be derived:

$$\Delta \ln(A_t) = \gamma + \lambda . \ln\left(\frac{A_{t-1}^{US}}{A_{t-1}}\right) \tag{1}$$

where λ and γ are both functions of openness, human capital, R&D etc. A_t and $\Delta\ln(A_t)$ denote the level and rate of growth of productivity respectively in the relevant sector in the United Kingdom, and A_t^{US} denotes the level of productivity in the United States. The subscript (*t*) corresponds to time.

(1) Assuming the two samples are drawn from two normally distributed populations with the same variance, we can reject the null hypothesis that the TFP growth rates are the same in each population at the 90% level.
(2) We make use of the fact that the rate of growth of labour productivity may be decomposed into the rate of growth of TFP and the capital share times the rate of growth of the capital/labour ratio.
(3) *Productivity convergence and international openness*, by Gavin Cameron, James Proudman and Stephen Redding (August 1997).

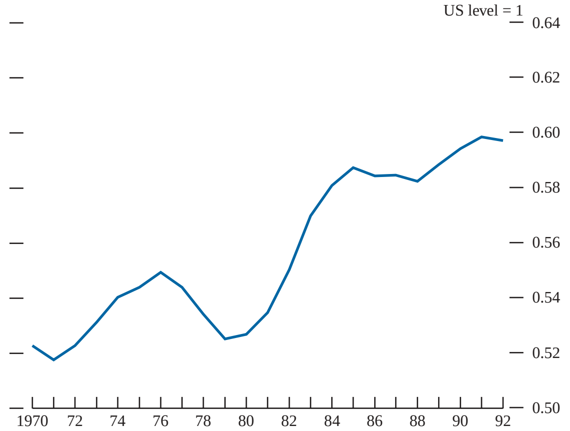
Equation **(1)** states that the rate of growth of UK productivity depends on two terms. The first term (γ) captures the effect of various economic variables (such as domestic R&D intensity and human capital) on the rate of innovation, and the second implies that, other things being equal, a sector's rate of productivity growth will be higher as the gap between UK and US productivity increases. The parameter (λ) determines the rate at which productivity in the United Kingdom catches up with that in the United States. This parameter is allowed to be a function both of the level of openness in each sector and of other economic factors that may affect the rate of convergence.

One of the most important features of the model of technology transfer is the level of productivity relative to the technological leader. But to measure relative productivity, one must first convert values of output and physical capital into a common currency. So in principle, the exchange rate is central to relative productivity measurement.

Conceptually, the appropriate exchange rate is the purchasing power parity (PPP) exchange rate, which represents the number of dollars required to buy the same quantity of goods that can be purchased with one pound sterling. But since relative prices may vary significantly across different industries, it would be misleading to use a single, economy-wide PPP. The approach taken is to use the industry-specific PPPs presented in Van Ark (1992), derived from unit value ratios[(1)] for a variety of individual products within each manufacturing sector. Though we favour the unit value approach, we have tested the sensitivity of our data by replicating our estimates of relative productivity using four other sets of disaggregated PPPs.[(2)] The evolution of relative TFP over time was generally robust to the choice of PPP.

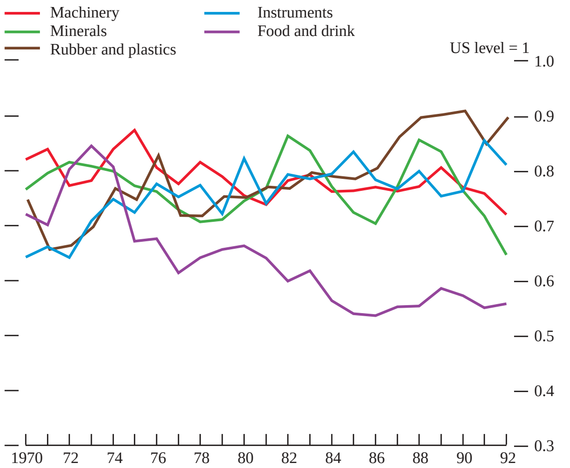
Charts 12–15 plot the evolution of TFP in the United Kingdom relative to the United States for total manufacturing and the disaggregated manufacturing subsectors.[(3)] Two features stand out fairly clearly. First, UK TFP rose towards US levels in the period from 1970–92. TFP in aggregate UK manufacturing rose from around 52% of the US level to roughly 60%, implying a closing of roughly 15% of the productivity gap with the United States in the 22-year period. How fast the productivity gap was closed varied during the sample period (see Chart 12). At the end of the 1973–79 peak-to-peak business cycle, there was very little change in UK relative productivity from its 1973 level. In contrast, in the 1979–89 business cycle, UK relative productivity rose from about 53% of the US level to about 58%. This improvement is consistent with the earlier evidence showing a rise in the United Kingdom's domestic rate of TFP growth.

