Evolving patterns of international trade[*]

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Abstract

Theoretical models of growth and trade suggest that patterns of international specialisation are inherently dynamic and evolve endogenously over time. Initial comparative advantages are either reinforced or gradually unwound with the passage of time. This paper puts forward an empirical framework to evaluate the dynamics of international trade patterns, that uses techniques widely employed in the cross-country literature on income convergence. Applying this framework to industry-level data, we find evidence of significant differences in international trade dynamics among the G5 economies.

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All Figures and Tables are at the end of the paper

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1 Introduction

A number of dynamic models of international trade have emerged over recent years (selected examples include Krugman (1987), Grossman and Helpman (1991) and Rivera-Batiz and Romer (1991)), in which rates of economic growth and patterns of international trade are jointly and endogenously determined. The exact speci…cation of the growth process varies from paper to paper, but an important subset of this literature (of which the three papers cited above are all examples) emphasises the links between international trade and endogenous technological change.

In the presence of country-speci…c knowledge spillovers or local increasing returns to scale in individual sectors, it is easy to derive the theoretical result that initial comparative advantages and patterns of international trade will be reinforced or 'locked-in' over time (see, for example, Krugman (1987) and Grossman and Helpman (1991) Chapter 8). However, it is equally clear that this prediction of 'persistence' in international trade ‡ows is very sensitive to the assumptions made about knowledge spillovers. If ideas spillover across economies, or there are variations in either the rate at which learning by doing occurs or the productivity of Research and Development (R&D) expenditures, then initial patterns of international trade may instead change or exhibit 'mobility' over time (Brezis et al. (1993) and Grossman and Helpman (1991), Chapter 7).

Thus, whether international trade ‡ows persist or exhibit mobility over time is ultimately an empirical question. The objective of this paper is to provide an empirical framework within which it is possible to address questions of international trade dynamics. The empirical framework consists of two components. The …rst is a measure of an economy's pattern of international specialisation at any given point in time. This is provided by the distribution of a modi…ed version of Balassa's (1965) index of 'Revealed Comparative Advantage' (RCA) across industries. The second element is a technique for analysing the evolution of this measure of international specialisation over time. This is achieved using a model of distribution dynamics, introduced into the cross-country literature on income convergence by Quah (1993), (1996a) and (1996c).

The paper is structured as follows. Section 2 presents a relatively standard theoretical model of international trade and endogenous technological change, that combines elements from Dornbusch et al. (1977), Krugman (1987) and Bernard and Jones (1994, 1996). This is used to derive the basic theoretical prediction that international trade flows may exhibit either persistence or mobility over time. Section 3 introduces an empirical framework for analysing international trade dynamics. Later Sections implement this empirical methodology using industry-level manufacturing data from the G5 economies. The dynamics of patterns of international trade are analysed in two stages.

First, Section 4 undertakes the preliminary data analysis. Measures of RCA are presented for the manufacturing sectors of France, Germany, Japan, the United Kingdom and the United States, and the evolution of patterns of international trade over time is analysed graphically. Second, the model of distribution dynamics is estimated econometrically in Section 5. Transition probability matrices are presented for each of the G5 economies and for the sample formed by pooling observations across economies. The extent of persistence and mobility in patterns of international trade is quantified using formal indices of mobility. We find evidence of significant differences in international trade dynamics among the G5 economies. Interestingly, France exhibits the most mobility and Japan the least. Japan is also the only G5 economy to experience an increase in the degree of international specialisation over time. Section 6 summarises our conclusions.

2 A theoretical model of international trade dynamics

This Section presents a simple theoretical model of international trade and endogenous technological change. The model uncovers some forces that lead to persistence in patterns of international trade and other conflicting influences that tend to induce mobility. Static equilibrium is determined exactly as in the standard Ricardian model with a continuum of goods (Dornbusch et al. (1977)). There are two economies (home and foreign) and A_{ij} denotes the productivity of labour in sector j of economy $i \in \{H; F\}$. Each economy may produce any of a fixed number of goods indexed by $j \in [0; n]$. An individual good j will be produced in home (H) if and only if the unit cost of producing that good in home is below or equal to that in foreign (F),

$$\frac{w_H(t)}{w_F(t)} \leq \frac{A_{Hj}(t)}{A_{Fj}(t)} \tag{1}$$

where w_H and w_F are the home and foreign wage rates respectively.

If we denote home productivity relative to foreign by $B_j \equiv A_{Hj}/A_{Fj}$, and index goods so that higher values of j correspond to lower values of home productivity relative to foreign (B_j), then the right-hand side of (1) may be illustrated diagrammatically by the downward sloping curve in Figure 1. Given a value for the home relative wage w_H/w_F, all goods $j \leq \tilde{j}$ in Figure 1 are produced in home and all goods $j > \tilde{j}$ are produced in foreign. $\tilde{j}$ denotes the limit good such that home's relative wage is exactly equal to home productivity relative to foreign's.

In static equilibrium, home's relative wage is pinned down by the additional requirement that home income equals world expenditure on home goods (or alternatively that trade is balanced). Under the assumption that instantaneous utility is a symmetric, Cobb-Douglas function of the consumption of each good j (with the elasticity of instantaneous utility with respect to the consumption of each good equal to β), this condition may be expressed as,

$$\frac{w_H}{w_F} = D_{\tilde{z}}; \qquad \text{where} \qquad D_{\tilde{z}} \equiv \frac{\tilde{z}.\beta}{1 - \tilde{z}.\beta}.\frac{\bar{L}^*}{\bar{L}} \tag{2}$$

where $\bar{L}$ and $\bar{L}^*$ are the home and foreign supplies of labour respectively, and the right-hand side of (2) is illustrated diagrammatically by the upward sloping curve in Figure 1. Static equilibrium is defined by the intersection of the two curves, where both (1) and (2) are satisfied.

