Input-Output Based Measures of Interindustry Linkages Revisited - A Survey and Discussion*

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Abstract. Hirschman's concepts of forward and backward linkages have been embraced by input-output economists due to an apparent intimate tie between the interdependencies studied in input-output analysis and the causal relations expressed in Hirschmanian linkages. The present paper assesses the properties of different attempts to operationalise Hirschman's original concepts of backward and forward linkages starting with Rasmussen's dispersion indices and moving on to subsequent developments of the so-called Hirschman-Rasmussen linkage measures. The paper also explores the possibilities of developing the linkage concept further by introducing knowledge, and thus a more dynamic dimension, into a linkage specification. Empirical analyses applying Danish input-output data for the period 1966 to 1992 show a high degree of stability over time of the individual linkage measures, but the 'strength' of the key industries is very weak. This indicates that linkage measures are more applicable on incomplete input-output matrices with several empty cells than on advanced matrices for a strongly interrelated economic system.

Keywords: Input-output analysis, linkages, key-industries.

JEL classifications: C43, O11

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1. Introduction

Interindustry linkages have been studied since the late 1950's with the purpose of identifying ‘key industries’ that are central for economic development. The classical linkage literature, led by Hirschman’s (1958) Strategy of Economic Development, can be viewed as a first attempt to measure the ‘pattern’ of industrial interdependence. This literature was not particularly concerned with the relation between interdependence on the one side and technological development and technology diffusion on the other, which has gained much interest in the last decade (see e.g. Schnabl, 1994; Schnabl, 1995; Leoncini et al., 1996; Verspagen, 1997; Los and Verspagen, 2000). Rather it was solely focussed on demand and supply effects, searching for the industries that had the maximal effects on the total system through their demand and supply relations with other industries. This should be seen in the light of the prevailing economic conditions in the After-War Period. After World War II Keynesian demand-stimulating policies were dominating the agenda, thus making it a natural task for linkage studies to have as their main aim the identification of industries likely to have the most widespread demand stimulating effects. Linkages have recently gained a new interest in relation to studies of clusters of industries, see e.g. OECD (1999).

The present paper assesses the applicability of input-output based linkage measures in an analysis of interdependence in an advanced economic system. The theoretical starting point is Hirschman’s original linkage concept, followed by an assessment of different specifications of linkage measures. The overview of linkage measures does not include all types of input-output based linkage measures developed since the late 1950’s. Rather the paper focuses on linkage specifications within the narrow Hirschman-Rasmussen tradition.

The theoretical discussion is supported by an assessment of the empirical strengths and weaknesses of the different measures based on illustrations using Danish input-output data for the years 1966, 1979 and 1992.

Section 2 below presents Hirschman's linkage concept and discusses different attempts to measure Hirschman-linkages, taking Rasmussen's (1956/'57) indices of dispersion as the point of departure, but also introducing attempts to refine Rasmussen's indices. In Section 3 an empirical comparison of the different measures is carried out applying Danish input-output data as a basis for a discussion of the qualities of the different measures. The last part of this section is devoted to an attempt to include technology in the traditional measures. Section 4 applies the different measures in identifying key sectors in the Danish economy. The paper ends up with a discussion of the value of the linkage measures in analysing interdependence in an advanced economic system (Section 5).

2. Introducing the classical linkage concept

Backward and forward linkages were first presented by Hirschman (1958). Hirschman was primarily a development economist with a particular interest in Latin American countries. The Strategy of Economic Development (1958), which introduced the backward and forward linkage concepts, was thus founded on experiences gained as an official advisor and private consultant in Columbia in the first half of the 1950's (Hirschman, 1986a). But the economic ideas developed in Strategy of Economic Development turned out to have a general applicability.

The linkage concept is generalised to the observation that ongoing activities 'induce' agents to take up new activities. This effect expresses a linkage between the ongoing and the new activity (Hirschman, 1977, p. 80). Backward linkage effects are related to derived demand, i.e. the provision of input for a given activity. Forward linkage effects are related to output utilisation, i.e. the outputs from a given activity will induce attempts to use this output as inputs in some new activities (Hirschman, 1958, p. 100).

The total linkage effect for an industry *i* is defined as $TL=\Sigma x_i p_{ij}$, with x_i being the net outputs of industry *i*, and p_{ij} being the probability that each of the industries *j* will be set up as a consequence of the establishment of industry *i*.

For backward linkages the probability can be interpreted as the ratio of annual inputs required from industry *i*, denoted *y*, over the minimum economic size, in terms of annual productive capacity, of firms that would produce these outputs, *z* (i.e. $p=y/z$) (Hirschman, 1958, p. 101).

For forward linkages the probability is not easily defined, since the size of the market for the industries that might be established as the consequence of forward linkages does not depend on their suppliers. The probability is related to the importance of the products of industry *i* as inputs into the production of the output of the 'to-be-linked' industry. If these inputs are a very small fraction of the industry's eventual output, then their domestic availability is not likely to be an important factor in calling forth that industry.

2.1 Attempting to measure linkages

The Rasmussen dispersion indices, which were presented in the Danish economist P. Nørregaard Rasmussen's 1956 doctoral thesis Studies in Inter-Sectoral Relations[1], have been widely used as measures of Hirschman-linkages, despite the fact that Rasmussen's thesis was published before Hirschman introduced his linkage concept in The Strategy of Economic Development in 1958. Actually Rasmussen's thesis was primarily concerned with the effects of price changes on inter-industry relations as expressed by 'terms of trade'. But it is for the development of the index of the 'power of dispersion' of an industry as a means for identifying key industries, that Rasmussen has gained his fame. The index describes the relative extent to which an increase in final demand for the products of a given industry is dispersed throughout the total system of industries. The power of dispersion index is defined as

$$\sum_i U_{ij} = \frac{\frac{1}{n}\sum_i B_{ij}}{\frac{1}{n^2}\sum_{ij} B_{ij}} \qquad (1)$$

where n is the number of industries, and Σ_i $\boldsymbol{B}_{ij}$ is the sum of the column elements in the Leontief inverse matrix $\boldsymbol{B}=(\boldsymbol{I}-\boldsymbol{A})^{-1}$. It can be interpreted as the total increase in output from the entire system of industries needed to cope with an increase in the final demand for the products of industry j by one unit (Rasmussen, 1957, pp. 133-134). This index has been widely applied as a measure of backward linkages.