Chart 12
The evolution of TFP in aggregate UK manufacturing relative to the United States(a)



(a) Five-year moving average.

Chart 13
The evolution of relative TFP in the five UK manufacturing sectors with the *highest* initial level of TFP



Second, the rate at which relative productivity catches up with US levels is on average higher in sectors with low initial levels of relative productivity. This is shown in Charts 13–15, where we compare the evolution of relative TFP for each of the disaggregated manufacturing sectors, grouping sectors by the initial levels of UK productivity relative to that of the United States. This evidence is confirmed by a cross-section regression of average annual rates of growth of relative TFP between 1970–92 against 1970 levels of relative TFP. The estimated coefficient on the initial level of TFP is negative and statistically significant: the rate of productivity catch-up across sectors was inversely related to the initial level of relative productivity.[(4)] The estimated coefficients are shown in Table H.

(1) A unit value ratio is simply the ratio of producers' sales values to the corresponding quantities.
(2) The four alternative sets were: the OECD whole-economy PPP; disaggregated PPPs taken from Pilat (1996); disaggregated OECD estimates derived from the UN International Comparisons Project [ICP see Kravis, Heston and Summers (1978)]; and our own estimates derived from the UN ICP.
(3) To obtain data in the same industrial classification in the United States and the United Kingdom, we have had to aggregate data into 14 manufacturing sectors.
(4) In terms of the cross-country convergence literature, relative productivity exhibits absolute β-convergence. Note that the fact that the rates of growth of relative TFP are negatively correlated with the initial level (β convergence) does not necessarily imply that the dispersion of relative TFP levels across sectors is declining over time (σ convergence). To suppose so is to fall foul of Galton's fallacy (see Quah (1993b)).

Chart 14
The evolution of relative TFP in the five UK manufacturing sectors with the *intermediate* initial level of TFP

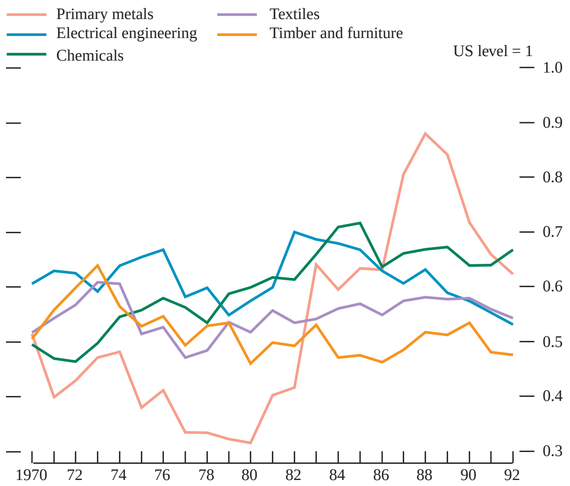


Chart 15
The evolution of relative TFP in the four UK manufacturing sectors with the *lowest* initial level of TFP

