Openness and its association with productivity growth in UK manufacturing industry

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Abstract

A large theoretical literature exists that suggests that differences in growth performance may be related to variations in the extent of international openness. This paper is concerned with quantifying measures of openness and examining their association with productivity growth across 19 sectors in UK manufacturing between 1970 and 1992. Using the statistical technique of discriminant analysis, sectors were sorted into groups on the basis of their measured values of openness in 1970. Sectors classified as relatively open enjoyed significantly higher rates of total factor productivity (TFP) growth between 1970 and 1992 than those classified as closed. There was a positive correlation between the growth in labour productivity and lagged values of each of the observed measures of openness. This relationship was explained by a strong relationship between lagged values of openness and TFP growth. But, there was no evidence of a positive relationship between openness and that part of labour productivity growth explained by capital accumulation.

1 Introduction

A large theoretical literature suggests that differences in growth performance may be related to variations in the extent of international openness. Section 2 begins with a brief review of the theoretical links between international openness and rates of economic growth, drawing on the recent endogenous growth literature.[1] This literature suggests that there are several distinct channels (flows of goods, of factors of production and of ideas) through which the international environment can affect an economy's rate of growth. It is likely that the net effect of these flows will be positive, although the theoretical literature also suggests that international openness is multi-faceted and its relationship with economic growth is unlikely to be straightforward.

In the light of this complexity, the objective of this paper is to take some simple preliminary steps in considering the relationship between openness and Total Factor Productivity (TFP) growth across 19 sectors in UK manufacturing between 1970 and 1992.

A necessary first step in estimating the strength of the relationship is to quantify the extent of international openness in different sectors, and most of the empirical work in this paper is devoted to this task. Conceptually, the definition of 'international openness' is relatively uncontentious: an industry or economy is said to be more open the smaller the extent of barriers to the free movement of goods and services, factors of production and ideas. However, moving from this conceptual definition to an empirical measure of international openness is problematic. Section 3 discusses some of the problems inherent in measuring openness and presents different measures for each of the three categories of goods, ideas and financial capital. We then move from quantifying openness to characterising it. In particular, we show that there exists a quite surprisingly strong and positive correlation between different measures of openness (corresponding to the flow of goods, of Foreign Direct Investment (FDI) and of ideas). Using principal components analysis, it is possible to derive a single, broadly based, empirical measure of openness, which explains over 70% of the total variation of these individual measures.[2]

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[1] See Redding (1998) for a more detailed review of the theoretical links between international openness and rates of economic growth.
[2] This finding contrasts with results presented by Pritchett (1996) who shows, at the cross-country level, that there is little pair-wise correlation between different measures of openness.

The final part of the paper, Section 4, presents some stylised facts about the cross-sectional relationship between the measures of openness discussed earlier in the paper and rates of TFP growth across 19 manufacturing sectors.[3] This relationship can only be examined in depth through formal econometric testing of a well-specified hypothesis. But intricate econometrics may be misleading if it is not preceded by a proper analysis and characterisation of the data. The purpose of this section, therefore, is to undertake such preliminary data characterisation, leaving more formal testing of the robustness and specification of these relationships for further work (see Cameron, Proudman and Redding (1998b)). The analysis proceeds in two stages.

In the first, we adopt an approach similar to that employed by Sachs and Warner (1995) in the cross-country convergence literature and combine the information contained in the different measures of openness by making use of simple group characteristics. In particular, we make use of the statistical technique of discriminant analysis to sort sectors into groups on the basis of their measured values of openness in 1970 and show that sectors classified as relatively open across a range of openness measures enjoyed significantly higher rates of TFP growth between 1970 and 1992 than did the group classified in 1970 as relatively closed.

In the second stage of the analysis, we show that the association between openness and TFP growth is robust to the introduction of continuous measures of openness. We also consider the relationships between labour productivity and the same measures of openness, and make use of the fact that the rate of growth of labour productivity can be decomposed into TFP growth and the contribution of increases in the capital-labour ratio (see, for example, Cameron, Proudman and Redding (1998a)). We find that there is a positive correlation between the growth in labour productivity and lagged values of each of the observed dimensions of openness. Moreover, this relationship is explained by a strong and positive relationship between lagged values of openness and TFP growth. But, there is no evidence of a positive relationship between openness and that part of labour productivity growth explained by capital accumulation. We then bring together the information contained in the different measures of openness by considering the cross-sectional relationship between the growth in labour productivity and TFP and the broadly based measure of openness derived from the

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[3] See Cameron, Proudman and Redding (1998a) for a detailed discussion of the measurement of TFP growth and its behaviour over time and across sectors in UK manufacturing.

principal component. Regressing the rate of growth of labour productivity on 'openness' so defined across sectors, we obtain a positive and statistically significant estimated coefficient of 0.0029 (and 0.0027 for TFP growth). We are unable to reject the hypothesis that this coefficient is different between the 1973-79 and 1979-89 'peak-to-peak' business cycles.

The main contributions of the paper are therefore to provide empirical measures of openness at a disaggregated level in the United Kingdom, and to establish a clear, positive, cross-sectional association between the openness measures and TFP growth across a range of UK manufacturing sectors. That is, more open sectors tend to have higher rates of productivity growth. There are, however, many things this paper does not attempt to show. For example, it does not attempt to consider whether this association is causal, although the fact that there remains an association when lagged values of openness are used is suggestive. Neither do we examine the robustness of the econometric specification to the inclusion of other explanatory variables. Hence we cannot infer whether the estimated coefficient represents a structural parameter and it should not be interpreted as such. In particular, it is likely that the interaction between openness and both domestically funded research and development (R&D) and productivity differentials with more advanced economies may well provide an important element of the relationship between openness and growth. Nevertheless, the strength of the association between openness and growth uncovered in this paper is a useful finding, which provides both a characterisation of the data and a step towards a more complete examination of the links between openness and growth.

2 Theoretical links between international openness and growth

International openness is defined as the extent of barriers to the free movement of ideas, goods and services, and factors of production.[4] This section briefly reviews the theoretical links between international openness so defined and an economy's rate of growth.

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[4] Although recent work by Quah (1996a) and (1996b) suggests that the distinction between ideas and goods is somewhat artificial. According to Quah, an increasing proportion of value-added is embedded in logical units 'bits and bytes of memory' whether computer, biological or chemical rather than in physical or material form, a process that is a described as 'dematerialisation' or 'increasing weightlessness'.

Our research follows the recent literature on endogenous growth in arguing that the rate of technological progress is both endogenously determined by the profit-seeking choices of economic agents and is the prime determinant of an economy's long-run rate of growth. It is likely 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. Hence, even if physical and human capital are accumulated at a constant rate, an economy's rate of growth of output will fall over time as diminishing returns set in in the absence of further technological progress.

However, technological change is capable, under certain conditions, of sustaining long-run growth. Each technological innovation directly increases the flow of output produced with given stocks of physical and human capital and, by raising the marginal product of each factor of production, indirectly increases output through the accumulation of physical and human capital that it induces. To assess informally the role of technological change in fuelling long-run growth, consider how modern manufacturing would proceed without electricity, the internal combustion engine and the computer.

A benchmark model in the literature on endogenous growth and trade is that of Grossman and Helpman (1991a), who consider open-economy models of growth through both increasing variety (following Romer (1990))[5] and rising product quality (following Aghion and Howitt (1992)). In fact, Grossman and Helpman argue that the effects of international openness are, to a large degree, independent of whether technological change is modelled in terms of increasing variety (increasing specialisation) or increasing quality. Skilled labour may either be employed in the production of current output or in research. The rate of growth of output is determined by the rate of introduction of the new designs for goods discovered by research. This is itself a function of the flow of skilled labour employed in research and the productivity of research.