<Figure 1 about here>

Within this framework, the evolution of patterns of international trade over time is determined by rates of technological progress in each sector of the two economies. A wide range of empirical evidence exists that learning by doing is an important source of productivity improvement. For example, Lucas (1993) cites evidence that each doubling of cumulative output of 'Liberty Ships' in 14 US shipyards during World War II was associated with a reduction in man-hours required per ship of between 12 and 24 per cent. By definition, learning by doing is associated with actual experience of the production process and will thus occur in an individual sector of a particular economy. At the same time, it is plausible that production knowledge may spillover across economies, and we wish to allow technology in each sector to transferred from a leading to a follower economy.

Therefore, technological progress is assumed to occur endogenously as a result of both learning by doing and (unless the economy is the world technological leader in a particular sector) technological transfer. The particular specification chosen combines the model of learning by doing in Krugman (1987) with one of technological transfer in Bernard and Jones (1996) (see also Bernard and Jones (1994)). Specifically, $A_{ij}(t)$ is assumed to evolve over time as follows,

$$\ln\left(\frac{A_{ij}(t)}{A_{ij}(t-1)}\right) = \gamma_{ij} + \psi_j \ln(1 + L_{ij}(t-1)) + \lambda_j \ln\left(\frac{A_{Xj}(t-1)}{A_{ij}(t-1)}\right) \tag{3}$$

$$\gamma_{ij},\ \chi_{ij},\ \lambda_{ij} \geq 0 \quad \forall i;j$$

where A_{Xj} denotes productivity in sector j in whichever of the two economies $i \in \{H;F\}$ is the world's technological leader, γ_{ij} is a sector and country-specific constant reflecting the exogenous determinants of rates of technological change, χ_j parameterises the rate of learning by doing, and λ_j characterises the rate of technological catch-up. Throughout the analysis, technological change is modelled as a pure externality of current production and is therefore consistent with the assumption of perfect competition in the Ricardian model.

Equation (3) implies that, in each sector j of the two economies i, the evolution of productivity relative to the world technological leader may be expressed as,

$$\Delta \ln\left(\frac{A_{ij}(t)}{A_{Xj}(t)}\right) = (\gamma_{ij} - \gamma_{Xj}) + \chi_j \ln\left(\frac{1+L_{ij}(t-1)}{1+L_{Xj}(t-1)}\right) - \lambda_j \cdot \ln\left(\frac{A_{ij}(t-1)}{A_{Xj}(t-1)}\right) \tag{4}$$

The dynamics of international trade patterns are fully characterised by the static equilibrium conditions (1) and (2), together with the specification of productivity growth in equations (3) and (4). Initial levels of productivity determine the pattern of comparative advantage and international specialisation. The pattern of international specialisation (with its associated allocation of labour across sectors) then affects rates of productivity growth and hence the evolution of international trade flows over time.

On the one hand, the presence of sector-specific learning by doing means that initial patterns of international specialisation will tend to be reinforced over time. On the other hand, technological transfer and differences in the exogenous rates of productivity growth across sectors may both be responsible for reversing initial patterns of international specialisation - depending upon the correlation between initial levels of relative productivity and the steady-state levels implicit in equation (4).

For example, consider two special cases. First, suppose that there is a common rate of exogenous technological change across all sectors and economies ($\gamma_{Hj} = \gamma_{Fj} = \gamma$ for all j) and no international knowledge spillovers ($\lambda_j = 0$ for all j). Static equilibrium at time t implies that home will specialise completely in the production of the range of goods $j \in [0; \bar{j}]$ and foreign in goods $j \in (\bar{j}; n]$. That is, in home, $L_j(t) > 0$ for $j \in [0; \bar{j}]$ and $L_j(t) = 0$ for $j \in (\bar{j}; n]$, while in foreign $L_j(t) = 0$ for $j \in [0; \bar{j}]$ and $L_j(t) > 0$ for $j \in (\bar{j}; n]$. It follows immediately, from (3) and the parameter restrictions imposed above, that home productivity relative to foreign will rise in the sectors where home initially specialises and fall in the sectors where home does not initially specialise. As a result, initial patterns of international specialisation persist and will become increasingly locked-in over time (as in Krugman (1987)).

Second, suppose that there is no sector-specific learning by doing ($\psi_j = 0$ for all j); nonetheless, exogenous technological progress occurs at varying rates across sectors and economies ($\gamma_{ij} > 0$ for all $i; j$, $\gamma_{Hj} \neq \gamma_{Fj}$ for all j) and is accompanied by knowledge spillovers ($\lambda_j > 0$ for all j). Suppose also that those sectors in which home productivity is initially less than foreign are the same sectors in which $\gamma_H > \gamma_F$, and that the converse is also true. Then, from equation (4), sectors where home productivity is initially less than foreign will become - in steady-state - sectors in which home productivity exceeds foreign. This is sufficient (though not necessary) for initial patterns of international specialisation to be reversed over time.[1]

[1] Remember that it is relative values of A_{Hj}/A_{Fj} across sectors j that matter for comparative advantage and international specialisation.

3 Empirical modelling of trade dynamics

Thus, economic theory pin-points some forces that lead to persistence in international trade flows and others that induce mobility. Whether initial patterns of international trade are reinforced or reversed over time is therefore an empirical question. This Section proposes an empirical framework for analysing the dynamics of international trade flows. The framework will enable the question of persistence versus mobility to be addressed, while also yielding information about other related aspects of international trade dynamics - for example, whether the overall degree of international specialisation is rising over time.

The extent of specialisation in an individual sector is characterised using a modified version of Balassa's (1965) index of Revealed Comparative Advantage (RCA).[2] An economy i's RCA in sector j is given by the ratio of its share of exports in sector j to its average export share in all sectors,[3]

$$RCA_{ij} = \frac{Z_{ij} / \sum_i Z_{ij}}{\frac{1}{N} \sum_j (Z_{ij} / \sum_i Z_{ij})} \tag{5}$$

where Z_{ij} denotes the value of economy i's exports in sector j.

RCA yields information about the pattern of international specialisation insofar as it evaluates an economy's export share in an individual sector relative to some benchmark - namely, the economy's average export share in all sectors. The pattern of international specialisation at any one point in time t is characterised by the distribution of RCA across sectors. A value of RCA_{ij} above unity indicates an industry in which economy i's share of exports exceeds its average share in all industries: that is, an industry in which economy i specialises.