Rasmussen also presents a supplementary index describing the extent to which the system of industries draws upon a given industry - an index of the 'sensitivity of dispersion'. The sensitivity of dispersion index measures the increase in the production of industry i, driven by a unit increase in the final demand for all industries in the system. This index is defined as

$$\sum_j U_{ij} = \frac{\frac{1}{n}\sum_j B_{ij}}{\frac{1}{n^2}\sum_{ij} B_{ij}} \qquad (2)$$

where Σ_j $\boldsymbol{B}_{ij}$ is the sum of the row elements, which is interpreted as the increase in output in industry i needed in order to cope with a unit increase in the final demand for the product of each industry. The sensitivity of dispersion index has been interpreted as a measure of forward

[1] The version referred to in the following is the 2nd edition from 1957.

linkages.

An industry with a high power of dispersion (and a relatively small value of a standard deviation index, indicating that the industry draws evenly on the total system of industries) has the features of a 'key industry', since it will hand over a relatively large share of the increase of final demand for its products to the system of industries in general.

The interdependence measured through Rasmussen's indices is restricted to demand pull and supply push effects of changes in final demand. The indices are an expression of the way that input and output relations diffuse demand changes for the final products of a given industry j to other industries in the economic system, as the amount of inputs they provide to the directly affected industry j are dependent on the final demand for the products produced by industry j. Thus what is studied is the systemic character of an economy: no unit - firm or industry - exists in isolation from the other units in the system.

The definition of a linkage effect is closely related to the discussion of how an input-output system emerges. This can be illustrated by the way Hirschman presents Rasmussen's index of 'power of dispersion' as a measure of backward linkages based on a mental experiment, assuming for every industry in turn that the country's development started with just that industry, so that all the industry's sales to and purchases from other domestic industries are imagined to have developed as a sequel to the foundation of the industry in question (Hirschman, 1958, p. 105). Thus 'true' Hirschman-linkages are only at play in the process of development of an input-output system, where new industries emerge as a result of the linkage effects. The sequential development of an input-output system presented by Hirschman has - at least theoretically - some radically different implications as opposed to perceptions of the input-output system as either emerging out of a 'Big Bang' or alternatively as having always existed (which is the way the system is often treated by statisticians). A Hirschmanian system is in theory always developing as long as the effects are at play, and thus this is a dynamic system, which is continuously evolving. The existing industries provide the incentives and driving forces for the development/expansion of the system through their activities, or rather through the input demands as well as output production stemming from these activities. This implies that economic systems with a high degree of interrelatedness and strong causal linkage effects are more dynamic than systems with few causal linkages due to few incentive-driving activities in the existing industries. 'Authentic' Hirschman-linkages could in fact be perceived as induced innovations in term of 'new activities' (Schumpeter 1934) emerging as the consequence of the demand and supply effects of ongoing activities.

Due to the causal effect that influences, or rather creates, the set-up of an economic (input-output) system, linkages and interdependence cannot be used interchangeably in a Hirschman setting. The industry which shows the highest degree of interdependence could very well have been set up last, thus providing that maximum interdependence is quite compatible with complete absence of active (causal) linkage effects (Hirschman, 1958, p. 105). The way that the linkage concept is most often used in input-output analysis is interchangeable with interdependence though, but that is basically due to a misuse of Hirschman's original concept:

> *input-output analysis is by nature synchronic, where as linkage effects need time to unfold. [....] This basic difference has bedevilled various ingenious attempts at comprehensive, cross-section measurement of linkage effects and thereby "testing the linkage hypothesis". The more illuminating uses of the concept are perhaps to be found in a number of historically oriented studies which paid close attention to the sequence of development in individual countries* (Hirschman, 1977, pp. 70-71).

Hirschman suspects that the reason for the success of the linkage concept in particular in development economics is to be found in the apparent intimate tie with input-output analysis, which is seen as a representative of the technical corpus of economic knowledge. But Hirschman claims that even though linkages seem easy to make operational, this draws on a misconception of the true character of linkages (Hirschman, 1977, p. 70).

One element that illustrates this is the fact that backward and forward linkages are not automatic. It is thus not just the relation between the market size and the economic size of a plant (i.e. the ratio *y/z*) that will trigger the private or public entrepreneurship needed to take up the opportunities for linkage investments. Variables such as technological 'strangeness' or 'alienness' of the new economic activities in relation to the ongoing ones, as well as obstacles in the form of the need of large amounts of capital due to scale requirements and the lack of marketing access and knowledge are also at work (Hirschman, 1977, p. 77-78). These factors are somewhat parallel to the concepts of 'absorptive capacity' (Cohen and Levinthal, 1990) or 'technological relevance' (Fikkert, 1997) in the spillover literature: a certain degree of technological closeness is necessary for the linkage to have an actual effect.

The elaborations on the linkage concept discussed above clearly illustrate that the linkages that Hirschman had in mind are much more complex than what can be captured in a simple input-output index. But most of the attempts that have been made to make the linkage concept more operational have developed Rasmussen's dispersion indices without being truly capable of capturing the causality and probability incorporated in Hirschman's linkage concept. And while an input-output table cannot reveal which additional industrial branches are likely to be created in the wake of industrial investment in a given product line in a country setting out to industrialise, Hirschman does porpose that once a country has a fairly broad industrial base, where the expansion of a given industry leads primarily to the expansion of existing industries rather than the creation of new industries, then the measurement of linkage effects on the basis of input-output tables becomes more meaningful (Hirschman, 1986b, pp. 58-59).

2.2 Refinements of the linkage measure

Jones (1976) presents a central problem of making linkages of the Hirschman type operational in an input-output setting in pointing to the fact that in an input-output framework sales of industry *A* to industry *B* are recorded as industry *A*'s forward linkages and industry *B*'s backward linkages. But only one of these linkages can be effective in a causal Hirschman sense. Each industry's backward linkage is equivalent to a weighted sum of the forward linkages of its supplier industries, while each forward linkage is a weighted sum of the user's backward linkages (Jones, 1976, p. 329). As a consequence of this, for an economy as a whole the backward linkages equal the forward linkages (both weighted by the value of output), implicating that at the system level the total linkages are precisely the double of the maximum causal ('Hirschmanian') potential. For an industry though, where upstream and downstream linkages are expected to differ, the total linkages represent the maximum potential causal linkages.