Within this framework, international openness will affect an economy's rate of growth, in-so-far as the barriers to the free movement of goods, ideas and factors of production affect incentives to innovate, the underlying productivity of that innovation or the dissemination of research discoveries across national boundaries.

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[5] See also Rivera-Batiz and Romer (1990a and 1990b).

Grossman and Helpman (1991a) identify a number of ways in which international flows of ideas and international trade in goods may affect economic growth. International spillovers of ideas directly raise an economy's rate of growth by enabling domestic researchers to exploit ideas discovered by their foreign counterparts.[6]

International trade in goods will also have an effect on economic growth. However, the precise effect will depend upon the magnitude of international knowledge spillovers (so that the different aspects of international openness interact, see Grossman and Helpman (1991a) and Redding (1998) for further discussion). International trade in intermediate inputs has a positive effect on growth in-so-far as it eliminates any incentive for duplication in the research sector producing new designs for such inputs. In addition, trade in intermediate inputs increases the market size available to successful researchers but also enhances the intensity of product market competition.[7] Finally, it is sometimes argued that international trade in intermediate inputs may be directly responsible for spillovers of ideas: for example, domestic firms may 'reverse engineer' the products of their foreign rivals.[8]

International trade in either intermediate or final goods may have another ambiguous effect on the economy's growth rate, in-so-far as considerations of comparative advantage result in changes in the allocation of resources between research and current production. If the exploitation of comparative advantage leads an economy to specialise in sectors that exhibit little potential for further growth, then an economy's aggregate growth may fall (see, for example, Redding (1998) and Grossman and Helpman (1991a)). The nature of the effect of specialisation according to comparative advantage again depends upon whether knowledge spillovers are national or international in scope (see Grossman and Helpman (1991a)). Proudman and Redding (1998) document evidence of considerable changes in patterns of

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(6) One of the essential characteristics of ideas as economic goods is their non-rivalry: one individual's use of an idea does not preclude its use by another. As a result, research is characterised by a form of increasing returns: once the fixed cost of discovery has been incurred, an idea may be employed in either research or production in any number of different contexts (both home and foreign).

(7) In simple models of innovation and growth, increases in product market competition reduce flows of temporary monopoly profits from successful research and therefore decrease the incentive to invest in research and development (R&D). However, richer models of innovation and growth suggest that enhanced competition may raise the incentive to innovate (see, for example, Aghion, Dewatripont and Rey (1996)), a result that accords with the empirical evidence of Nickell (1996) and Nickell, Nicolitasas and Dryden (1997).

(8) See for example Grossman and Helpman (1991b).

international specialisation in UK manufacturing. However, the analysis of Cameron, Proudman and Redding (1998a) suggests that changes in the allocation of resources between sectors were relatively unimportant in explaining the growth in aggregate manufacturing productivity during the sample period. Therefore, in this paper we discount the last of the channels discussed above, and we focus on the effect of international trade on rates of productivity growth within individual manufacturing sectors.

The analysis of Grossman and Helpman (1991a) is largely concerned with the effects of international flows of ideas and trade in goods. Financial capital and, in particular, flows of foreign direct investment (FDI) may also have a positive effect on rates of economic growth. For instance, a wide range of different models (see for example Ethier and Markusen (1991)) suggest that FDI may well play an important role in facilitating spillovers of ideas across countries.

While the theoretical literature suggests many positive effects of international openness on growth, some of the effects identified above were ambiguous. In practice, it seems plausible that the positive effects of international spillovers of ideas, increased market size and enhanced product market competition will dominate. In this case, one would expect to see international openness positively correlated with rates of economic growth (as in many cross-country growth analyses, see for example, Sachs and Warner (1995) or Proudman, Redding and Bianchi (1998)). However, what the preceding analysis does make clear is that international openness is multi-faceted and its relationship with rates of economic growth is unlikely to be straightforward.

3 Quantifying international openness in the United Kingdom

3.1 Measuring the dimensions of openness

Moving from a theoretical framework for the impact of openness on growth to an empirical measure of each of the dimensions of openness for different manufacturing sectors in the United Kingdom presents a number of practical difficulties. Openness is neither directly observable, nor is there a generally accepted measure derived from theory. As a result, a large literature has grown up, both at the cross-country and the cross-sector level, proposing and evaluating alternative openness measures.[9] There are two main approaches adopted in the literature.[10]

The first approach is the incidence-based one. Incidence-based measures involve direct observation of the stance of trade policy, such as, for example, tariff rates, average trade barriers, the degree of exchange control, and have been used in numerous cross-country studies of the effect of openness.[11]

But comprehensive disaggregated data on barriers to trade in goods and services during the sample period are simply not available for UK manufacturing. And no indicators of trade policy stance are available for flows of ideas or financial capital at the sectoral level in UK manufacturing. Information on the extent of external tariff and non-tariff barriers in the EU is only available for the manufacturing industries of the OECD'S International Standard Industrial Classification (ISIC) for the years 1988, 1993 and the measures agreed at the Uruguay Round.[12] Information is available on the following measures of trade policy: mean tariff rates, value-added weighted mean tariff rates, frequency ratios and import coverage ratios.[13] Table A reports values for these measures for each SIC manufacturing sector in the year 1988 and for the ISIC agriculture and mining sectors.

Even where coverage was complete, the measures would still provide only a crude guide to the underlying stance of trade policy. For example, all tariffs are applied 'most favoured nation' (MFN) rates and therefore do not take into account special preferences or exemptions.

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(9) For an excellent discussion of the merits of alternative measures of openness at the cross-country level, see Edwards (1997).
(10) See for example, Baldwin (1989b), Pritchett (1996) and Proudman, Redding and Bianchi (1998).
(11) See, for example, Balassa (1985), Dollar (1992), Edwards (1992), Leamer (1988), Proudman, Redding and Bianchi (1998), and Sachs and Warner (1995).
(12) This information is derived from the UNCTAD, TRAINS (Trade Analysis and Information System) Database. The OECD's ISIC classification corresponds reasonably closely but not exactly to the ONS's Standard Industrial Classification (SIC) used in this analysis. It has therefore been necessary to construct a mapping between the two different classifications.
(13) The frequency ratio corresponds to the percentage of tariff lines affected by non-tariff barriers, while the coverage ratio denotes the percentage of a country's imports that are subject to these measures.

Table A
UK tariff and non-tariff barriers by sector, 1988

Industry	SIC 1980	M tariff	WM tariff	F-ratio	Coverage
Total Manufacturing	2 to 4	6.55	7.06	16.31	12.38
Food and Drink	41/42	66.57	66.57	0.00	35.01
Textiles and Clothing	43/4/5	12.19	11.82	75.96	44.94
Timber and Furniture	46	5.52	5.52	0.00	0.00
Paper and Printing	47	7.26	6.1	2.86	5.51
Minerals	23/24	7.04	7.3	8.05	1.76
Chemicals	25/6+48	7.18	7.16	4.61	1.50
Chemicals nes	25+26-257	6.87	6.87	3.89	1.53
Pharmaceuticals	257	6.23	6.34	1.50	0.37
Rubber and Plastics	48	3.08	3.08	0.00	0.00
Basic Metal	22	5.10	5.15	37.45	18.25
Iron and Steel	221/2/3	5.39	5.39	53.30	69.66
Non-Ferrous Metals	224	4.44	4.44	0.41	0.01
Fabircated Metals	3	5.11	5.28	4.61	6.94
Metal Goods nes	31	5.13	5.13	0.00	0.22
Machinery	32	4.19	4.21	5.53	8.31
Computing	33	4.19	4.21	5.53	8.31
Electrical Machinery	34	5.87	6.05	6.34	12.04
Other Electrical	34-344-345	5.87	6.05	6.34	12.04
Electronics	344/5	5.87	6.05	6.34	12.04
Motor Vehicles	35	6.44	5.86	4.03	3.86
Aerospace	364	6.44	5.86	4.03	3.86
Instruments	37	5.45	5.33	0.60	0.05
Other Manufacturing	49	2.99	2.99	0.00	1.21
Agriculture		8.48	8.48	17.87	15.49
Mining		0.80	0.80	0.00	0.00

nes is not elsewhere specified. **M tariff** a simple mean of tariff rates on all tariff lines within a given sector, while **WM tariff** is a value-added weighted mean of these tariff rates. **F- ratio** denotes the frequency ratio or the percentage of national tariff lines that are affected by a particular non-tariff barrier. **Coverage** or coverage ratio refers to the percentage of a country's own imports that is subject to a particular non-tariff barrier.