[2] For a more recent application of Balassa's original index, see Dollar and Wolff (1993).

[3] Balassa (1965)'s actual measure of RCA is the ratio of economy i's export share in sector j to its share of total exports of all sectors. This measure suffers from the disadvantage that its arithmetic mean is not necessarily equal to one, and may vary both across economies and over time. The measure used in this paper is formally equivalent to normalising Balassa's measure by its cross-sectional mean. See Appendix B for further discussion.

Evaluating the dynamics of patterns of international specialisation over time involves an analysis of the evolution of the entire cross-section distribution of RCA. Issues such as persistence versus mobility in international trade flows correspond to questions of intra-distribution dynamics. What is the probability that a sector moves from one quartile of the RCA distribution to another ? Are the sectors in which $RCA_{ij} > 1$ at time $t + k$ ($k \geq 1$) the same sectors as at time t ? Changes in the overall degree of international specialisation may be evaluated by analysing the evolution of the external shape of the RCA distribution. Do we observe an increasing specialisation in a limited subset of industries (a polarisation of the RCA distribution towards extreme values), or has the degree of international specialisation remained broadly unchanged ?

The evolution of the RCA distribution over time may be modelled formally, employing techniques already used in the cross-country growth literature to analyse income convergence (see Quah (1993), (1996a) and (1996c)). Thus, denote RCA by the measure x and its distribution across sectors at time t by $F_t(x)$. Corresponding to F_t, we may define a probability measure λ_t where $\forall x \in \Re$, $\lambda_t((-\infty, x]) = F_t(x)$. Following Quah op cit., the evolution of the distribution of RCA over time is then modelled in terms of a stochastic difference equation,

$$\lambda_t = P^*(\lambda_{t-1}, u_t); \qquad \text{integer } t \tag{6}$$

where $\{u_t : \text{integer } t\}$ is a sequence of disturbances and P^* is an operator that maps disturbances and probability measures into probability measures. For simplicity, we assume that this stochastic difference equation is first-order and that the operator P^* is time invariant. Even so, equation (6) is intractable and cannot be directly estimated. However, setting the disturbances u to zero and iterating the stochastic difference equation forwards, we obtain,

$$
\begin{aligned}
\lambda_{t+s} = P^*(\lambda_{t+s-1}, 0) &= P^*(P^*(\lambda_{t+s-2}, 0), 0) \\
&\vdots \\
&= P^*(P^*(P^* \ldots (P^*(\lambda_t, 0), 0) \ldots 0), 0) \\
&= (P^*)^s \lambda_t
\end{aligned} \tag{7}
$$

If the space of possible values of RCA is divided into a number of distinct, discrete cells, P^* becomes a matrix of transition probabilities which may be estimated by counting the number of transitions out of and into each cell.[4] From these transition probabilities, one is able to characterise the extent of mobility between different segments of the RCA distribution. Furthermore, by taking the limit $s \to \infty$ in equation (7), one obtains the implied ergodic RCA distribution, which provides information concerning the evolution of the external shape of the RCA distribution.

4 Preliminary data analysis

The empirical methodology outlined above is used in the remainder of this paper to analyse the evolution of patterns of international specialisation in the manufacturing sectors of the G5. The techniques used enable a wide range of issues concerning international trade dynamics to be addressed. For example, we consider the extent to which there are changes in patterns of specialisation over time and at what levels of specialisation the greatest degree of mobility is observed. It is possible to examine whether international trade dynamics are different in the US from Japan or the major European economies. We evaluate the degree to which each economy is increasingly specialising in small sub-sets of manufacturing sectors.

This Section presents the RCA data on patterns of specialisation in the G5 economies, and looks informally at changes in international specialisation over time. The following Section estimates the formal model of distribution

[4] More generally, if we continue to treat RCA as a continuous variable, one may estimate the stochastic kernel associated with P^* (see for example Quah (1996c)). However, in the present application, there are too few cross-sectional units to permit such estimation.

dynamics econometrically. The source for all the data is the OECD's Bilateral Trade Database (BTD). This provides consistent information on exports to the OECD and 15 trade partners for 22 manufacturing industries for the period 1970-93.[5] We begin by characterising the distribution of RCA at any one point in time in the United Kingdom and the United States, before widening the analysis to encompass the other three members of the G5. Table 1 presents measures of RCA for the United Kingdom in each of the 22 manufacturing industries in the sample for the period 1970-93. For ease of exposition, the data are presented in the form of ...ve-year averages.

<Table 1 about here>

Table 2 presents exactly the same information for the United States. From a comparison of the tables, the two economies' patterns of international specialisation show several similarities, although there are also important di¤erences. In Table 3, we list all the UK and US industries in which RCA exceeds one in either or both of the periods 1970-4 and 1990-3. Industries in which an RCA is either acquired or lost in each economy during the sample period are denoted by italics. In the ...rst of these two periods, industries in which the United Kingdom had an RCA and the United States did not were Petroleum Re...ning, Metal Products, Nonferrous Metals, Pharmaceuticals and Other Manufacturing; industries in which the US had an RCA but the UK did not were Motor Vehicles and Communication.

<Table 2 about here>

Table 3 also makes clear that the industries in which an economy has an RCA change substantially over time. On the one hand, between the periods 1970-4 and 1990-3, the United Kingdom lost its RCA in Electrical Machinery, Non-electrical Machinery, Metal Products and Non-ferrous Metals. On the other hand, the United Kingdom gained an RCA in Industrial Chemicals and Communication. In the United States, a comparison of patterns

[5] Further details concerning the data used, including an industrial classi...cation, are contained in Appendix A.

of international specialisation in 1970-4 and 1990-3 reveals the acquisition of an RCA in Food and Drink and Paper and Printing, combined with the loss of an RCA in Motor Vehicles.

<Table 3 about here>

Exactly the same analysis is undertaken for the other three members of the G5. Table 4 lists all the French, German and Japanese industries in which RCA exceeds one in either or both of the periods 1970-4 and 1990-3.[6] Again, changes in patterns of international specialisation occur. The case of Japan is particularly worthy of note, where an RCA is lost in Rubber and Plastic, Textiles and Clothing and Other Manufacturing, and an RCA is acquired in Non-electrical Machinery, Electrical Machinery, Motor Vehicles and Computers. From these two tables alone, patterns of international specialisation in France and Germany appear to be less mobile than those in Japan and the United Kingdom.