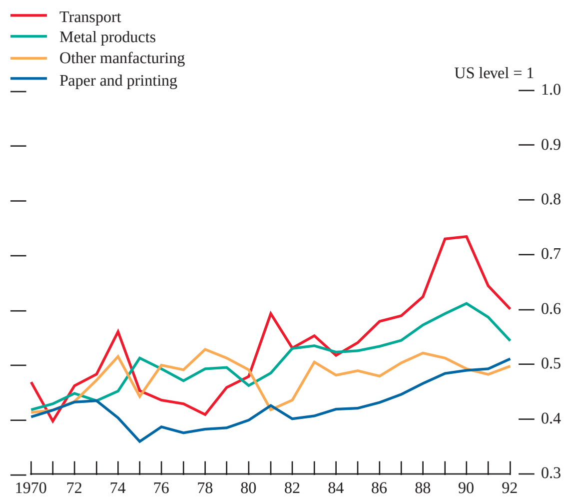


Table H
Cross-section regression of average relative TFP growth (1970–92) on 1970 values of relative TFP (standard errors in brackets)

Dependent variable:	Average annual relative TFP growth
Constant	-0.0098 (a)
	(0.0049)
Initial relative TFP	-0.0232 (a)
	(0.0078)

(a) Indicates significance at the 95% level.

Having analysed movements in relative TFP during the sample period, we model econometrically the role of the productivity gap between the United States and United Kingdom in determining the growth of UK TFP.

In our estimation, we wish to allow the rate of growth of TFP in a sector to be a function of a number of variables that, in addition to openness, we believe may affect either the rate of innovation (γ) or the rate of technological transfer (λ). These variables include the intensity of commercially funded R&D, levels of human capital, the degree of trade unionisation, changes in capacity utilisation, and the ratio of input to output prices, which may distort the estimation of TFP. Not only does this approach permit a more general specification of growth, but it also allows us to explore the robustness of the association between productivity growth and openness to the inclusion of other economic variables.

We capture the impact of economic variables, including openness, on the rate of technology transfer econometrically by including more than one productivity gap term. One is simply the size of the productivity gap: the level of US TFP relative to that of the United Kingdom. The others are the size of the productivity gap multiplied by the level of variables—including international openness—that may influence the rate of technology transfer.[(1)] A positive coefficient for the first term implies that the sectors with low initial levels of UK TFP relative to the United States grow more rapidly; a positive coefficient for the openness interaction term implies that more open sectors converge more rapidly with the technological leader for a given size of the technological gap.

Our data set includes time-series and cross-section dimensions, with a total of about 300 observations. The technique of fixed-effects panel estimation was used to estimate the model. This pools observations across sectors and time, but allows for differences between sectors by estimating separate constant terms for each. Within this framework, the model was estimated using least squares.[(2)] The precise specification of the model—reported in Table I—was arrived at by initially including a large number of variables that we believed might be important, and then dropping those that were insignificant. The most notable variable that we were able to drop was the degree of trade unionisation.

Reflecting the variety of measures of openness corresponding to the flow of goods, ideas and capital, the system was estimated separately for each measure in an otherwise identical regression. In Table I, we report the regression results for the export and the import ratios. Identical regressions were run—but are not reported here—measuring openness as the inward and outward FDI ratios and as the trade-weighted R&D stock ratio.

We find that the coefficient of the openness interaction term (‘ln(openness) interaction (-1)’) is correctly signed and significant at the 95% level when estimated using the export ratio and the import ratio. The term is also correctly signed when openness is measured using the trade-weighted R&D

(1) Formally, the terms are $\ln(A^{US}_{t-1}/A_{t-1})$ and ln(*openness*).t-1 $\ln(A^{US}_{t-1}/A_{t-1})$.
(2) Least squares can potentially generate inconsistent estimated coefficients within a fixed effects panel. To test for the extent of this potential problem, we re-estimated the system using an instrumental variables approach. The instrumental variables estimates differed little from their OLS counterparts. We also tested for the sensitivity of the results to extreme values. Again, this made little difference to the results.

Table I
Fixed effects panel data least squares estimation[(a)] (dependent variable: UK TFP growth) Sample period, 1970–92. Total panel observations 294.