The approach adopted in this paper therefore, in common with the majority of empirical studies of openness, is to use behavioural measures that are the *ex-post* outcomes of choices by economic agents. In this paper, five behavioural measures of openness are used. Corresponding to flows of goods and services, we employ the export/domestic output ratio and the import/domestic sales ratio.[14] For flows of financial capital, we make use of inward and outward foreign direct investment flows as a share of output, and for flows of ideas, we employ an openness-weighted international R&D stock/output ratio.

Behavioural measures, such as the ratios of exports to output and imports to home sales, are the endogenous outcomes of both trade policy and a variety of other economic factors, among which may be the growth rate itself. The use of these behavioural measures is therefore conditional upon them being correlated with some underlying measure of trade policy or 'international openness'. Where the data are available, that is for export and import ratios in 1988, there does exist a degree of negative correlation between behavioural measures and tariff and non-tariff data (see Table B). The correlations are far from perfect. However, it is unclear whether this reflects the endogeneity of trade shares (which may be affected by a number of other variables) or the inability of the trade policy measures to capture the myriad of different restrictions and special exemptions.

Table B
Partial correlations between trade shares and measures of trade policy restrictiveness

	M/S	X/Y	Mtar	Cov	WMtar	Freq
M/S	1.000					
X/Y	0.8959	1.000				
Mtar	-0.2470	-0.3234	1.000			
Cov	-0.1572	-0.1860	0.3455	1.000		
WMtar	-0.2484	-0.3195	0.9997	0.3451	1.000	
Freq	-0.0775	-0.0928	-0.0331	0.8118	-0.0355	1.000

The hypothesis that the behavioural measures of openness are correlated with an underlying measure of trade policy or 'international openness' relates to the question of the extent of correlation between the five openness measures. We explore these issues further using principal components analysis, which may be interpreted as a search for a latent ('openness') variable that is pairwise correlated with each of the individual behavioural measures.[15]

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[14] Where 'home sales' are domestic production for the home market plus imports, and 'domestic output' is domestic production for the home market plus exports.
[15] Edwards (1997) also makes use of principal components analysis, at the cross-country level to derive a unique openness measure from a variety of different indicators.

The problem of potential endogeneity affects not merely behavioural measures of openness. Direct measures of the underlying stance of trade policy, if they were available, would also be subject to the same criticism. As the recent literature on the political economy of trade policy (see for example Grossman and Helpman(1995)) points out, trade policy is not free of endogeneity problems.

There are a number of responses to the problem of endogeneity. One is to instrument the endogenous explanatory variable with another variable, correlated with the explanatory variable but uncorrelated with the error term. Another is simply to make use of lagged values of openness as explanatory variables, which will avoid contemporaneous correlation problems.[(16)] In this paper, the econometric results of the second technique are reported on the grounds that the effects of openness are likely to be lagged. But as a cross-check on this approach, instrumental variables were also used, taking lagged values of openness as instruments.[(17)]

3.2 Quantifying the dimensions of openness

3.2.1 International flows of goods

Table C presents information on the average ratios of imports to home sales and exports to domestic output over the sample period. The extent of variation in both ratios across the 19 industries is quite substantial: average exports to domestic output ratios (X/Y) vary from 6.0% in Paper and Printing to 54.2% in Aerospace (with a coefficient of variation of 0.585), while average imports to home sales ratios (M/S) vary from 12.6% in Metal Goods not elsewhere specified (nes) to 55.5% in Other Electrical (with a coefficient of variation of 0.531).

There is also considerable variation over time. Broadly speaking, the period 1970 to 1992 is characterised by rising ratios of both exports to domestic output X/Y and imports to home sales M/S: total manufacturing exhibits increases of 52.8% and 79.34% respectively. Nonetheless, the extent of the increase in trade varies significantly across sectors and as a result, the rankings in terms of either X/Y or M/S change considerably over time.

[(16)] Of course, the two approaches are quite distinct. But using a dual approach is a useful cross-check on the robustness of the results.

[(17)] Should there be lag structures in the system, the use of lagged values of openness as instruments will not necessarily generate consistent estimators. Were we to attempt to estimate structural parameters, a more sophisticated econometric approach, such as FIML, would clearly be more appropriate.

Table C
Exports and imports in UK manufacturing

Industry	Average X/Y	Average M/S
Total Manufacturing	0.259	0.287
Food and Drink	0.102	0.183
Textiles and Clothing	0.278	0.350
Timber and Furniture	0.104	0.200
Paper and Printing	0.060	0.285
Minerals	0.149	0.128
Chemicals nes	0.393	0.336
Pharmaceuticals	0.387	0.228
Rubber and Plastics	0.192	0.195
Iron and Steel	0.204	0.189
Non-Ferrous Metals	0.369	0.489
Metal Goods nes	0.142	0.126
Machinery	0.393	0.307
Computing	0.822	0.860
Other Electrical	0.504	0.555
Electronics	0.302	0.300
Motor Vehicles	0.347	0.377
Aerospace	0.542	0.459
Instruments	0.496	0.519
Other Manufacturing	0.321	0.364
Standard deviation	0.187	0.180
Coefficient of variation	0.585	0.531

nes is not elsewhere specified.

3.2.2 International flows of ideas

The theoretical analysis of Section 2 suggests that the rate of innovation is an important determinant of an economy's long-run rate of growth. One of the most important sources of innovation is commercially funded research and development (R&D). Current flows of R&D expenditures yield discoveries that may be thought of as contributing to a stock of knowledge. Cumulating R&D spending, one may arrive at a proxy for the (unobserved) stock of knowledge, which may be both productivity-enhancing and also serve as an input into future research, so that each generation of researchers 'stands upon the shoulders' of past generations.

A wide range of empirical evidence exists that cumulative R&D expenditure is positively correlated with productivity growth at the firm, industry and economy-wide level (see for example Griliches (1980), Nadiri (1980) and Cameron and Muellbauer (1996): Cameron (1996) reviews this literature). For an open economy, productivity levels are likely to depend both upon domestic research effort and that in other economies, and a number of studies have sought to quantify knowledge spillovers from foreign research and development: see for example Bayoumi, Coe and Helpman (1996), Coe, Helpman and Hoffmaister (1995), Coe and Helpman (1995), Keller (1996), and Lichtenberg and Van Pottelsberge de la Potterie (1996).

To gauge the extent of the effect of knowledge spillovers from foreign R&D on productivity growth at a disaggregated level in the United Kingdom, we follow Coe and Helpman (1995) in constructing foreign R&D stocks. In particular, we follow Keller (1996) in assuming a zero elasticity of substitution between inputs designated for different industries and no overlap between intermediates produced in different countries, so that we can aggregate R&D stocks across sectors and across countries.[18] To calculate R&D stocks, we deflate nominal expenditures by disaggregated (1985=100) price deflators and convert to constant-price sterling flows using 1985 purchasing power parity rates.