Tables 3 and 4 provide one means of analysing the dynamics of patterns of international specialisation. Although some interesting information can be obtained, the conclusions that may be drawn from these tables are necessarily limited. First, the analysis is concerned with only two of the ...ve-year periods. Second and more importantly, by restricting attention to movements of RCA above or below the value of one, one loses a vast amount of information on changes in the degree of specialisation in individual industries. Movements between other segments of the RCA distribution are also of interest. For example, between 1970-4 and 1980-4, RCA in the US Textiles and Clothing rose to 173% of its original value, while that in the US Ferrous Metals industry fell to 64% of its initial value. Neither of these substantial changes in patterns of international specialisation enters into Table 3.

<Table 4 about here>

[6] In the interests of brevity, actual values of RCA are not reported. This information is available from the author on request.

A more complete - although still informal - analysis of international trade dynamics is undertaken for the United Kingdom in Figures 2-7. In Figure 2, UK industries are ordered in terms of increasing RCA for the period 1970-4, and the cross-section distribution of RCA is graphed. Figures 3, 4, 5 and 6 preserve the same ordering of industries and plot the RCA distribution for the periods 1975-79, 1980-4, 1985-9 and 1990-3 respectively. Figure 7 re-orders industries in terms of increasing RCA for the period 1990-3, and again graphs the cross-section distribution of RCA.

Taken together, Figures 2-6 yield information concerning intra-distribution dynamics. If patterns of international specialisation in the United Kingdom exhibited substantial persistence, one would expect the distribution of RCA to remain very similar across successive time periods. Industries with high values of RCA in 1970-4 would also have high values of RCA in 1990-3. In fact, what one observes is considerable mobility in international trade ‡ows in the United Kingdom - particularly in the middle of the distribution. For example, between 1970-4 and 1985-9, the UK's RCA in Motor Vehicles fell from 0.94 to 0.48, before rising to 0.67 in 1990-3.

A similar analysis is undertaken for each of the G5 economies. If industries are ordered in terms of increasing RCA for the period 1970-4, and the cross-section distribution of RCA in successive time periods is graphed, the story again appears to be one of considerable mobility - a …nding that will be con…rmed in the formal analysis to follow.

Figures 2-7 may also be used to gain information about changes in the overall degree of international specialisation in the United Kingdom - changes in the external shape of the cross-section distribution of RCA. If the United Kingdom were increasingly specialising in a limited subset of industries, one would observe RCA systematically increasing in speci…c sectors and systematically decreasing in others, so that the distribution of RCA would exhibit an increasing mass at extreme values of RCA. A comparison of Figures 2 and 7 in particular reveals no evidence of this being the case.

With the exception of Japan (to be discussed in the following Section), the same is also true for each of the other G5 economies.

<Figures 2-7 about here>

5 Econometric estimation

This Section estimates the formal model of distribution dynamics introduced above econometrically. If the space of possible values of RCA is divided into m discrete cells, the operator P^* in equations (6) and (7) becomes an $m \times m$ matrix of transition probabilities,

$$\lambda_t = P^* \cdot \lambda_{t-1} \tag{8}$$

The matrix P^* contains elements p_{kl}, each of which denotes the probability that an industry moves from cell k to cell l (where $k, l \in \{1, \ldots, m\}$) and which may be estimated by counting the number of transitions out of and into each cell. All empirical estimation was undertaken using Danny Quah's TSRF econometrics package.[7] In each case, the boundaries between cells were chosen such that industry-year observations are divided roughly equally between the grid cells.

In order to provide a benchmark against which to compare the results for individual economies, we begin by pooling observations across economies. Table 5 presents the estimated transition probability matrix for the pooled sample (implicitly, we assume that the stochastic process determining the evolution of RCA in each economy is the same). The interpretation of this table is as follows. The numbers in parentheses in the first column are the total number of industry-year observations beginning in a particular cell, while the first row of numbers denotes the upper endpoint of the corresponding grid cell. Thereafter each row denotes the estimated probability of passing from one state into another. For example, the second row of

[7] Responsibility for any results, opinions and errors is of course solely the authors'.

numbers presents (reading across from the second to the fifth column) the probability of remaining in the lowest RCA state and then the probability of moving into the lower-intermediate, higher-intermediate and highest RCA states successively. The final row of the upper section of the table gives the implied ergodic distribution, while, in the lower section of the table, the one-year transition probability matrix is iterated five times.

<Table 5 about here>

Transition probability matrices are then estimated for each of the G5 economies individually (allowing the stochastic process shaping the evolution of RCA to vary across economies). The results of this estimation are presented in Tables 6 and 7. The interpretation of the tables is directly analogous, except that the one-year transition probability matrix iterated five times is now omitted.

<Tables 6 and 7 about here>

Estimated values of transition probabilities close to one along the diagonal are indicative of persistence in the distribution of RCA across sectors, while large off-diagonal terms imply greater mobility. The results for individual G5 economies in Tables 6 and 7 confirm the main finding in the informal analysis of the previous Section. That is, there is evidence of a relatively high degree of mobility in patterns of international specialisation. For example, in France the probability of moving out of one grid cell after one year ranges from 11%-27%, while in the United States the same probability varies from 10%-21%. Iterating the one-year transition matrix five times (not shown in Tables 6 and 7), the extent of mobility is brought out more strongly: for France, the probability of remaining in the same cell over the five-year period ranges from 64% to only 37%.

In each of the G5 economies and in the pooled sample, mobility is highest in the middle of the distribution (out of the lower- and upper-intermediate grid cells). Of the six matrices of estimated transition probabilities, a comparison of diagonal and off-diagonal terms suggests that those for France and the United Kingdom exhibit the greatest mobility, while those for Japan and the pooled sample display the least. This conclusion would not be drawn from Tables 3 and 4 alone, and confirms the limitations of the informal analysis that were pointed out earlier. By restricting attention solely to movements in RCA above and below the value of one, one rules out of consideration a wide range of interesting international trade dynamics.