The relation between input-output dependencies and pure Hirschman-linkages is summarised by Jones in the following statements:

- Interdependence is a necessary, but not sufficient, condition for linkage effects. High interdependence thus suggests potential linkages which could be further examined for causality, e.g. through case studies;
- Even when a linkage is inoperative in the causal sense, it may still have economic importance (Jones, 1976, p. 324).

Interdependence in an input-output framework can only be identified with linkages if the linkage concept is broadened to include ‘permissive and inoperative linkages’, i.e. sectoral interdependencies which are not ‘crucial’ in the sense that one industry has induced the existence of the other, as well as ‘true’ causal Hirschman-linkages (Jones, 1976, p. 325).

Jones also questions the use of Rasmussen’s index of sensitivity of dispersion as a measure of forward linkages, arguing that there is not much economic sense in exploring what happens to an industry if all industries, no matter their size, are to expand their output by an identical unit increase. Jones finds such an identical unit-increase an unlikely situation, and instead proposes to utilise the output inverse matrix in the calculation of the index. The output inverse matrix is calculated from output coefficients (x_{ij}/X_i), and contains elements expressing the increase in output of an industry *j* required to utilise the increased output brought about by a unit of primary input into an industry *i*. The matrices of output coefficients and input coefficients share the same diagonal since $X_i = X'_j$.

Jones does not describe how to measure Hirschman-linkages, rather he is refining Rasmussen’s indices, since ‘pure’ Hirschman-linkages, as discussed above, cannot be measured by the use of coefficient matrices alone. At most it can be argued that the Rasmussen-type indices are proxies of Hirschman-linkages (as suggested by Hirschman himself), disregarding the qualitative factors that also play an important role in the establishment of causal linkages.

An attempt to make up for some of the deficiencies of the linkage measures based on coefficient matrices is presented in Cuello et al. (1992), who incorporate information from outside the Leontief inverse matrix in order to obtain a more accurate measure of the economy-wide importance of key industries. Cuello et al. use the original Rasmussen definition as the starting point in calculating both types of indices, i.e. also in the case of the forward linkage measure is the Leontief inverse matrix based on input coefficients used.

Cuello et al. reformulate the traditional linkage measures by including a vector of parameters which is used in weighting the coefficients in the Leontief inverse matrix. Two different vectors are used in the analysis: the relative importance of final demand

$$\alpha_i = y_i \big/ \sum y_i \qquad (3)$$

and the relative importance of total sectoral output

$$\beta_i = \frac{\sum_j (x_{ij} + y_{ij})}{\sum_{ij} (x_{ij} + y_{ij})} \qquad (4)$$

The backward (U_{wj}) and forward (U_{wi}) linkages are now calculated as:

$$U_{wj} = \frac{\frac{1}{n}\sum_i w_i b_{ij}}{\frac{1}{n^2}\sum_{ij} w_i b_{ij}} \qquad (5)$$

$$U_{wi} = \frac{\frac{1}{n}\sum_j w_j b_{ij}}{\frac{1}{n^2}\sum_{ij} w_j b_{ij}} \qquad (6)$$

with w being the chosen weight (either α or β) and b_{ij} being the elements of the Leontief inverse (**B**).

The purpose of the present paper is not to find a more appropriate measure of true Hirschman-linkages in an input-output framework since, as pointed out by Hirschman himself, other more qualitative methods are called for to fulfil this task. Rather the aim is to assess the virtues and shortcomings of different linkage measures, which share the common feature that they all relate to Hirschman's linkage concepts. The above discussion has revealed that whereas the original Rasmussen specification of a power of dispersion index does contain valuable information about the economic relations between industries in relation how an industry draws on supplier industries (backward linkages), the value of the sensitivity of dispersion index as an expression of forward linkages to producers is more doubtful. The measure of linkages to users can be improved considerably by using the output-inverse matrix in stead of the Leontief-inverse matrix, which makes more sense when calculating relations to suppliers. The output-inverse relates the index to increases in output due to input to the analysed industry, rather than relating the output of the analysed industry to a unit-increase in output in all related industries. Jones' modification of the forward linkage measure thus appears to be more in line with Hirschman's original idea behind a forward linkage: a linkage related to the output utilisation. Jones' specification also provides more (policy) relevant information since it expresses the increase in output of an industry *j* required to utilise the increased output brought about by an initial unit of primary input into an industry *i.*

Cuello et al.'s suggestion of introducing weights indicating the sectors' economic size into the specifications also appear to increase the policy relevance compared to the original Rasmussen indices. However, Cuello et al. use the Leontief-inverse in calculating forward linkages, rather than the output-inverse, and the measure could thus be improved further by drawing on the lessons from Jones (1976).

Drawing on the discussion of the theoretical features of the different types of linkage specifications within the Hirschman-Rasmussen tradition, the next section is devoted to an empirical comparison and assessment of the different measures, applying Danish input-output data for the years 1966, 1979 and 1992.

3. An empirical comparison of linkage measures

This section will compare the different measures presented in Section 2 from an empirical perspective. The data applied are Danish input-output matrices for the years 1966, 1979 and 1992 supplied by Statistics Denmark. The data are classified according to a 117-industry classification based on the United Nations' ISIC-1968 classification standard. The availability of input-output tables as far back as the mid-1960's allows for an analysis of the stability of the linkage measures. Danish input-output data are also available in a 130-industry aggregation based on the United Nations' System of National Accounts 1993 (SNA93). This classification is used from 1993 an onwards, but data for the years 1966-1992 have been reclassified according to the SNA93. The present analysis applies the original matrices only. The matrices used for calculating the linkages are domestic intermediate deliverances and total domestic production. Matrices of final demand are used in calculating the α- and β- weights. All matrices are in current prices.