Dependent variable: UK TFP growth	Coefficient number	Export/output		Import/sales	
		Coefficient	Standard error	Coefficient	Standard error
ln (openness interaction (-1))	(α_1)	0.0780 (b)	0.0347	0.0394 (b)	0.0198
ln (gap(-1))	(α_2)	0.2178 (b)	0.0376	0.2025 (b)	0.0357
ln (R&D intensity (-1))	(α_3)	0.0350 (b)	0.0142	0.0352 (b)	0.0142
ln (human capital interaction (-1))	(α_4)	0.0899 (b)	0.0389	0.0788 (c)	0.0413
Δln (capacity utilisation (-1))	(α_5)	-0.0904 (b)	0.0139	-0.0908 (b)	0.0139
ln (input/output prices (-1))	(α_6)	-0.0901 (b)	0.0349	-0.0942 (b)	0.0356
Fixed effects:	($\alpha_{i,0}$)				
Food and drink		0.1024		0.0778	
Textiles		0.0935		0.0877	
Timber and furniture		0.1774		0.0970	
Paper and printing		0.1051		0.0497	
Minerals		0.1236		0.1212	
Chemicals		-0.0204		-0.0041	
Rubber and plastics		0.1441		0.1423	
Primary metals		0.0347		0.0316	
Metal products		0.0839		0.0902	
Machinery		0.0609		0.0721	
Electrical engineering		-0.0197		-0.0139	
Transport		-0.0560		-0.0334	
Instruments		0.0378		0.0536	
Other manufacturing		-0.0908		-0.0443	
R-squared		0.2619		0.2591	
Adjusted R-squared		0.2132		0.2102	
S E of regression		0.0630		0.0631	
Log likelihood		724.3306		727.8821	
Durbin-Watson stat		2.0530		2.0559	
Mean dependent variable		0.0131		0.0131	
S D dependent variable		0.0710		0.0710	
Sum squared residual		1.1437		1.1481	
F-statistic		20.4346		20.1392	
Prob (F statistic)		0.0000		0.0000	

Note: Differences between US and UK industrial classifications mean that we can only disaggregate relative TFP into 14 sectors rather than the original 19.

(a) Estimated equation:

$$\dot{A}_{i,t} = \alpha_{i,0} + \alpha_1.\ln(\Omega_{i,t-1}).\ln\left(A^{US}_{i,t-1}/A_{i,t-1}\right) + \alpha_2.\ln\left(A^{US}_{i,t-1}/A_{i,t-1}\right) + \alpha_3.\ln(R_{i,t-1}) + \alpha_4.\ln(H_{i,t-1}).\ln\left(A^{US}_{i,t-1}/A_{i,t-1}\right) + \alpha_5.\Delta\ln(C_{i,t-1}) + \alpha_6.\ln(IO_{i,t-1}) + \xi_{i,t}$$

(b) Denotes significance at the 95% level.
(c) Denotes significance at the 90% level. (-1) denotes variables lagged by one period.

ratio. These results suggest that trade in goods and the flow of ideas are channels through which technology transfer occurs. But the coefficient on the openness interaction term is incorrectly signed and insignificant when estimated using either the inward or the outward FDI ratio. This suggests that though FDI is positively correlated with TFP growth across sectors, this correlation does not persist when the size of the technology gap in a sector and a number of other determinants of economic growth are also taken into account.

Turning to the other variables in the model, the coefficient of the productivity gap term ('ln(gap$_t$(-1)) is significant and correctly signed, consistent with the technological transfer theory. Domestic R&D intensity is also significant and our measure of human capital (given by the ratio of workers with high and medium qualifications to workers with low qualifications) is positive and significant when combined with the productivity gap (hence implying that higher levels of human capital accelerate the speed of technology transfer). We also find that the change in capacity utilisation is a significant influence on TFP growth.