Research and development stocks (*S*) are calculated from these expenditures (*R*) by the widely used perpetual inventory model,

$$S_t = (1-d)S_{t-1} + R_{t-1} \qquad \textbf{(1)}$$

where * is the depreciation (or obsolescence) rate, which was assumed to be 15%, in line with a number of other studies (for example, Griliches (1980) and Coe, Helpman and Hoffmaister (1995)).[19] The initial capital stock was calculated following the procedure suggested by Griliches (1980) and Coe and Helpman (1995) as,

$$S_0 = R_0 /(g+d) \qquad \textbf{(2)}$$

where (*g*) is the average annual logarithmic growth rate of R&D expenditures over the period for which R&D expenditure is available. The absence of

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(18) Disaggregated data on nominal local current R&D expenditures by business enterprises between 1973 and 1992 are available for 14 of the United Kingdom's principal trading partners from the OECD's ANBERD database. This was converted from the OECD's Adjusted ISIC (Revision 2) Classification to the UK SIC 1980 Classification used in this paper. We are unable to distinguish between commercially and government funded R&D by business enterprises within this database.
(19) Changes in the rate of depreciation do not typically alter the results substantially (see, for instance, Coe and Helpman (1995)).

measures of initial capital stocks (which instead must be proxied by the above procedure) is a possible source of inaccuracy, particularly near the start of the sample period. However, the magnitude of any discrepancy will diminish over time as the initial capital stock is depreciated away. In order to abstract from scale effects, we normalise the R&D stock by the flow of output in each sector.[(20)]

Table D presents information on the time-averaged level and rate of growth of the ratio of R&D stock to output for each of the 19 manufacturing industries over the period 1973 to 1991. Over the entire sample, Aerospace was characterised by the highest R&D stock to output ratio (30.82) and Timber and Furniture by the lowest (0.37); while rates of growth varied from 9.06% in Iron and Steel to -0.58% in Aerospace.

If the interchange of knowledge were complete, either because knowledge was instantaneously and costlessly transmitted or because all intermediate inputs were traded internationally, the relevant proxy for a country's stock of knowledge, as described in Section 2, would be the entire world's stock of R&D capital. As such, domestic productivity growth would be a function of international R&D stocks.

But knowledge is not instantaneously and costlessly transmitted. Not all intermediate inputs are traded internationally, or traded equally with all trading partners. Indeed, trading partners may be chosen precisely in an attempt to maximise the flow of technological knowledge from abroad, as described by Quah (1997). Rather, international knowledge is likely to flow between countries in proportion to the amount of contact between countries, particularly contact resulting from trade, FDI, the flow of technological licences, patents and so on.

[(20)] This is a natural normalisation if cumulative R&D expenditure is a proxy for the stock of knowledge in a neoclassical production function. Alternatively, one might normalise the R&D stock by the physical capital stock, or look at R&D intensities, the ratio of the flow of R&D expenditure to the flow of output, or the stock of knowledge as a fraction of the stock of physical capital.

Table D
Ratio of international R&D stocks to value-added (1985 constant prices) by sector

Industry	Mean R&D/Y	Mean) (R&D/Y)(%)
Total Manufacturing	4.30	5.65
Food and Drink	0.61	4.71
Textiles and Clothing	0.41	4.24
Timber and Furniture	0.37	7.05
Paper and Printing	0.46	2.66
Minerals	1.06	6.95
Chemicals nes	5.24	5.88
Pharmaceuticals	8.94	3.66
Rubber and Plastics	2.01	2.64
Iron and Steel	2.51	9.06
Non-Ferrous Metals	3.59	8.83
Metal Goods nes	1.11	6.15
Machinery	2.01	7.67
Computing	20.37	-0.21
Other Electrical	8.91	-0.28
Electronics	13.79	4.43
Motor Vehicles	9.00	8.14
Aerospace	30.82	-0.58
Instruments	13.42	4.53
Other Manufacturing	2.50	4.03

nes is not elsewhere specified.

The precise microeconomic mechanisms by which ideas flow between economies are not specified in any great detail in the existing theoretical literature. In consequence, the majority of the empirical literature assumes that the degree of information flowing from a trading partner is proportional to the trading partner's share in the imports of the domestic economy.[(21)] These studies typically find a significant and positive impact of import share weighted foreign R&D stocks when regressed alongside domestic R&D stocks on domestic TFP growth. Here we follow Coe and Helpman (1995) and calculate the value of the contribution of foreign R&D to domestic knowledge stocks in each sector (S_i^f),

$$S_i^f = \sum_j \frac{m_{ij}}{m_i} . S_j^d \quad \textbf{(3)}$$

[(21)] See, for example, Bayoumi, Coe and Helpman (1996), Coe, Helpman and Hoffmaister (1995), Coe and Helpman (1995), Keller (1996), Lichtenberg, and Van Pottelsberge de la Potterie (1996).

where, for each sector, (m_{ij}) is the value of imports in that sector from country (j) to country (i) and (S_j^d) is the value of country (j)'s domestic R&D stock in that sector.[22]   Table E presents information on the time-averaged level and rate of growth of the trade-weighted R&D stock to output ratio in each of the 19 manufacturing industries.

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[22]Although informative, there are clearly limitations with this approach. First, the assumption that the spillover of R&D stocks is proportional to import flows is a strong one. Keller (1996) provides evidence, as a counter-factual, that foreign R&D stocks calculated using import shares randomly generated by Monte Carlo simulation perform nearly as well as regressors as the 'true' foreign R&D stocks. In addition, Lichtenberg and Van Pottelsberge de la Potterie (1996) find that R&D stocks weighted by outward foreign direct investment (FDI) have a significant and different impact on productivity levels than the import weighted ones, although inward FDI-weighted R&D stocks were insignificant. Taken together, these results suggest that the mechanism through which foreign knowledge stocks are transferred across borders is considerably more complicated than a linear relationship with import flows.

Table E
Trade-weighted R&D stock to output ratios by sector

Industry	Mean TWR&D/Y	Mean) (TWR&D/Y)(%)
Total Manufacturing	0.58	5.94
Food and Drink	0.03	6.54
Textiles and Clothing	0.03	3.94
Timber and Furniture	0.03	12.01
Paper and Printing	0.04	4.24
Minerals	0.11	7.22
Chemicals nes	0.76	5.17
Pharmaceuticals	1.24	0.08
Rubber and Plastics	0.23	1.92
Iron and Steel	0.18	10.52
Non-Ferrous Metals	0.34	9.84
Metal Goods nes	0.15	6.20
Machinery	0.33	7.53
Computing	6.97	-1.32
Other Electrical	1.77	-2.68
Electronics	2.62	5.85
Motor Vehicles	1.05	9.09
Aerospace	11.29	0.37
Instruments	3.95	3.90
Other Manufacturing	0.86	3.65

nes is not elsewhere specified.

3.2.3 International flows of financial capital: foreign direct Investment (FDI)

International flows of financial capital, in particular FDI, may play an important role in facilitating knowledge spillovers (see for instance, Lichtenberg and van Pottelsberge de la Potterie (1996) and Barrell and Pain (1997)). This linkage may be two way. First, FDI from a technologically advanced economy into a lesser developed one is a mechanism by which the recipient of the investment can acquire information from the investor. This can either be directly. As the multinational applies new technology, it automatically increases the average productivity of the sector. Or it can be indirectly, as domestic competitors learn new technology by observing the behaviour of the foreign entrant and head-hunting staff. Second, FDI into an advanced economy from a less-developed one may be a mechanism by which the investor acquires information, as it effectively buys the superior technology in an existing company abroad or that knowledge possessed by the foreign labour force employed.[23]

Table F presents information on time-averaged constant (1985) price flows of both inward and outward FDI for each of the manufacturing sectors, and as ratios to domestic output. Because the FDI data are net of capital repatriation, some annual entries are negative. It seems reasonable to assume that knowledge is not repatriated with these capital flows, so we truncate the FDI flows at zero. Pharmaceuticals, Computing and Instruments are the sectors with the highest flows of both inward and outward FDI as shares of output.[24] Paper and Printing, Motor Vehicles and Aerospace are the three sectors with the lowest flows of outward FDI as a share of output, while Textiles and Clothing, Rubber and Plastics and Iron and Steel are the sectors with the lowest flows of inward FDI as a share of output.