3.1 The stability of linkage indices over time

Table 1 shows the correlation between the individual linkages over time, as well as the correlation between the different linkage specifications. The linkage specifications compared in Table 1 are Rasmussen's indices of power of dispersion (backward linkages) and sensitivity of dispersion (forward linkages); Jones' specification of forward linkages applying the output inverse in stead of the Leontief-inverse coefficient matrix; as well as Cuello et al.'s specification of α- and β-weighted linkage measures. The Cuello forward linkages are calculated with the output inverse matrix in stead of the traditional Leontief-inverse, and thus differ from the original specification proposed by Cuello et al. (1992).

Table 1 illustrates that the linkage indices are quite stable even over considerable time periods (illustrated in the dark grey cells). The correlation between the Rasmussen backward linkages in 1966 and 1979 is 0.90, while it is 0.83 between 1979 and 1992. Between 1966 and 1992 the correlation is 0.70. A similar pattern is found for the Cuello-α and β-backward linkages, in fact the correlations between 1979 and 1992 are even stronger for these two types of linkages.

TABLE 1 APPROXIMATELY HERE

The forward linkages are as stable over time as the backward linkages, with correlations between 1966 and 1992 varying between 0.62 for Jones' and the α-weighted linkages to 0.87 for Rasmussen's forward linkages.

Even though it is a well-known fact that input-output structures are quite stable over time, the above results are remarkably strong, considering the changes which the Danish economy has undergone during the 26-year period covered by the tables. This could indicate that the linkage measures are not very suitable for analyses over time, at least in advanced countries with a developed inter-industrial structure. Furthermore, the identification of new key industries is limited by the prevailing industry classification principle.

3.2 Correlation between different linkage measures - does the specification make a difference?

As described above the different linkage specifications dealt with here share the common feature of being very stable over time. But apart from that the specifications generally lead to quite different results. Looking first at the backward linkages, both Cuello et al.-specifications are negatively correlated with Rasmussen's power of dispersion index. The choice of specification between Rasmussen's and Cuello et al.'s method does thus make a considerable difference. But the difference between Cuello et al.'s α- and β-specifications of backward linkages is moderate although decreasing over time, with correlations of 0.88 in 1966, 0.64 in 1979 and 0.52 in 1992.

The choice of backward linkage measure depends on the purpose of the analysis. Rasmussen's index does not take the size of industry into consideration in calculating the linkage effects, i.e. this is a 'pure' measure of the extent of interrelatedness of industries, distinguishing between industries on the basis of the size of multiplier alone. Thus this specification is of value in an analysis of the extent to which industries draw more, respectively less, than average on the total system of industries. But when it comes to the application of the concept of key industries for policy[2] purposes the inclusion of a measure of the size of the industry becomes relevant, which leads to the application of one of Cuello et al.'s specifications. The α-weight seems most appropriate since final demand is more easily manipulated through policy measures than total production.

Turning to the forward linkages it is primarily Jones' specification that stands out by being most weakly correlated with the other forward linkage specifications. In particular the correlation with the α- and β-weighted Cuello et al. specifications is weak, in case of the α-specification the correlation is in fact negative. This is despite the Cuello et al. specification being altered compared to the original specification by applying the output inverse coefficient matrix, just like it is the case in Jones' specification. But a further examination of the correlation matrix in Table 1 reveals that the Cuello et al. forward and backward linkages are perfectly correlated. This finding is due to the dominance of the weights relative to the pure linkage element of the specification. This explanation will be elaborated further in Section 4.1.

Jones' forward linkages are also rather weakly correlated with Rasmussen's specification of forward linkages, and further the correlation between the two measures decreases over time, from 0.30 in 1966, to 0.21 in 1979 and 0.16 in 1992 (the correlation coefficient for 1992 is not significant at the 5% level).

Rasmussen's forward linkage measure is positively and significantly correlated with both Cuello et al.-specifications, but the correlation between Rasmussen and the β-specification is

[2] 'Policy' is primarily used in the sense 'Keynesian policy', as the linkage measure was originally developed from the perspective of Keynesian policy thinking (cf. the introduction to the paper).

much higher (0.74, 0.92 and 0.93 respectively for the three years) than between Rasmussen and the α-specification. Thus the use of total sectoral output as a weight does not alter the forward linkage measure much compared to the 'pure' Rasmussen specification. An explanation of this high correlation could be that the industries which are most influenced by increases in final demand are generally the industries with the largest total output because of large intermediate deliverances.

Summing up the choice between different linkages specification does in most cases make a considerable difference, both with regards to forward and backward linkages. The comparison between different linkage specifications however reveals an important downside of applying one type of linkage specification, which otherwise appears very appealing from a policy perspective: in the case of the Cuello et al. linkage specification there is a risk of the weights overshadowing the value of the linkage effect completely. Thus the measures proposed by Cuello et al. risk being a ranking of industries according to size measured in relation to production for final demand or total output without really being able to take the interconnectedness, which is the core of the linkage concept, into account.

3.3 Introducing knowledge into linkage measures

Cuello et al.'s approach can easily be adapted to introduce other types of weights into linkage measures. Based on the assumption that linkages that involve knowledge intensive industries are likely to be more dynamic than 'traditional' linkages of the type discussed above, knowledge is introduced as a weight into a Cuello et al. type linkage measure in the following by replacing the α- and β-weights by the knowledge weight, γ, based on formal qualifications:

$$\gamma_i = \frac{TE_i}{E_i} \qquad (7)$$

TE_i expresses the number of employees with a degree in technical or natural sciences within each industry, and E_i expresses the total number of employees within each industry, i.e. γ is a measure of the relative number of technical employees within a given industry.

Education data are only available from 1980 an onwards, i.e. 1966 is left out of the analysis, and the input-output data for 1979 are combined with education data for 1980. Just like the input-output data, the education data are supplied by Statistics Denmark. The education data are organised in matrices where employees are classified according to 77 different education categories and 117 industries of employment. Four education categories have been selected to represent technical and natural science employees: medium-length higher education in natural sciences; medium-length higher education in engineering; long cycle higher education in natural sciences; and long cycle higher education in engineering.

Key industries identified through applying the knowledge linkage measure are industries that have above average linkages and/or a high knowledge level. This implies that these industries can be perceived as key (knowledge intensive) user industries through the combination of the extent of their demand as well as through their knowledge level.