The finding that mobility is highest in France and the United Kingdom, and lowest in Japan and the pooled sample is confirmed with the use of formal indices of mobility (see, for example, Shorrocks (1978), Geweke et al. (1986) and Quah (1996b)). Table 8 presents the values of four such indices for the pooled sample and the individual G5 economies. Each of these indices seeks to reduce information about mobility from the matrix of transition probabilities P^* to a single summary statistic.

<Table 8 about here>

Thus, M_1 (following Shorrocks (1978)) evaluates the trace (tr) of the matrix. M_2 (see Shorrocks (1978)) presents information on the average number of class boundaries crossed by a sector originally in state k weighted by the corresponding proportions π_k of the ergodic distribution. M_3 (following Geweke et al. (1986) and Quah (1996b)) is based on the eigenvalues λ_j of the matrix, while M_4 (see Shorrocks (1978)) evaluates the determinant (det).[8]

A key advantage of the present approach is that, by analysing the evolution of the entire distribution of RCA, we are able to evaluate the degree of mobility through all possible values of RCA. Thus, it is not only the overall degree of mobility that is interesting in Japan's case, but also the pattern. The probabilities of moving out of the lower- and upper-intermediate grid cells (characterising the degree of mobility in the middle of distribution) are not dissimilar to those estimated for the United States. What is particularly

[8] For the exact relationship between these indices and the circumstances under which they yield transitive rankings of transition probability matrices see Shorrocks (1978) and Geweke et al. (1986).

noteworthy about the transition probability matrix estimated for Japan is the extreme immobility in the lower and upper grid cells. As a result, industries that move into these grid cells are extremely likely to remain there. It is this combination of mobility in the centre of the distribution and immobility at the extremes, that is driving some of movements in RCA above and below the value of one in Table 4 - and this is confirmed by replicating for Japan the informal analysis undertaken for the UK in Figures 2-7.

The techniques implemented in this Section may also be used to address the question whether the stochastic process determining the evolution of RCA across industries is the same in each of the G5 economies. Anderson and Goodman (1957) show that, for each state k, under the null hypothesis $p_{kl} = \bar{p}_{kl}$,

$$\sum_{l=1}^{m} n_k^{*} \cdot \frac{(p_{kl} - \bar{p}_{kl})^2}{\bar{p}_{kl}} \sim \chi^2(m-1); \qquad n_k^{*} \equiv \sum_{t=0}^{T-1} n_k(t) \tag{9}$$

where p_{kl} are the estimated transition probabilities, $\bar{p}_{kl}$ are the probabilities of transition under the (known) null and $n_k(t)$ denotes the number of sectors in cell k at time t.

The test statistic in equation (9) may be used to test the hypothesis that the transition probabilities estimated for an individual G5 economy are the result of a Data Generation Process (DGP) given by the transition probabilities estimated for the pooled sample. From equation (9), this test may be undertaken for each state $k = 1, ..., m$. Furthermore, since the transition probabilities are independently distributed across states, we may sum over states and test the hypothesis that, for all states $k = 1, ..., m$, the estimated transition probabilities are equal to those under the null. The resulting test statistic is asymptotically distributed $\chi^2(m(m-1))$.

Implementing this test procedure for the G5 economies, the null that the DGP is given by the matrix of transition probabilities estimated for the pooled sample is rejected at the 5% in France and the United Kingdom (the two most mobile economies). The same hypothesis is not rejected at conventional levels of statistical significance in Germany, Japan and the United States (though the hypothesis is close to rejection at the 10% level in Japan). These results suggest that, as well as there being considerable mobility in patterns of international specialisation in each economy, there are significant differences in international trade dynamics across economies.[9]

Tables 5-7 are not only of interest in terms of the light they shed on the degree of mobility versus persistence in international trade flows (an issue of intra-distribution dynamics), but are also revealing in terms of the information they yield about changes in the degree of international specialisation over time (a question of the evolution of the external shape of the RCA distribution). If an economy were increasingly specialising in a few sectors, we would expect to observe RCA systematically increasing in some industries and systematically decreasing in others. That is, we would expect to observe a polarisation of the RCA distribution towards two sets of extreme values.

This hypothesis may be evaluated in terms of both the informal techniques considered in Section 4 and the results of the econometric estimation of this Section. In each of Tables 5-7, the ergodic or stationary distribution implied by the transition probability matrix is reported. This is the cross-section distribution of RCA generated by iterating the matrix of estimated transition probabilities forwards in time and letting the number of iterations tend to infinity. It gives the unconditional probability of an industry being in a given grid cell. The ergodic distribution is approximately uniform for both the pooled sample and four of the G5 economies (France, Germany, the United Kingdom and the United States). For these economies, there is no evidence of an increase in the degree of international specialisation over time. The exception to this pattern is Japan, where the high persistence in

[9] It is also possible to test the null hypothesis for one G5 economy that the DGP is given by the matrix of transition probabilities estimated for another G5 economy. For a more detailed analysis of international trade dynamics in Germany and the UK, see Proudman and Redding (1997).

the lower and upper grid cells discussed above is re‡ected in a polarisation of RCA towards extreme values in the ergodic distribution. Thus, it is only in Japan where we …nd evidence of an increase in the degree of specialisation over time.[10]

In order to test the robustness of these results, the transition probability matrices were re-estimated in two ways. First, the space of values of RCA was divided into …ve cells rather than four. Second, the transition probabilities were estimated allowing transitions to occur over …ve-year rather than one-year periods. The probabilities estimated over …ve-year transition periods exhibit small di¤erences from the one-year transition probabilities iterated …ve times, suggesting that the evolution of RCA is not fully characterised by a …rst-order, time homogenous model. Nonetheless, in both cases, the results suggested a broadly similar interpretation to that given above.

6 Conclusion

Theoretical models of growth and trade suggest that patterns of international specialisation are inherently dynamic and evolve endogenously over time. Economic theory pin-points some forces that lead to persistence in international trade ‡ows (eg sector-speci…c learning by doing) and others (eg technological transfer) that induce mobility. Thus, whether initial patterns of international trade persist or are unwound with the passage of time is ultimately an empirical question.