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[23] The main source of data on FDI into and out of the United Kingdom is the ONS, which maintains data on FDI flows net of repatriation of capital. The ONS definition of FDI is investment that 'adds to, deducts from or acquires a lasting interest in an enterprise operating in an economy other than that of the investor, the investor's purpose being to have an effective voice (an 'effective voice' means that a single foreign (non-resident) investor controls 20% or more of the ordinary shares or voting power of an incorporated enterprise) in the management of the enterprise'. In accounting terms, direct investment includes the investor's share of the unremitted profits (net profits less repatriated dividends) of the subsidiary or associated company, the net acquisition of share and loan capital, changes in the inter-company accounts and changes in branch/head office indebtedness. Direct investment can therefore take the form of purchase of an existing overseas company, greenfield investment, retained earnings on an existing investment or an increase in indebtedness of an affiliate or branch to parent on inter-company account.

[24] As with stocks of R&D, this is a natural normalisation in a neoclassical production function. But an alternative approach might be to normalise by the stock of capital.

Table F
Flows of inward and outward FDI by manufacturing sector (£ million, 1985 prices) and as a share of value-added

Industry	Mean IFDI	Mean OFDI	Mean IFDI/Y	Mean OFDI/Y
Total Manufacturing	8522.8	17561.9	0.021	0.043
Food and Drink	1573.4	4285.6	0.030	0.078
Textiles and Clothing	113.3	n/a	0.003	n/a
Timber and Furniture	n/a	n/a	n/a	n/a
Paper and Printing	750.8	1293.0	0.018	0.033
Minerals	n/a	n/a	n/a	n/a
Chemicals nes	1648.8	4219.7	0.048	0.138
Pharmaceuticals	1648.8	4219.7	0.167	0.445
Rubber and Plastics	181.8	n/a	0.007	n/a
Iron and Steel	281.0	517.6	0.013	0.044
Non-Ferrous Metals	281.0	517.6	0.027	0.109
Metal Goods nes	1552.4	1207.8	0.059	0.049
Machinery	1552.4	1207.8	0.026	0.022
Computing	1385.9	1580.2	0.198	0.224
Other Electrical	1385.9	1580.2	0.074	0.077
Electronics	1385.9	1580.2	0.063	0.066
Motor Vehicles	1378.5	309.3	0.033	0.011
Aerospace	1378.5	309.3	0.051	0.018
Instruments	1385.9	1580.2	0.239	0.253
Other Manufacturing	818.3	4439.6	n/a	n/a

nes is not elsewhere specified.

3.3 Characterising openness

We now move from quantifying each measure of openness individually to characterising the relationship between them. In particular, we examine whether it is possible to speak of sectors being ‘broadly open’ across a range of measures, or whether different measures of openness yield conflicting predictions about which sectors are open and closed. Pritchett (1996) provides evidence at the cross-country level that there exists very little correlation between different measures of international openness.

Theoretical considerations provide no clear indication of whether openness measures are complimentary. In an open economy where trade is entirely inter-industry and trade patterns are determined solely by patterns of comparative advantage, then export and import shares would be negatively correlated. In models that analyse the strategic behaviour of multinationals, foreign (home-based) firms may view the decision whether to access the domestic (international) market via importing (exporting) or inward (outward) foreign direct investment as alternative strategies (see, for example, Markusen and Venables (1996) and Devereux and Griffith (1996)). If firm-specific considerations of this kind dominate at the industry level, it could be possible to generate a degree of negative correlation between either exporting and outward FDI and/or between importing and inward FDI. Other theoretical considerations suggest that some of the different dimensions of openness could exhibit a degree of positive correlation. Differences in transport costs and the degree of tradability of goods between sectors, or models of intra-industry or intra-firm trade (such as Brander and Krugman (1983)) provide reasons why, for instance, export, import and FDI flows may be positively correlated. But a high degree of positive correlation between a number of the measures of openness may well also indicate that sectors are characterised by some underlying latent variable that corresponds to a measure of trade policy or of the degree of impediments to the free flow of goods, factors and ideas and that it does make sense to speak of some sectors being more 'open' than others.

In fact, the data suggest that the correlation between the openness measures is strong and positive. The pairwise correlation coefficients between each of the five measures of openness are shown in Table G. We find that the correlation coefficient between the import/sales and export/output ratio is as high as 90%, while that between the two FDI flows is 70%. The correlation coefficient between the inward FDI/output ratio and each of the trade ratios is around 60%, while that between the trade-weighted R&D/output ratio and each of the trade ratios is well over 60%. The variable for which the degree of correlation is the lowest is the outward FDI/output ratio. Its correlation coefficient with the inward FDI/output ratio is nevertheless 70%. This high degree of correlation between the different dimensions of openness is exhibited in both the 1973-79 and 1979-89 business cycles as well as in the sample as a whole.

Table G
Pairwise correlation coefficients between measures of openness, period averages

	M/S	X/Y	IFDI/Y	OFDI/Y	TWRD/Y
M/S	1.00				
X/Y	0.90	1.00			
IFDI/Y	0.57	0.65	1.00		
OFDI/Y	0.20	0.26	0.70	1.00	
TWRD/Y	0.61	0.69	0.41	0.04	1.00

Given the high degree of correlation between these measures, is it possible to back out a single latent variable corresponding to openness? Principal components analysis makes use of the covariance between variables to reduce the dimensions of the data under consideration, and is a potentially useful statistical technique for combining the information in the openness measures. Principal components are orthogonal, linear transformations of the data. Under certain scaling assumptions, it may be shown that the variances of the principal components are the eigenvalues (8_i) of the variance-covariance matrix (*V*) of the data, and the coefficients of the linear combinations of the data are the elements of the corresponding eigenvector.

The technique is data driven and, as a result, one should not place a strict theoretical interpretation upon the resulting principal components. But one may well have theoretical priors concerning the signs of the coefficients on each variable in the data matrix. In this case, any principal component with a serious claim to estimate a latent variable corresponding to a broadly based measure of openness should be monotonically increasing in each measure of openness and would therefore assign positive weights to each. Since, by definition, each of the eigenvectors (representing the vector of weights for each principal component) is orthogonal to all others, it follows that at most one eigenvector, and hence principal component, can have the same structural interpretation.

Another property of principal components enables us to gain some feel for how much of the variation of the original dataset is explained by the structural principal component. Since by definition,

$$\sum_{i=1}^{P} l_i = trace(V) \qquad \textbf{(4)}$$

the sum of the eigenvalues is equal to the sum of the total variance of the different variables in the data matrix (*X*). As a result, the first (*m*) principal components with the largest variances may be said to account for a proportion of the total variation of the data matrix given by

$$\frac{\sum_{i=1}^{m} l_i}{\sum_{j=1}^{p} l_j} = x \qquad \textbf{(5)}$$

Thus, we may arrive at a measure of how much of the variation in the data can be explained by the structural principal component, or indeed, by any subset of principal components.[25]

Principal components were estimated on the data matrix of the average values of the logs of the five standardised behavioural variables over the period 1970-92. The estimated eigenvalues and their corresponding eigenvectors are presented in Table H.