Table 2 shows that the knowledge-weighted measures are only weakly correlated with the other linkage specifications. Like it was the case with the α- and β- weighted measures, the γ-weighted backward and forward linkages are perfectly correlated, i.e. the weakness detected in the previous section with the weight totally dominating the index remains. The knowledge weighted indices for 1979 are significantly correlated with the Rasmussen forward linkages for both 1979 and 1992. However, the correlation is only 0.21 and 0.22 respectively for the two years. The knowledge weighted linkage specification shows and even higher stability over time than the other linkage measures, as the correlation between 1979 and 1992 is 0.99. This indicates that the knowledge structure of an industry in terms of formal employee qualifications is very rigid.

TABLE 2 APPROXIMATELY HERE

Whether the knowledge weight is more useful than the other specifications of the linkage measure depends on the purpose of the analysis. If the intent is to analyse the importance of technological inter-industry linkages then the knowledge weight can be a useful modification of Cuello et al.'s specification, although the problem with the dominance of the weight over the linkage measure remains. Below the values of the linkage measures will be discussed in further detail.

4. Key industries in Denmark

Whereas the above sub-sections have compared the features of the different linkage measures, the present section will look into which industries are actually identified as key industries applying the different measures. The complete list of key industries in Denmark according to the different linkage specifications is shown in appendix A.

When Rasmussen's linkage measures are applied, key backward linked industries are mainly found in traditional manufacturing industries, i.e. various food processing industries, textiles and footwear, printing, bookbinding and publishing, some chemicals (specific industries varies between years), iron steel and non-ferrous metals, electrical home appliances, accumulators and batteries, bicycles, and water works. In 1979 services to water transport is also a key industry, but otherwise no service industries are identified as key industries applying Rasmussen's specification of backward linkages.

Applying Cuello et al.'s α- and β-weighted specifications of backward linkages, food-processing industries are also identified as key industries, but to a lesser extent than is the case with Rasmussen's specification. Other key industries identified with both the α- and β-specification are agriculture, construction, wholesale trade, refrigerators and accessories as well as financial institutions and government services. Applying the α-weight, retail trade, dwelling as well as different transport-industries, i.e. shipbuilding and repair, railroad and auto equipment and water transport, are also identified as key industries. More key industries are identified with the β- than the α-weight. These industries range from fishing, over paper and printing, petroleum refineries, other fabricated products, electrical supplies, electrical light and power, to a broad group of service industries: other land transport, air services, services allied to transport, repair of motor cycles, communication, and business services. The β-weight thus contributes with an increased focus on the service sector.

The final specification of backward linkages is the knowledge-weighted measure introduced in the previous section. This specification distinguishes itself from the other specifications by identifying relatively few traditional manufacturing industries as key industries. There are a few exceptions, such as soap and cosmetics, fertilisers (1992), non-metallic mineral products (1979), metal cans and containers and manufacture of jewellery etc., but except from these industries, the key industries within manufacturing are all related to machinery and equipment. These industries include agricultural machinery, repair of machinery, telecom equipment, electrical home appliances, shipbuilding and repair as well as railroad and auto equipment. The knowledge-weighted γ-specification also identifies a wide range of services industries as key industries: wholesale and retail trade, restaurants and hotels, other land transports, financial institutions, insurance, dwellings, business services (only 1992) and education (market services). The identification of wholesale and retail trade as well as restaurants and hotels as key industries applying the knowledge weighted linkage specification is somewhat surprising, but the result appears to be an effect of people with very different educational backgrounds working in these industries.

Comparing the results of the four different backward linkage specifications, the Rasmussen specification generally identifies (old) manufacturing industries, the α- and β-specifications identify key industries within all areas of the economic system, whereas the γ-specification is more oriented towards services as well as manufacturing industries producing machinery and equipment. The weighted specifications thus serve to illustrate the importance of the non-manufacturing section of the Danish economic system, in terms of production volume or knowledge level, as opposed to Rasmussen's backward linkage index, which illustrates the degree of interconnectedness in the manufacturing section of the system.

Moving to the forward linkages, only Rasmussen's and Jones' specifications are discussed here, as the α-, β- and γ-specifications generate practicaaly identical forward and backward linkages on the present data set. Rasmussen's forward linked industries cover a broad range, from agriculture and fishing, over different food processing industries, paper and printing, various chemicals, plastic products, iron and steel (excl. 1992), other fabricated products, repair of machinery, refrigerators and accessories, electrical supplies, toys and sporting goods and construction, to services. The services industries identified are wholesale trade, other land transports, services allied to transport, repair of motor vehicles, communication, business services, household services, and in 1992 also government services. Rasmussen's forward linked industries do thus coincide considerably with in particular the β-weighted Cuello specification, which is also illustrated in Table 1's correlation matrix above.

The final linkage specification is Jones' forward linkage. Except for services allied to transport, which is a key industry in 1966 and 1979, Jones' forward linkage specification is characterised by only identifying primary sectors and manufacturing as key industries. It is thus fishing, other mining, together with oil mills and different food processing, various textile-related industries, pulp, paper and printing, chemicals, glass, non-ferrous metal works, metal cans and containers, accumulators and batteries, which are identified as key industries by applying Jones' specification of forward linkages. Jones' forward linkages are thus much more concentrated around traditional manufacturing than Rasmussen's forward linkage specification. However, from a policy perspective the forward linked industries are not as interesting as the backward linked industries, which influence the rest of the system through the multiplier effect. Rather the forward linked industries are those industries that are most influenced by the backward linkages.

Summing up, this section has confirmed the findings from Section 3.2 that the applied linkage specification makes a considerable difference for the characterisation of an economic system applying linkage indices. The results of such an analysis should be however interpreted with caution and preferably only be applied in a broader context rather than as stand-alone indicators. The above discussion has not dealt with explicitly with the strength of the linkage measures in terms of their deviation from the neutral value 1 and how this affects the results of applying the specifications that include measures. This issue is the theme of the following subsection.

4.1. The strength of the linkage measures

As mentioned in Section 3.2 the reason for the α-, β- and γ-weighted measures being practically identical in the forward and backward specifications is to be found in the narrow ranges of the 'pure' measures which are the basis for calculating the weighted measures. Table 3 illustrates just how narrow the ranges of both the Rasmussen backward and forward linkages, as well as of the Jones forward linkages, are.