This paper has put forward an empirical framework for analysing the dynamics of international specialisation, which combines a modi…ed version of Balassa's (1965) measure of Revealed Comparative Advantage (RCA) with a model of distribution dynamics taken from the cross-country literature

[10] This result is con…rmed by looking directly at the evolution of the RCA distribution across industries during the sample period. The increase in international specialisation is particularly evident in the upper tail of the distribution. In 1970-4, there were four Japanese industries with values of RCA greater than or equal to 1.2; by 1990-3, this …gure had increased to eight.

on income convergence (Quah (1993), (1996a) and (1996c)). International specialisation at any point in time is characterised by the distribution of RCA across industries, while an investigation of the dynamics of patterns of international specialisation corresponds to an analysis of the evolution of the entire cross-section distribution of RCA over time.

This empirical framework was then implemented using industry-level data from the G5 economies. The evolution of the cross-section distribution of RCA was …rst analysed informally using graphical techniques for the UK; the formal model of distribution dynamics was then estimated econometrically. Transition probability matrices were estimated for both the pooled sample (pooling observations on RCA across economies) and for each of the individual G5 economies.

The results of both the formal and informal analysis revealed considerable mobility in patterns of international specialisation. Thus, in the United States the estimated probability of moving out of one grid cell ranged from 10%-21% after one year and from 34%-56% after …ve years. Using formal indices of mobility, it was possible to quantify the overall degree of mobility in international trade ‡ows in the G5 economies. Overall mobility was found to be highest in France and the United Kingdom and lowest in Japan.

However, one of the key advantages of the present approach is that, by analysing the evolution of the entire distribution of RCA, we are able to evaluate the degree of mobility through all possible values of RCA. In Japan's case, the degree of mobility in the centre of the distribution (in the lower- and upper-intermediate grid cells) is not dissimilar from that in the United States; what is noteworthy about in Japan is the extreme immobility in the tails of the RCA distribution (in the lower and upper grid cells).

Besides evaluating the degree of mobility versus persistence in patterns of international specialisation, the framework employed in this paper may also be used to consider changes in the degree of international specialisation over time. If an economy were increasingly specialising in a few sectors, we would expect to observe RCA systematically increasing in some industries and systematically decreasing in others. In France, Germany, the United Kingdom and the United States, there is no evidence of such an increase in the degree of international specialisation. Only in Japan is there evidence that the distribution of RCA is polarising towards extreme values at high and low values of RCA.

Appendix A

The data source for the indices of Revealed Comparative Advantage is the OECD's Bilateral Trade Database (BTD). This provides information on the value of exports and imports between the 23 OECD countries and 15 partner economies. The partner countries are: Argentina, Brazil, China, Czech and Slovak Republics, Hong Kong, Hungary, India, Indonesia, Malaysia, Mexico, Philippines, Singapore, Korea (South), Taiwan and Thailand. Although OECD imports from and OECD exports to these partner countries are included in the database, trade entirely outside the OECD area (eg from one partner country to another) is not. The OECD estimates that 90%-95% of world trade in goods is included in the database. Information is available for the 22 industries listed in Table 9.

<Table 9 about here>

Appendix B

Measuring Revealed Comparative Advantage

Balassa (1965) defines an economy i's measure of 'Revealed Comparative Advantage' (RCA_{ij}) in sector j as the ratio of its share of exports in sector j to its share of exports of all sectors,

$$RCA_{ij} = \frac{Z_{ij} / \sum_i Z_{ij}}{\sum_j Z_{ij} / \sum_i \sum_j Z_{ij}}; \qquad (10)$$

where Z_{ij} denotes the value of economy i's exports in sector j. A value of $R\tilde{C}A_{ij}$ above unity indicates an industry in which economy i's share of exports exceeds its share of total exports: that is, an industry in which economy i specialises.

So defined, $R\tilde{C}A$ yields information about the pattern of international specialisation insofar as it evaluates an economy's export share in an individual sector relative to some benchmark - here, the economy's share of total exports.

However, $R\tilde{C}A$ suffers from the disadvantage that its arithmetic mean across sectors is not necessarily equal to one. The numerator in equation (10) is unweighted by the proportion of total exports accounted for by a given sector, while the denominator is a weighted sum of export shares in all manufacturing sectors. Thus, if an economy's pattern of trade is characterised by high export shares in a few sectors, each of which accounts for a small share of total world exports (as is generally true for small economies), this implies high values for the numerator and low values for the denominator in equation (10). As a result, the economy will be characterised by a mean value of $R\tilde{C}A$ of above one.[11] Furthermore, mean values of $R\tilde{C}A$ may change over time, so that as measured by $R\tilde{C}A$, an economy exhibits changes in its average extent of specialisation over time.

Therefore, this paper adopts an alternative measure of Revealed Comparative Advantage (RCA), in which an economy's export share in a given sector is evaluated relative to a different benchmark - namely, its average export share in all manufacturing sectors. By construction, the mean value of RCA is constant and equal to one.

It is straightforward to show that $RCA_{ij} = R\tilde{C}A_{ij} / \frac{1}{N}\sum_j R\tilde{C}A_{ij}$. So an alternative interpretation of the present analysis is that, at each point in time, we normalise Balassa's measure by its cross-sectional mean in order to

[11] For example, suppose there are two economies (the UK and France) and two goods (beer and wine). The total value of the UK's exports is £500 (£400 Beer and £100 Wine) and the total value of France's is £10,100 (£100 Beer and £10,000 Wine). It is straighforward to show that the UK's mean RCA is considerably above one (it is in fact 8.59) and France's considerably below one (it is in fact 0.63).

abstract from the changes in the average extent of specialisation that this measure is subject to.

References

Anderson, T. and L. Goodman, 1957, Statistical Inference about Markov Chains, Annual of Mathematical Statistics, 28.

B. Balassa, 1965, Trade Liberalisation and Revealed Comparative Advantage, The Manchester School of Economic and Social Studies, 33, 99-123.