Table H
Eigenvalues and eigenvectors, period averages

	Eigenvalues				
	8_1	8_2	8_3	8_4	8_5
	3.5349	0.8902	0.3484	0.1202	0.1063
	Eigenvectors				
M/S	0.4279	0.3843	0.7851	0.2298	-0.0054
X/Y	0.4574	0.4419	-0.2571	-0.7159	-0.1294
IFDI/Y	0.4624	-0.4524	0.0108	-0.1238	0.7524
OFDI/Y	0.4089	-0.6367	0.0993	-0.0511	-0.6441
TWRD/Y	0.4759	0.2162	-0.5546	0.6456	-0.0483

(8_1) is the principal component with a structural interpretation that corresponds to a complementary measure of openness. Moreover, it is the overwhelmingly dominant principal component and explains 71% of the sum of the individual variances of the openness measures. The structural interpretation of the other eigenvectors is far less clear. The relative weights of this principal component for each of the openness measures are fairly equal in size: the trade-weighted R&D/output ratio is accorded the highest weight (0.4759), compared with the lowest weight of 0.4089 for the outward FDI/output ratio. Using the elements of the structural principal component (8_{1i}, i=1...5), we can back out a general and one-dimensional measure of openness, which we term (P), for each sector (j) in each period (t),

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[25] Note that an additional property of principal components is that they depend on the scale on which the original variables are measured; that is, they are not scale-invariant. As a result, it is standard in principal components analysis to work with standardised variates,

$$(X_i - m)/s_{ii} = Z_i \qquad \textbf{(6)}$$

which have expected value of 0 and unit variance. In this case, the variance-covariance matrix of (Z_i) is the correlation matrix of (X). This standardisation has been used in the following analysis, although it should also be noted that it makes little substantive difference to the analysis whether standardised or unstandardised variables are considered.

$$P_{jt} = \exp(Y_{1,jt}) = \prod_{m=1}^{5} (x_{m,jt})^{l_{lm}} \quad , \quad j, t, J, T \qquad \textbf{(7)}$$

where (x_m) is the *m*-th measure of openness.

Over the period as a whole, the degree of openness ranges from a maximum in Computing to a minimum of about one tenth of that value in Wood Products. The four most open sectors, over the period as a whole, were Computing, Professional Goods, Other Manufacturing and Pharmaceuticals. The four most closed sectors were Wood, Non-ferrous metals, Textiles and Rubber and Plastics. Over time, there was a general and substantial increase in levels of openness throughout UK manufacturing: all sectors apart from Computing, Electrical Machinery and Professional Goods experienced a rise in openness between 1970-75 and 1985-92. Although most sectors experienced increases in openness over the period, more open sectors tended to enjoy more rapid increases in openness than relatively closed sectors. For example, one measure of the extent of dispersion across the distribution, the coefficient of variation, rose from 1.06 in 1970-75 to 1.72 in 1985-92. There was also little leap-frogging within the distribution. The correlation coefficient between the ordinal rankings of sectors with their rankings in 1970-75 was over 0.9 for each of the subsequent five year sub-periods, suggesting that few sectors moved up or down the distribution over the period.

Using a simple first-order approximation, we decompose the growth of openness into the contribution of the different behavioural measures underlying it. Equation **(7)** can be re-written in simple function form,

$$P_{j,t} = f(O_{j,t}) \qquad \textbf{(8)}$$

where ($O_{j,t}$) is the vector of openness measures in sector (*j*) in time (*t*). Hence its evolution over time can be approximated,

$$\frac{\Delta P}{\Delta t} \approx \sum_{i=1}^{5} f'_{o_i} \cdot \frac{\Delta o_i}{\Delta t} \qquad \textbf{(9)}$$

where (f'_{o_i}) is the first derivative of (*f*) with respect to openness measure (o_i), and ($\frac{\Delta o_i}{\Delta t}$) the change in each of the five openness measures over the period. This decomposition was undertaken for aggregate manufacturing in the entire sample period, and for the two peak-to-peak business cycles 1973-79 and 1979-89. The results are reported in Table I. In the period as a whole, the contributions made by individual behavioural measures to the rise in the Principal component measure of openness in aggregate manufacturing are of reasonably similar size. They range from a low of 14% for the export/output ratio to a high of roughly twice that amount for the trade-weighted R&D/output ratio. However, this aggregate story conceals considerable variation between the two business cycles. In 1973-79, the rise in openness was driven by increases in flows of goods, as measured by the export and import ratios, and in flows of ideas. Taken together, the contribution of the two measures of capital flows was actually negative. However, this pattern was radically reversed in the 1980's business cycle: the change in openness was driven by the contribution of inward and outward foreign direct investment, which accounted for over 80% of the entire change.

Table I
Decomposition of openness measures, 1970-92 (shares)

Contribution to openness	Period average	1973-79	1979-89
M/S	0.21	0.34	0.04
X/Y	0.14	0.33	0.03
IFDI/Y	0.15	0.18	0.51
OFDI/Y	0.22	-0.35	0.36
TWRD/Y	0.29	0.51	0.06
Total	1.01	1.01	1.00

4 International openness and TFP growth

Is there a positive cross-section relationship between the measures of openness discussed in the previous section and rates of productivity growth as predicted in Section 2? The spirit of this section is to ‘attempt to gauge the strength of associations rather than to estimate structural parameters’ (Summers (1991)). That is, the approach we follow is to build up a step-by-step presentation of a number of relatively simple statistical tools that attempt to uncover some of the stylised facts about the relationship between productivity growth and the measures of openness constructed in earlier sections. The data on productivity are discussed and examined in some detail in Cameron, Proudman and Redding (1998a).

4.1 Discriminant analysis

One of the major problems of evaluating the impact of openness on growth rates is the number of distinct ways in which the international economy can affect domestic productivity and the complexity of deriving accurate empirical measures of the extent of openness. One way to address this issue is to reduce the dimensions of openness as discussed in Section 3, and to which we return below. But we begin the analysis very simply by ranking the 19 manufacturing sectors by period-average TFP growth and dividing them into two groups of (nearly) equal size. The differences in the openness properties of the two groups are then considered. The results are given in Tables J and K.

Table J
Openness and growth characteristics of the nine fastest-growing sectors

Industry	M/S	X/Y	IFDI/Y	OFDI/Y	TWRD/Y	)TFP
Computing	0.86	0.82	0.198	0.224	7.05	5.67
Aerospace	0.46	0.52	0.051	0.018	11.69	4.17
Pharmaceuticals	0.23	0.39	0.167	0.445	1.23	3.85
Electronics	0.30	0.30	0.063	0.066	2.61	3.01
Instruments	0.52	0.50	0.239	0.253	3.84	2.95
Iron and Steel	0.19	0.20	0.013	0.044	0.17	2.22
Textiles	0.35	0.28	0.003	0.000	0.03	1.76
Other Electrical	0.55	0.50	0.074	0.077	1.86	1.68
Rubber and Plastics	0.19	0.19	0.007	0.000	0.23	1.58
Average Fast	0.41	0.41	0.09	0.13	3.19	2.99
St. deviation	0.22	0.20	0.09	0.15	3.89	1.38

Table K
Openness and growth characteristics of the ten slowest-growing sectors

Industry	M/S	X/Y	IFDI/Y	OFDI/Y	TWRD/Y	)TFP
Metal Goods nes	0.13	0.14	0.059	0.049	0.15	1.39
Paper and Printing	0.28	0.06	0.018	0.033	0.04	1.32
Other Manufacturing	0.36	0.32	0.157	0.831	0.87	1.27
Non Ferrous Metals	0.49	0.37	0.027	0.109	0.32	1.20
Chemicals nes	0.34	0.39	0.048	0.138	0.75	1.10
Motor Vehicles	0.38	0.35	0.033	0.011	1.02	0.93
Machinery	0.31	0.39	0.026	0.022	0.33	0.72
Timber and Furniture	0.20	0.10	0.000	0.000	0.02	0.27
Food and Drink	0.18	0.10	0.030	0.078	0.03	-0.26
Minerals	0.13	0.15	0.000	0.000	0.11	-1.06
Average Fast	0.28	0.24	0.04	0.13	0.36	0.69
St. deviation	0.19	0.14	0.04	0.25	0.38	0.81

nes is not elsewhere specified.