TABLE 3 APPROXIMATELY HERE

The primary reason for these very narrow ranges of the indices is - somewhat paradoxically - to be found in the quality of the input-output tables, as well as in the high degree of interrelatedness in the Danish economy, which implies that practically no cells in the input-output matrix are empty. The original indices calculated by Rasmussen were based on a Danish input-output matrix for the year 1947, which had 293 empty cells out of a total of 441 cells (i.e. a 21x21 matrix). In this case the power of dispersion (backward linkage) index ranged from 0.85 to 1.24. If only two decimals were to be applied in reporting the results of the calculations based on the 1966-1992 matrices, all index values would equal 1.

The linkage measures based on Cuello et al., i.e. the original α- and β-weighted measures, as well as the γ-weighted knowledge linkage, have a much wider range than the 'pure' linkage measures because of the influence of the weights. But several decimals have to be included to detect any differences between the weighted forward and backward linkages in the Danish economy. This is not a generally applicable result though, as mentioned above it is a consequence of the completeness of the input-output tables. Cuello et al., in their original calculations on Italian data, are thus able to get different results for forward and backward linkages.

Summing up on the above findings it appears that Rasmussen's and Jones' indices only really make sense as a tool for identifying key industries in the cases of incomplete input-output matrixes with several empty cells, while their use is very limited in cases with advanced matrices with no or very few empty cells. Even though the indices are stable over time, i.e. it is largely the same industries that are identified as key industries at different points of time, the weak power of key industries reduces the value of the results. These findings do not support Hirschman's proposition that input-output based linkages measures like the Rasmussen specifications are more meaningful estimations of linkage effects in developed economies than in developing economies, since in a country with a fairly broad industrial base, the expansion of a given industry will primarily lead to the expansion of existing industries rather than the creation of new industries. Rather it appears that the more developed the economy is, and thus the more complete the input-output tables are, the weaker are the fluctuations in the index values between industries, i.e. no individual industries can be identified as strong locomotives pulling the rest of the system through demand and supply relations alone.

The weak strength of the traditional measures could speak in favour of the weighted measures. These measures on the other hand face the problem that the weights tend to overshadow the linkage element, resulting in the indices primarily resulting in a ranking of the industries according to size or knowledge intensity.

5. Summary and conclusions

The paper has attempted to revive and bring forward the discussion of the use of input-output based linkages in the analysis of economic systems, taking a discussion of the linkage concept, both in its original theoretical form as presented by Hirschman, as well as in its empirical form as expressed by different input-output related measures, as the point of departure.

The empirical measures discussed are Rasmussen's power of dispersion (backward linkages) and sensitivity of dispersion (forward linkages) indices, Jones' forward linkage index applying the output coefficient matrix instead of the input coefficient matrix, and Cuello et al.'s backward and forward linkages introducing weights into the specification. The two weights used by Cuello et al. are an α- and a β-weight respectively. The α-weight is the relative importance of final demand while the β-weight is the importance of total sectoral output. Finally a new knowledge weight, γ, is introduced, applying employees' formal education as the knowledge indicator.

A Hirschman linkage effect is in its original formulation an effect of an ongoing activity, i.e. the ongoing activity invites operators to take up new activities, either through an output utilisation effect (forward linkage) or an input requirement effect (backward linkage). In the case of a developed country with a broad industrial base, the linkage effect is primarily an expansion of the linked activities rather than the creation of new activities, in this case expressed as industries. Thus in developed countries the input-output approach for identifying linkages seems more appropriate than in the case of an industrialising country where the purpose is to analyse the emergence of new industries. In developed countries the linkage effects could be reduced to demand stimulating (backward) linkages or production requirement (forward) linkages. Thus in this respect Rasmussen's power of dispersion index could be an appropriate measure of backward linkages. But Rasmussen's specification has the problem of leading to index values very close to unity for all industries in the case of a developed, quite interrelated economic system like the Danish. Thus Rasmussen's specification turns out to be more appropriate in the case of economic systems which are represented by input-output matrices with several blank cells expressing lack of interdependence, in order to lead to a clear-cut distinction between the 'key industries' and less linked industries. Thus, also respecting Hirschman's original linkage concept, keeping in mind that Hirschman has a strong focus of the policy perspective, it seems appropriate to follow Cuello et al. in changing the linkage specification in order to also take the size of the industry into account when calculating the indices for developed countries. A very small industry with an above average backward linkage index is hardly very interesting as a 'key industry' for the economic system thus making the combination of linkage effect and size an important development of the linkage measure.

Cuello et al.'s specification serves to illustrate the importance of the non-manufacturing section of the Danish economic system in terms of production volume, as opposed to

Rasmussen's backward linkage index, which illustrates the degree of interconnectedness in the manufacturing section of the system.

The introduction of weights makes the separation between forward and backward linkages impossible in the Danish case, since the weight plays a very large role in calculating the index. Also the forward linkage measure does not have the same value from a policy perspective as the backward linkage which has a straightforward interpretation as a demand stimulating industry. If a forward linkage measure is to be applied then Jones' specification is to be preferred relative to Rasmussen's sensitivity of dispersion index, as Jones' index expresses the increase in output of an industry required to utilise the increased output brought about by an initial unit of primary output into another industry with which the first industry is linked as a user. Rasmussen's sensitivity of dispersion index simply expresses the effect for a single industry of an increase in the expansion of output by all industries by an identical unit. This does not have much in common with a forward linkage as presented by Hirschman. This is why Cuello et al.'s specification has been altered in the present context to based on the output inverse matrix rather than applying the traditional Leontief inverse matrix.

The paper also suggests the introduction of a new weight to be applied in a Cuello et al. type specification of linkages: the knowledge indicator weight γ. The purpose of introducing this knowledge weight is to introduce a more dynamic dimension into the linkage specification, as knowledge is assumed to be a prerequisite for economic development. Thus if the linkage is to express a development potential, as was Hirschman's primary intent, this weight seems more appropriate than size related weights like the α- and β-weights originally introduced by Cuello et al. However, all the Cuello et al.-linkage specifications share the problem that the weights tend to overshadow the linkage effect, i.e. the new specifications are basically rankings according to size or knowledge intensity rather than linkages. Summing up, the paper has illustrated that linkage measures and their related key industries should be interpreted with caution, and linkages can hardly stand alone in analyses of the systemic features of developed economies. Especially when applied on highly developed and interrelated economic systems do linkages provide little information, as the development of such systems, according to the Danish results, does not depend on locomotive industries pulling the rest of the system through their demand and supply relations – rather industries appear to draw very evenly on the system. This speaks in favour of exploring the avenues further for combining the issue of interrelatedness with ‘dynamic’ characteristics of the linked industries.