Bernard, A. and C. Jones, 1994, Comparing Apples to Oranges: Productivity, Convergence and Measurement across Industries and Countries, MIT Working Paper, 94-12.

Bernard, A. and C. Jones, 1996, Productivity Across Industries and Countries: Time Series Theory and Evidence, Review of Economics and Statistics, 78, 135-146.

Brezis, E. Krugman, P. and D. Tsiddon, 1993, Leapfrogging in International Competition: A Theory of Cycles in National Technological Leadership, American Economic Review, 83, 1211-1219.

Dollar, D. and E. Wol¤, 1993, Competitiveness, Convergence and International Specialisation (MIT Press).

Dornbusch, R. Fischer, S. and P. Samuelson, 1977, Comparative Advantage, Trade and Payments in a Ricardian Model with a Continuum of Goods, American Economic Review, 67, 823-839.

Geweke, J. Marshall, R. and G. Zarkin, 1986, Mobility Indices in Continuous Time Markov Chains, Econometrica, 54, 1407-1423.

Grossman, G. and E. Helpman, 1991, Innovation and Growth in the Global Economy (MIT Press).

P. Krugman, 1987, The Narrow Moving Band, the Dutch Disease and the Competitive Consequences of Mrs Thatcher: Notes on Trade in the Presence of Scale Economies, Journal of Development Economics, 27, 41-55.

R. Lucas, 1993, Making a Miracle, Econometrica, 61, 251-272.

Proudman, J. and S. Redding, 1997, Persistence and Mobility in International Trade, Bank of England Working Paper, 64.

D. Quah, 1993, Empirical Cross-Section Dynamics in Economic Growth, European Economic Review, 37, 426-34.

D. Quah, 1996a, Twin Peaks: Growth and Convergence in Models of Distribution Dynamics, Economic Journal, 106, 1045-1055.

D. Quah, 1996b, Aggregate and Regional Disaggregate Fluctuations, Empirical Economics, 21, 137-159.

D. Quah, 1996c, Convergence Empirics Across Economies with (some) Capital Mobility, Journal of Economic Growth, 1, 95-124.

Rivera-Batiz, L. and P. Romer, 1991, Economic Integration and Endogenous Growth, Quarterly Journal of Economics, 106, 531-555.

A. Shorrocks, 1978, The Measurement of Mobility, Econometrica, 46, 1013-1024.

Figure 1: Static Equilibrium and International Specialisation

Table 1
RCA in the United Kingdom

Industry	1970-4	1975-9	1980-4	1985-9	1990-3
Food and Drink	0.71	0.80	0.87	0.84	0.93
Textiles and Clothing	0.93	0.90	0.84	0.78	0.79
Timber and Furniture	0.22	0.35	0.32	0.28	0.29
Paper and Printing	0.54	0.58	0.62	0.62	0.80
Industrial Chemicals	0.96	1.04	1.16	1.16	1.17
Pharmaceuticals	1.46	1.44	1.54	1.51	1.61
Petroleum Re...ning	1.10	1.18	1.27	1.27	1.36
Rubber and Plastic	0.96	0.98	1.02	0.91	0.95
Non-metallic Minerals	0.98	0.94	0.84	0.79	0.81
Ferrous Metals	0.58	0.50	0.51	0.69	0.89
Non-ferrous Metals	1.27	1.13	1.21	0.96	0.98
Metal Products	1.12	0.98	0.96	0.83	0.82
Non-electrical Machinery	1.12	1.07	1.12	0.97	0.93
Computers	1.08	1.21	1.19	1.33	1.53
Electrical Machinery	1.03	0.96	0.99	0.86	0.84
Communication	0.72	0.77	0.72	0.77	1.02
Shipbuilding	0.59	0.61	0.52	1.85	0.94
Other Transport	0.72	0.61	0.61	0.42	0.40
Motor Vehicles	0.94	0.78	0.62	0.48	0.67
Aerospace	1.49	1.68	1.98	1.74	1.63
Instruments	1.00	0.97	1.15	1.09	1.07
Other Manufacturing	2.48	2.50	1.93	1.85	1.57
Mean	1.00	1.00	1.00	1.00	1.00
Standard Deviation	0.45	0.45	0.43	0.44	0.36

Table 2
RCA in the United States

Industry	1970-4	1975-9	1980-4	1985-9	1990-3
Food and Drink	0.91	0.96	0.96	1.07	1.02
Textiles and Clothing	0.37	0.54	0.64	0.50	0.59
Timber and Furniture	0.61	0.69	0.70	0.74	0.89
Paper and Printing	0.88	0.89	0.95	0.92	1.02
Industrial Chemicals	1.15	1.15	1.19	1.10	1.15
Pharmaceuticals	0.92	0.97	1.12	1.12	0.83
Petroleum Re…ning	0.59	0.41	0.59	0.87	0.93
Rubber and Plastic	0.65	0.66	0.63	0.69	0.78
Non-Metallic Minerals	0.58	0.58	0.57	0.53	0.58
Ferrous Metals	0.39	0.31	0.25	0.20	0.33
Non-ferrous Metals	0.65	0.62	0.70	0.66	0.82
Metal Products	0.80	0.79	0.81	0.66	0.76
Non-electrical Machinery	1.32	1.40	1.39	1.14	1.11
Computers	2.03	2.11	2.30	2.08	1.75
Electrical Machinery	1.04	1.07	1.01	0.98	1.05
Communication	1.11	1.11	1.17	1.25	1.40
Shipbuilding	0.48	0.35	0.46	0.46	0.47
Other Transport	0.47	0.54	0.50	0.56	0.61
Motor Vehicles	1.10	1.09	0.84	0.82	0.80
Aerospace	3.83	3.71	3.16	3.57	3.08
Instruments	1.30	1.33	1.39	1.41	1.36
Other Manufacturing	0.80	0.72	0.67	0.68	0.68
Mean	1.00	1.00	1.00	1.00	1.00
Standard Deviation	0.74	0.73	0.65	0.70	0.57