The tables show that the fastest-growing sectors experienced considerably higher average annual TFP growth (2.99%) than did the slowest (0.69%). At the same time, they also enjoyed a considerably higher degree of international openness, as measured by each openness variable apart from the outward foreign direct investment/output ratio. Using a simple statistical sampling technique, it is possible to reject the hypothesis that the mean values of the openness variables are the same in each of the two groups at the 10% level (but not at the 5% level).(26)

This allocation of sectors into groups of either relatively 'fast growing' or relatively 'slow growing' provides interesting information about the correlation between growth rates and measures of openness, an approach similar to that employed at the cross-country level by Sachs and Warner (1995). However, the statistical technique of discriminant analysis provides

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(26) To get around the Fisher-Behrens problem, we assume the two samples are drawn from two normally distributed populations with the same variance. In which case the test statistic is,

$$\frac{x-y}{S\sqrt{\frac{1}{n_x}+\frac{1}{n_y}}} \sim t\left(n_x+n_y-2\right)$$

where,

$$S^2 = \frac{\left(n_x-1\right)S_x^2+\left(n_y-1\right)S_y^2}{\left(n_x+n_y-2\right)}$$

and where (Si) is the estimated sample variance of the (i-th) sub-group, (ni) is the number of observations in the (i-th) sub-group and (x) and (y) are the two sub-groups.

a method for improving upon the allocation rule used above. Discriminant analysis is concerned with the separation of data into distinct populations on the basis of shared features, and is well described in Mardia, Biby and Kent (1979) (see also the discussion in Proudman, Redding and Bianchi (1997)). There are several forms of discriminant analysis, and in this paper we apply a variant that does not assume any specific form for the probability density functions for the populations, but looks instead for a 'sensible' rule to distinguish between them. 'Fisher's Linear Discriminant Function' is based on maximising the ratio of the sum of squares of sub-group means to the sum of squares of observations around their sub-group means, by taking linear combinations of the different openness variables. Intuitively, the function sorts the data into groups in such a way as to emphasise both the similarities of elements within the same group and the differences between the representative properties of the separate groups. In the analysis below, we apply Fisher's Linear Discriminant Function to the 1970 values of the five continuous measures of openness (import/sales, exports/output, inward and outward FDI output and trade-weighted R&D/output ratios). Since we subsequently wish to relate a sector's growth performance over the period 1970-92 to whether it is open or closed, we use the 1970 values to address concerns about the potential endogeneity of the openness measures (see the discussion above). The results of implementing this procedure are presented in Table L.

The classification of industries chosen by the discriminant function allocates five sectors to the 'closed' group (Textiles, Timber and Furniture, Minerals, Iron and Steel and Non-ferrous Metals) and 14 to the 'open' group. Each sector is closest to the sub-group mean of its allocated group for the composite measure, derived as the optimal linear combination of openness measures. In practice, this means that most sectors are closest to their allocated sub-group means in each openness indicator, although a few sectors are closest in only one, dominant indicator.

The main point to note is that average annual TFP growth of the group of open sectors is considerably higher than that of the group of closed, at 2.10% compared with 0.88%. The null hypothesis that the two groups are drawn from populations with the same mean can be rejected at the 10% level, using the same test statistic as above. Three of the group of closed sectors were amongst the seven slowest-growing sectors within manufacturing as a whole: none of them was among the five-fastest growing sectors.

Discriminant analysis therefore provides another useful indicator of the association between cross-sectional growth rates and measures of openness. It is, however, subject to the caveat that, in general, openness may be thought to be a continuous rather than a binary variable. In the following section, we consider the relationship between growth and continuous measures of openness.

Table L
Openness and growth characteristics of sectors classified as relatively 'and 'closed'

Industry	**M/S**	**X/Y**	**IFDI/Y**	**OFDI/Y**	**TWRD/Y**	**) TFP**
Number of open sectors	14.0					
Average open	0.36	0.36	0.08	0.16	2.26	2.10
Number of closed sectors	5.0					
Average closed	0.27	0.22	0.01	0.03	0.13	0.88

4.2 Regression analysis

We begin tests of whether the association between openness and growth is robust to the introduction of continuous measures of openness with some simple single-variable least squares regressions on the individual measures of openness. The average rate of TFP growth over the entire sample period 1970-92 is regressed on the 1970 value of each of the measures of international openness considered above and a constant. Table M reports the coefficient $ on each successive measure of openness in the cross-section regression,

$$\frac{1}{T}\sum_{s=1}^{T}\left(\frac{\Delta TFP_{t+s(i)}}{TFP_{t+s-1(i)}}\right)=a+b.(open_{70}(i))+u_i \ , \qquad i\ 0\ [1,19] \qquad \textbf{(10)}$$

The estimated coefficient on each measure of openness is found in the third column of Table N (standard errors in parentheses), where two asterisks indicate significance at the 5% level and one asterisk significance at the 10% level. Although the focus of the present analysis is on TFP growth, a number of authors have argued that openness may influence rates of economic growth through capital accumulation. We make use of the fact that the rate of growth of labour productivity may be decomposed into the rates of growth of total factor productivity and the contribution of increases in the capital-labour ratio (see, for example, the discussion in

Cameron, Proudman and Redding (1998a)).[27] The first two columns of Table M report the coefficient on international openness in regressions where the dependent variable in **(10)** is replaced by time-averaged labour productivity growth and the time-averaged contribution of capital accumulation.

Over the entire sample period, the estimated coefficient on the openness measure in the labour productivity growth regression *($\$_{YL}$)* is positive for all five measures and statistically significant (at either the 5% or 10% critical values) for three measures: the inward and outward foreign direct investment/output ratio (FDI/Y), and the trade-weighted R&D/output ratio (TWRD/Y). In the TFP growth regression, the coefficient on the openness measure is positive and statistically significant (at the 5% critical value) for the same three variables and also for the ratio of exports to output. Perhaps surprisingly, in view of the strength of the visual relationship presented above, the ratio of imports/domestic sales is marginally insignificant.[28] Moreover, none of the measures of openness considered is statistically significantly correlated (at the 10% or 5% critical value) with that part of labour productivity growth explained by increases in the capital-labour ratio.

Hence it appears that labour productivity growth is correlated with measures of international openness over the cross-section of 19 industries. Furthermore, this correlation is not explained by openness being associated with higher rates of capital accumulation, but rather by openness being accompanied with increased rates of TFP growth.

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[27] In terms of the analysis of Cameron, Proudman and Redding (1997a), the contribution to labour productivity growth from increases in the capital-labour ratio is,

$$(1-\tfrac{1}{2}.(a_j(t+1)+a_j(t))).\ln\left(\frac{K_j(t+1)/L_j(t+1)}{K_j(t)/L_j(t)}\right) .$$

[28] The statistical significance of these estimates is greatly increased using an instrumental variables approach, instrumenting period-average openness measures with their 1970 values. All variables become significant at at least the 10% level. The reader is referred back to the discussion of endogeneity in Section 3.1.