The model of technology transfer described in equation **(1)** and estimated in Table I implicitly incorporates a long-run steady-state level of productivity in each sector relative to that of the United States. By definition, the growth rate of TFP in the United Kingdom will equal that in the United States in the steady state. So by setting the growth rate of TFP in the United Kingdom—the left-hand side of equation **(1)**—equal to the estimated long-run rate of growth of TFP in the corresponding US sector, we can derive an expression for the steady-state—or long-run—level of productivity in the United Kingdom relative to that of the United States.[(1)] Rearranging equation **(1)** and denoting steady-state values with a star yields the following expression:

$$\ln\left(\frac{A}{A^{US}}\right)^* = \frac{\gamma - \Delta\ln\left(A^{US*}\right)}{\lambda(openness)} \qquad \textbf{(2)}$$

It follows that in the long run, the level of relative productivity tends to a constant that is determined by the rate of catch-up, the level of openness and the levels of the other significant explanatory variables (domestic R&D intensity, human capital and the input/output price ratio). Openness accelerates the rate of productivity growth in the transition to the steady state (through the rate of convergence) and increases the long-run steady-state level of relative productivity.[(2)]

(1) We proxy the long-run rate of growth of TFP in the United States in each sector by the sample average annual growth rate of TFP.
(2) We do not attempt in this model to determine the long-run world growth rate. But it is consistent both with the theoretical literature in the second section and with the empirical framework outlined here for the long-run joint growth rate to be affected by changes in the degree of openness in the international economy.

We can use the estimated coefficients from Table I to make inferences about changes in the steady-state level of relative productivity. The implicit steady states in 1970 and 1990 are presented in Table J, using coefficients estimated using the import ratio. Taking the average of the 14 sectors, the steady-state level of productivity in UK manufacturing rose from roughly 58% of US levels in 1970 to some 69% in 1990.

Table J
Actual and steady-state levels of UK TFP relative to those in the United States at the start and end of the sample period (1970–90)

Steady-state levels derived from coefficients estimated using imports/sales ratios

	Relative TFP in 1970		Relative TFP in 1990	
Sector	Actual	Steady-state	Actual	Steady-state
Food and drink	0.7210 (a)	0.5527	0.5725	0.6743
Textiles	0.5171 (a)	0.5755	0.5801	0.5827
Timber and furniture	0.5054	0.5555	0.5349	0.5757
Paper and printing	0.4041	0.4537	0.4891	0.5298
Minerals	0.7654 (a)	0.7172	0.7629	0.8257
Chemicals	0.4951	0.5734	0.6397	0.7846
Rubber and plastics	0.7475	0.8192	0.9082	0.9212
Primary metals	0.5146	0.5381	0.7177 (a)	0.6693
Metal products	0.4172	0.5169	0.6107	0.7052
Machinery	0.8202 (a)	0.7240	0.7688	0.8595
Electrical engineering	0.6057 (a)	0.5166	0.5742	0.7010
Transport	0.4672 (a)	0.4626	0.7335 (a)	0.6633
Instruments	0.6431	0.8137	0.7620	0.7839
Other manufacturing	0.4119	0.4336	0.4914	0.5722

(a) Denotes a sector in which actual relative TFP exceeds estimated steady-state relative TFP.

This average conceals variations across sectors. But it is clear from the estimates that the steady-state level of relative TFP increased considerably across almost all sectors in the period. In only one sector (Instruments) did the steady-state level fall.

An important issue to explore is which factors contributed to the rise in steady-state relative productivity during the period. The contribution of each factor may be approximated by simulating the steady state using 1990 values of each explanatory variable in turn, holding all others constant at their 1970 level. This calculation indicates that some 51% of the rise in the steady-state level of productivity in the period was related to the increase in openness (as measured by the import ratio). 55% of the increase was linked to the increase in human capital. Changes in R&D intensity in UK manufacturing reduced the steady-state level of productivity by 17%, and the fall in the ratio of input to output prices made a small positive contribution.

Summary

The Openness and Growth Project examined how far variations in rates of UK economic growth across time and sectors are related to differences in the degree of international openness. Three main channels were identified through which openness may affect growth: international trade in goods and services, international movements in factors of production and the international spillover of ideas. Given these three dimensions to international openness, quantifying its overall effect on rates of productivity growth is not at all straightforward.