Appendix A: Backward and forward linkages in Denmark, 1966, 1979 and 1992

Only industries that are identified as a key industry by at least one linkage specification are included in the tables. Knowledge linkages(γ) cannot be calculated for 1966.

	Ras. BL 66	Ras. BL 79	Ras. BL 92	α-BL 66	α-BL 79	α-BL 92	β-BL 66	β-BL 79	β-BL 92	γ-BL 79	γ-BL 92	Ras. FL 66	Ras. FL 79	Ras. FL 92	Jones 66	Jones 79	Jones 92	α-FL 66	α-FL 79	α-FL 92	β-FL 66	β-FL 79	β-FL 92	γ-FL 79	γ-FL 92
1 Agriculture				x	x	x	x	x	x			x	x	x				x	x	x	x	x	x		
3 Fur farming etc.			x			x														x					
5 Forestry, logging															x										
6 Fishing							x	x	x			x	x		x	x	x				x	x	x		
7 Extr. coal, oil, gas	x								x														x		
8 Other mining	x	x													x	x	x								
9 Slaught. of pigs and cattle				x	x		x	x				x	x					x	x		x	x			
10 Poultry killing etc.	x	x	x																						
11 Dairies				x			x	x				x	x					x			x	x			
12 Cheese, cond. milk	x					x														x					
13 Ice cream mfr.	x	x	x																						
14 Proc. of fruits and vegetables	x	x																							
15 Proc. of fish	x																								
16 Oil mills			x				x	x				x	x	x	x	x	x				x	x			
17 Margarine mfr.	x	x	x													x									
18 Fish meal mfr.	x	x	x																						
19 Grain mill prods.	x	x	x				x	x				x	x		x	x	x				x	x			
20 Bread factories	x	x	x																						
21 Cake factories	x	x																							

	Ras. BL 66	Ras. BL 79	Ras. BL 92	α-BL 66	α-BL 79	α-BL 92	β-BL 66	β-BL 79	β-BL 92	γ-BL 79	γ-BL 92	Ras. FL 66	Ras. FL 79	Ras. FL 92	Jones 66	Jones 79	Jones 92	α-FL 66	α-FL 79	α-FL 92	β-FL 66	β-FL 79	β-FL 92	γ-FL 79	γ-FL 92
23 Sugar factories, refineries	x	x			x			x	x			x		x	x	x	x		x			x	x		
25 Mfr. of food prods n.e.c.	x	x													x										
26 Mfr. of animal feeds	x	x	x									x			x	x	x								
27 Dist and blending spirits	x	x	x													x	x								
30 Spinning, weaving (text)							x	x				x			x						x	x			
31 Made-up textile goods	x														x										
33 Cordage, rope and twine	x	x	x													x									
34 Mfr. of wearing apparel				x														x							
35 Leather, leather prods.	x	x	x									x			x	x	x								
36 Mfr. of footwear	x	x	x																						
37 Wood prods excl. furniture						x	x		x											x	x		x		
38 Wooden furniture, etc.						x														x					
39 Pulp, paper, paperboard		x	x				x					x			x	x	x				x				
40 Paper containers, wallpaper							x	x	x			x	x	x	x	x	x				x	x	x		
41 Reprod and comp. Services	x	x											x		x	x	x								
42 Book printing							x	x	x			x	x	x	x	x	x				x	x	x		
43 Offset printing	x						x	x	x			x	x	x	x	x	x				x	x	x		
44 Other printing	x	x							x			x			x	x	x						x		
45 Bookbinding	x	x	x												x	x	x								
46 Newspapers							x	x				x	x			x					x	x			
47 Book and art publishing	x	x	x																						
48 Magazine publishing	x	x	x												x										

	Ras. BL 66	Ras. BL 79	Ras. BL 92	α-BL 66	α-BL 79	α-BL 92	β-BL 66	β-BL 79	β-BL 92	γ-BL 79	γ-BL 92	Ras. FL 66	Ras. FL 79	Ras. FL 92	Jones 66	Jones 79	Jones 92	α-FL 66	α-FL 79	α-FL 92	β-FL 66	β-FL 79	β-FL 92	γ-FL 79	γ-FL 92
49 Other publishing	x	x	x												x										
51 Fertilizers and pesticides			x								x														x
52 Basic plastic materials	x							x					x		x	x						x			
53 Paints and varnishes												x			x										
55 Soap and cosmetics		x								x	x													x	x
56 Chemical products n.e.c.	x	x			x										x	x	x		x						
57 Petroleum refineries						x	x	x	x			x	x		x					x	x	x	x		
58 Asphalt, roofing mat.		x																							
59 Tyre and tube industries	x	x	x												x		x								
60 Rubber products n.e.c.												x			x										
61 Plastic products n.e.c.								x	x			x	x	x	x	x						x	x		
62 Earthenware and pottery	x	x	x																						
63 Glass and glass products	x	x													x	x	x								
64 Structural clay products		x	x																						
65 Cement, lime, plaster															x	x									
66 Concrete prods & stone cut.																									
67 Non-metallic mineral products n.e.c.										x														x	
68 Iron and steel works	x														x										
69 Iron and steel casting	x	x	x												x										
70 Non-fer. metal works	x	x	x				x	x				x	x		x	x	x				x	x			
71 Non-fer. metal casting	x	x	x												x	x									
72 Mfr. of metal furniture	x	x																							