Table M
Cross-section variation in TFP growth (1970-92) and international openness (1970): partial correlations across 19 UK manufacturing sectors.[29]

Openness measure	$\$_{YL}$	$\$_{KL}$	$\$_{TFP}$
ln(M/S)	0.0069	0.0025	0.0094
	(0.007)	(0.003)	(0.006)
ln(X/Y)	0.0109	0.0010	0.0112
	(0.007)	(0.003)	(0.005)**
ln(IFDI/Y)	0.0026	0.0004	0.0023
	(0.001)**	(0.001)	(0.001)**
ln(OFDI/Y)	0.0022	0.0005	0.0020
	(0.001)*	(0.001)	(0.001)**
ln(TWRD/Y)	0.0059	0.0004	0.0056
	(0.002)**	(0.001)	(0.001)**
ln(P)	0.0029	0.0004	0.0027
	(0.001)**	(0.001)	(0.001)**

But care should be taken in the precise interpretation of these coefficients. First, they do not necessarily represent structural coefficients. Second, the explanatory variables are highly correlated with each other and hence will be subject to positive omitted variable bias. By the same token, a multiple linear regression including more than one of these measures of openness will suffer from multicollinearity between the regressors. The latter point can be mitigated if we re-run equation **(10)** using the single measure of openness (*P*). The regression returns an estimated positive coefficient on the openness measure of 0.0028, which is statistically significantly different from zero at the 1% level. We consider how sensitive it is to the inclusion of outliers by ranking sectors according to the size of their deviation from the mean value of openness. Excluding from the sample the largest outlier in terms of levels of openness (WPP) and re-running the regression above, the regression coefficient is still positive and significant at the 95% level. Repeating the process, we can exclude the three most extreme values out of a total of 19 (WPP, NMM, OCE) without rejecting the significance of the coefficient. We also carry out this experiment by excluding outliers in terms of growth and an almost identical story emerges: we can again exclude the three most extreme sectors in terms of growth behaviour (OCE, FBT, AERO) without affecting the significance of the estimates.

[29] Each column of the table reports the coefficient $\$$ on each successive measure of openness in the cross-section regression for a different dependent variable. The three dependent variables are time averaged labour productivity growth, time-averaged contribution of capital accumulation and time-averaged TFP growth respectively.

The cross-sectional estimates presented above cover the entire sample period. In Section 3.3 however, we showed that the time series profile of (P) was quite different between the 1970's and 1980's owing to the rise in inward and outward FDI during the mid-1980's. Is it the case that the cross-sectional relationship between openness and growth changed between the two business cycles? To test this, we regress the average annual rate of TFP growth in each sector in each of the two completed business cycles (1973-79 and 1979-89) on the value of the log of the principal component at the start of the business cycle (ie 1973 and 1979 respectively) as follows:[30]

$$\frac{1}{T}\sum_{s=1}^{T}\left(\frac{\Delta TFP_{t+s(j)}}{TFP_{t+s-1(j)}}\right) \equiv g = a + b.\ln(P_t(j) + u_j \,, \qquad j \; 0 \; [1,19] \qquad \textbf{(11)}$$

The estimated coefficient on the general openness variable measured by the principal component is positive in each of the business cycles. Interestingly, however, the estimated coefficient was considerably lower over the period 1979-89. That is, over 1973-79, the estimated coefficient was 0.0028, statistically significantly different to zero at the 5% level. In comparison, the estimated coefficient over 1979-89 was only 0.0011, statistically insignificant even at the 10% level. In order to test more formally whether the relationship between growth and openness has changed between the two business cycles, we estimate the two equations (for 1973-79 and 1979-89) as a system of Seemingly Unrelated Regressions (SUR), allowing the coefficient on the openness measure to vary across the two business cycles and constraining it to be the same. Testing the constraint with a Wald Test, it was not possible to reject the hypothesis that the coefficient (*$*) was the same in each business cycle. We report the estimated constrained results in Table N below. We again derive an estimate that a 1% increase in (P) would be associated with a 0.0029 percentage point change in the sector's growth rate.

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[30] There are clearly more sophisticated econometric techniques for combining cross-section and time series information, such as panel data procedures. Panel data estimation is used in Cameron, Proudman and Redding (1998b) to examine the structural relationship between international openness and rates of TFP growth in the context of a formal econometric model.

Table N
Regression of TFP growth on the principal component

Estimated equation: $g(1973-79)(i) = a_1 + b\ \ln(P)_{73}(i) + u(i)$

coefficient	estimate	std. error	t-statistic
"$_1$	0.0115	0.0088	1.3085
$	0.0029	0.0011	2.6322
R-squared	0.2763	S.E. of regression	0.0256
Adjusted R-squared	0.2337	Sum Sq. residuals	0.011

Estimated equation: $g(1979-89)(i) = a_2 + b\ \ln(P)_{79}(i) + u(i)$

coefficient	estimate	std. error	t-statistic
"$_2$	0.0529	0.0088	5.9938
$	0.0029	0.0011	2.6322
R-squared	0.0409	S.E. of regression	0.0279
Adjusted R-squared	-0.0155	Sum Sq. residuals	0.0132

5 Summary

Openness is defined as the extent of barriers to the free movement of goods, ideas and factors of production. Relating this definition to the theoretical literature on endogenous growth, it is argued that each of these dimensions of openness might affect growth insofar as they alter the productivity of domestic research, incentives to undertake research and the dissemination of innovative ideas from abroad. But what is quickly apparent from the theoretical literature is that the precise quantification of these influences is not straightforward. In the light of this, the objective of this paper has been to compile disaggregated measures of international openness at the sectoral level in the United Kingdom, and then to consider the broad empirical associations that exist between openness and rates of productivity growth across UK manufacturing sectors during the period 1970-92.

Five empirical measures of the extent of international openness in UK manufacturing are discussed, corresponding to flows either of goods, ideas or financial capital. The period 1970-92 is characterised by increasing international openness, whether measured by shares of imports and exports, the ratio of R&D knowledge to value-added or the ratio of foreign direct investment (FDI) flows to value-added. The period is also characterised by strong positive pairwise correlation between each of these measures. Principal components analysis is then used to extract a single, broad-based empirical measure of openness by exploiting the high degree of correlation between the openness measures.

Having collated and characterised the data on international openness across UK manufacturing sectors, the paper moves on to present some empirical results concerning the statistical association between them and productivity growth. A generic problem well noted in both the theoretical and empirical literature is that any estimated measure can be argued to be endogenous. To address this issue at least partially in our empirical analysis, we make use both of instrumental variables techniques and lagged values of the openness measures.

The cross-section information on openness in 1970 is combined using discriminant analysis to sort manufacturing industries into discrete groups of relatively open and closed sectors. Using this sorting technique, it is shown that the group containing the most closed sectors in 1970 enjoyed statistically significantly lower growth over the period 1970-92 than the group containing the most open sectors. Regression analysis is then used to explore the relationship between productivity growth and continuous measures of international openness. In the entire sample period, the average rate of labour productivity growth across UK manufacturing sectors is found to be positively correlated with all five measures of international openness (statistically significant at the 10% level or above for three of the five measures). These correlations are explained by a positive correlation between openness and rates of TFP growth (statistically significant for four of the five measures), but not between openness and that part of labour productivity growth explained by capital accumulation. This finding is thus consistent with the hypothesis that openness influences economic growth through the rate of technological change.

Bringing together the information contained in the different measures of openness in the form of the broad-based measure derived from the principal component, we estimate that the effect of a 1% change in international openness would be associated with a rise of 0.0029 percentage points in the average annual growth rate. We are unable to reject the hypothesis that this coefficient was different between the 1970s and 1980s. Overall, therefore, our findings suggest that there is a fairly clear cross-sectional association between international openness so measured and TFP growth in UK manufacturing.

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