Table 3
RCA in the United Kingdom and the United States

Country	Industry	1970-4	1990-3
UK	Industrial Chemicals	£	p
	Instruments	p	p
	Electrical Machinery	p	£
	Computers	p	p
	Petroleum Re...ning	p	p
	Non-electrical Machinery	p	£
	Metal Products	p	£
	Non-ferrous Metals	p	£
	Pharmaceuticals	p	p
	Aerospace	p	p
	Other Manufacturing	p	p
	Communication	£	p
US	Electrical Machinery	p	p
	Motor Vehicles	p	£
	Communication	p	p
	Industrial Chemicals	p	p
	Instruments	p	p
	Non-electrical Machinery	p	p
	Computers	p	p
	Aeropsace	p	p
	Food and Drink	£	p
	Paper and Printing	£	p

Note: p indicates RCA_{ij} ¸ 1, £ indicates $RCA_{ij} < 1$

Table 4

RCA in France, Germany and Japan

Country	Industry	1970-4	1990-3
France	Metal Products	p	p
	Industrial Chemicals	p	p
	Electrical Machinery	p	p
	Motor Vehicles	p	£
	Pharmaceuticals	p	p
	Ferrous Metals	p	p
	Non-metallic Minerals	p	p
	Textiles and Clothing	p	p
	Food and Drink	p	p
	Other Transport	p	£
	Rubber and Plastic	p	p
	Aerospace	£	p
Germany	Rubber and Plastic	p	p
	Computers	p	£
	Pharmaceuticals	p	p
	Ferrous Metals	p	p
	Non-metallic Minerals	p	p
	Instruments	p	p
	Industrial Chemicals	p	p
	Metal Products	p	p
	Motor Vehicles	p	p
	Electrical Machinery	p	p
	Non-electrical Machinery	p	p
	Textiles and Clothing	£	p
Japan	Rubber and Plastic	p	£
	Textiles and Clothing	p	£
	Other Manufacturing	p	£
	Instruments	p	p
	Ferrous Metals	p	p
	Communication	p	p
	Shipbuilding	p	p
	Other Transport	p	p
	Non-electrical Machinery	£	p
	Electrical Machinery	£	p
	Motor Vehicles	£	p
	Computers	£	p

Note: p indicates RCA_{ij} ¸ 1, £ indicates RCA_{ij} < 1

Table 5
Transition probabilities, pooled sample
(one-year transitions)

Pooled sample		Upper endpoint		
Number	0.670	0.915	1.223	1
(609)	0.90	0.10	0.00	0.00
(604)	0.09	0.83	0.09	0.00
(607)	0.00	0.08	0.84	0.07
(600)	0.00	0.00	0.06	0.94
Ergodic	0.234	0.249	0.244	0.273
	1 £ transitions iterated 5 £			
	0.6518	0.2928	0.0574	0.0049
	0.2635	0.4928	0.2320	0.0421
	0.0459	0.2062	0.4892	0.2271
	0.0033	0.0321	0.1946	0.7655

Table 6
Transition probabilities for France, Germany and Japan (one-year transitions)

France	Upper endpoint			
Number	0.743	1.047	1.245	1
(114)	0.83	0.17	0.00	0.00
(116)	0.16	0.73	0.10	0.00
(118)	0.01	0.09	0.79	0.11
(114)	0.00	0.01	0.11	0.89
Ergodic	0.266	0.258	0.242	0.234
Germany	**Upper endpoint**			
Number	0.740	0.994	1.270	1
(121)	0.86	0.14	0.00	0.00
(123)	0.14	0.80	0.07	0.00
(120)	0.00	0.06	0.88	0.07
(120)	0.00	0.00	0.07	0.93
Ergodic	0.233	0.237	0.265	0.265
Japan	**Upper endpoint**			
Number	0.222	0.768	1.446	1
(122)	0.97	0.03	0.00	0.00
(119)	0.05	0.84	0.11	0.00
(124)	0.00	0.13	0.83	0.04
(119)	0.00	0.00	0.03	0.97
Ergodic	0.325	0.211	0.179	0.286

Table 7
Transition probabilities for the United Kingdom and United States (one-year transitions)

United Kingdom	Upper endpoint			
Number	0.739	0.942	1.176	1
(123)	0.90	0.09	0.00	0.01
(119)	0.08	0.78	0.13	0.00
(123)	0.00	0.15	0.72	0.12
(119)	0.01	0.00	0.12	0.87
Ergodic	0.253	0.269	0.235	0.243
United States	**Upper endpoint**			
Number	0.608	0.878	1.143	1
(118)	0.88	0.12	0.00	0.00
(114)	0.11	0.79	0.11	0.00
(115)	0.00	0.10	0.81	0.10
(115)	0.00	0.00	0.10	0.90
Ergodic	0.217	0.245	0.269	0.269

Table 8
Mobility Indices for the G5

Country	M_1	M_2	M_3	M_4
Pooled	0.163	0.121	0.163	0.426
UK	0.243	0.187	0.243	0.590
US	0.207	0.161	0.207	0.518
France	0.253	0.196	0.253	0.607
Germany	0.177	0.135	0.177	0.460
Japan	0.130	0.083	0.130	0.360

$M_1 = \frac{n - tr[P]}{n-1}$, $M_2 = \sum_k \pi_k \sum_l p_{kl} |k - l|$, $M_3 = \frac{n - \sum_m |\lambda_m|}{n-1}$, and $M_4 = 1 - |det(P)|$.

Table 9
Industrial Classification

Industry	ISIC Classification
1. Food, Drink and Tobacco	31
2. Textiles, Footwear and Leather	32
3. Wood, Cork and Furniture	33
4. Paper, Print and Publishing	34
5. Industrial Chemicals	351+352-3522
6. Pharmaceuticals	3522
7. Petroleum Refining	353+354
8. Rubber and Plastic Products	355+356
9. Non-metallic Minerals	36
10. Ferrous Metals	371
11. Non-ferrous Metals	372
12. Metal Products	381
13. Non-electrical Machinery	382-3825
14. Computers and Office Machinery	3825
15. Electrical Machinery	383-3832
16. Communication Equipment	3832
17. Shipbuilding	3841
18. Other Transport Equipment	3842+3844+3849
19. Motor Vehicles	3843
20. Aerospace	3845
21. Instruments	385
22. Other Manufacturing	39