An important part of the project has been to compile and estimate accurate measures of productivity and openness at a disaggregated level. Two particular data issues stand out. First, there are problems associated with the potential endogeneity of measures of openness. We have used a variety of econometric procedures to deal with this, and have shown that our results are robust to the use of alternative techniques. Second, problems of data availability and quality have necessarily restricted parts of our analysis to the manufacturing sector, where there are more and better data. Nonetheless, we have replicated our results with data for the whole economy wherever possible.

The recent theoretical literature provides two main mechanisms through which it is likely that openness may affect growth. International openness may affect either the rate of innovation or the rate of adoption of technologies from more advanced countries, thereby increasing an economy's rate of total factor productivity growth.

In summary, the main empirical findings of our research are:

- There is a clear association between openness and growth in *per capita* income across a large number of developed and developing countries.
- At the sectoral level in the United Kingdom, average rates of labour productivity growth across sectors are positively correlated with a number of measures of international openness. Labour productivity growth may itself be decomposed into changes in technical efficiency, as measured by Total Factor Productivity (TFP) growth, and the contribution of increases in the capital/labour ratio. TFP growth exhibits a statistically significant and positive correlation with international openness; that part of productivity growth explained by capital accumulation exhibits a low and statistically insignificant degree of correlation with openness.
- Using the statistical technique of discriminant analysis to classify sectors as relatively open and relatively closed, fourteen UK manufacturing sectors were found to be relatively open and five relatively closed. Open sectors exhibited higher average rates of TFP growth than closed ones.
- Between 1970–92, the pattern of specialisation in trade in UK manufactured goods underwent substantial change. In principle, changes in the allocation of resources across sectors as a result of international trade may affect an economy's growth rate. But during the same period, the vast bulk of UK productivity growth was found to be due to growth within sectors, rather than to movements of factor resources between sectors.
- Between 1970–92, some 15% of the initial gap between the UK and the US manufacturing TFP was closed, mostly during the 1980s. Manufacturing

sectors with the lowest productivity levels relative to the United States tended to experience the fastest rates of growth of relative productivity.

- The rate at which TFP in sectors within UK manufacturing converged with levels in the United States depended on the degree of international openness, as measured by flows of goods or flows of ideas. This finding remained true when we allowed for other explanatory variables, such as changes in capacity utilisation, the intensity of domestic research and development, education standards and the degree of trade unionisation. Measures of the flow of capital were found to be insignificant.

- Between 1970–90, the estimated average long-run level of productivity in UK manufacturing relative to that in the United States rose from 58% to 69%. It was estimated that about one half of this increase was attributable to the increase in openness during the period. The vast majority of the remainder was associated with improvements in educational standards.

Taken together, these empirical findings provide a body of evidence to suggest that greater international openness is closely associated with higher rates of productivity growth, both across countries and across sectors within the United Kingdom. Though the interactions between openness and growth are complex and not easy to disentangle, the evidence suggests that openness raises the rate of productivity growth in the United Kingdom by increasing the speed of productivity convergence with the technological leader.

Annex

List of research papers

Openness and Growth: theoretical links and empirical estimation, by Stephen Redding, *mimeo*, (July 1996).

'Is International Openness associated with Faster Economic Growth?' by James Proudman, Stephen Redding and Marco Bianchi, (June 1997), *Bank of England Working Paper*, No 63. Presented at the European Economic Association Conference, August 1997.

'Persistence and Mobility in International Trade', by James Proudman and Stephen Redding, (June 1997), *Bank of England Working Paper*, No 64. Presented at the Royal Economic Society Conference, March 1997 and at the European Economic Association Conference, August 1997.

'Deconstructing Growth in UK manufacturing', by Gavin Cameron, James Proudman and Stephen Redding, (May 1997). Presented at the LSE Money Macro Workshop, May 1997 and accepted for the *Bank of England Working Paper* series.

Openness and its association with productivity growth in UK manufacturing, by Gavin Cameron, James Proudman and Stephen Redding, *mimeo* (August 1997).

Productivity Convergence and International Openness, by Gavin Cameron, James Proudman and Stephen Redding, (August 1997). Presented at the European Science Foundation Conference on Growth in Open and Closed Economies, September 1997.

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