	Ras. BL 66	Ras. BL 79	Ras. BL 92	α-BL 66	α-BL 79	α-BL 92	β-BL 66	β-BL 79	β-BL 92	γ-BL 79	γ-BL 92	Ras. FL 66	Ras. FL 79	Ras. FL 92	Jones 66	Jones 79	Jones 92	α-FL 66	α-FL 79	α-FL 92	β-FL 66	β-FL 79	β-FL 92	γ-FL 79	γ-FL 92
73 Structural metal prods									x														x		
74 Metal cans, containers							x			x	x	x			x	x	x				x			x	x
75 Other fabricated prods					x		x	x	x			x	x	x					x		x	x	x		
76 Agricultural machinery						x				x	x									x				x	x
77 Industrial machinery						x														x					
78 Repair of machinery								x	x	x	x		x	x		x						x	x	x	x
79 Household machinery	x	x																							
80 Refrigerators, accessories				x	x	x	x	x	x			x	x	x				x	x	x	x	x	x		
81 Mfr. of telecom. equip.					x					x	x								x					x	x
82 Electrical home appl.	x	x	x							x	x													x	x
83 Accumulators, batteries	x	x	x											x	x	x	x								
84 Other electrical supplies							x	x	x			x	x								x	x	x		
85 Ship building and repair				x	x	x	x		x	x	x							x	x	x	x		x	x	x
86 Railroad, auto equip.				x	x	x				x	x							x	x	x				x	x
87 Cycles, mopeds, etc.	x	x	x																						
88 Prof. and measur. equip.					x	x													x	x					
89 Mfr. of jewellery, etc.		x	x							x	x													x	x
90 Toys,sporting goods,etc.						x														x					
91 Electric light and power							x	x	x			x	x	x	x						x	x	x		
92 Gas mfr. and distribution	x	x									x														x

	Ras. BL 66	Ras. BL 79	Ras. BL 92	α-BL 66	α-BL 79	α-BL 92	β-BL 66	β-BL 79	β-BL 92	γ-BL 79	γ-BL 92	Ras. FL 66	Ras. FL 79	Ras. FL 92	Jones 66	Jones 79	Jones 92	α-FL 66	α-FL 79	α-FL 92	β-FL 66	β-FL 79	β-FL 92	γ-FL 79	γ-FL 92
94 Water works and supply	x	x	x																						
95 Construction				x	x	x	x	x	x			x	x	x				x	x	x	x	x	x		
96 Wholesale trade				x	x	x	x	x	x	x	x	x	x	x				x	x	x	x	x	x	x	x
97 Retail trade				x	x	x			x	x	x							x	x	x			x	x	x
98 Restaurants and hotels								x		x	x											x		x	x
99 Railway and bus transportation								x														x			
100 Other land transports							x	x	x	x	x	x	x	x							x	x	x	x	x
101 Water transport				x	x	x						x						x	x	x					
102 Services to water transport		x																							
103 Air transport								x	x													x	x		
104 Services allied to transport							x	x	x			x	x	x	x	x					x	x	x		
105 Communication							x	x	x			x	x	x							x	x	x		
106 Financial institutions				x	x	x	x	x	x	x	x							x	x	x	x	x	x	x	x
107 Insurance										x	x													x	x
108 Dwellings				x	x	x				x	x							x	x	x				x	x
109 Business services						x	x	x	x		x	x	x	x						x	x	x	x		x
110 Education, market services										x	x													x	x
113 Repair of motor vehicles							x	x	x			x	x	x							x	x	x		
114 Household services								x	x				x	x								x	x		
117 Prod. of government services				x	x	x	x	x	x					x				x	x	x	x	x	x		

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Table 1: Pearson correlations between linkage measures for the years 1966, 1979 and 1992[#] (117-industry classification)

		Rasmussen BL			Cuello α BL			Cuello β BL			Rasmussen FL			Cuello α FL			Cuello β FL			Jones FL		
		1966	1979	1992	1966	1979	1992	1966	1979	1992	1966	1979	1992	1966	1979	1992	1966	1979	1992	1966	1979	1992
Rasmussen BL	1966	1.00a	0.90a	0.70a	-0.18	-0.27a	-0.26a	-0.28a	-0.33a	-0.30a	-0.29a	-0.27a	-0.20	-0.18	-0.26a	-0.26a	-0.28a	-0.33a	-0.30a	0.25b	0.26b	0.29a
	1979		1.00a	0.83a	-0.18	-0.28a	-0.27a	-0.29a	-0.37a	-0.34a	-0.29a	-0.29a	-0.23b	-0.18	-0.28a	-0.27a	-0.29a	-0.37a	-0.34a	0.20	0.25b	0.34a
	1992			1.00a	-0.17	-0.26a	-0.24b	-0.25b	-0.33	-0.33a	-0.23b	-0.24b	-0.20	-0.17	-0.26a	-0.24b	-0.25b	-0.33a	-0.33a	0.22b	0.30a	0.48a
Cuello α BL	1966				1.00a	0.78a	0.62a	0.88a	0.62a	0.50a	0.35a	0.31a	0.25b	1.00a	0.78a	0.62a	0.88a	0.62a	0.50a	-0.11	-0.07	-0.06
	1979					1.00a	0.94a	0.70a	0.64a	0.56a	0.35a	0.34a	0.32a	0.78a	1.00a	0.94a	0.70a	0.64a	0.56a	-0.16	-0.16	-0.12
	1992						1.00a	0.55a	0.54a	0.52a	0.26b	0.27a	0.28a	0.62a	0.94a	1.00a	0.55a	0.54a	0.52a	-0.18	-0.18b	-0.12
Cuello β BL	1966							1.00a	0.89a	0.77a	0.74a	0.70a	0.62a	0.88a	0.70a	0.55a	1.00a	0.89a	0.77a	0.06	0.06	0.03
	1979								1.00a	0.95a	0.88a	0.92a	0.87a	0.62a	0.64a	0.54a	0.89a	1.00a	0.95a	0.07	0.08	0.03
	1992									1.00a	0.83a	0.90a	0.93a	0.50a	0.56a	0.52a	0.77a	0.95a	1.00a	0.05	0.04	0.02
Rasmussen FL	1966										1.00a	0.95a	0.87a	0.35a	0.35a	0.26b	0.74a	0.88a	0.83a	0.30a	0.26a	0.18
	1979											1.00a	0.94a	0.31a	0.34a	0.27a	0.70a	0.92a	0.90a	0.19	0.21b	0.11
	1992												1.00a	0.25b	0.32a	0.28a	0.62a	0.87a	0.93a	0.14	0.14	0.16
Cuello α FL	1966													1.00a	0.78a	0.62a	0.88a	0.62a	0.50a	-0.11	-0.07	-0.06
	1979														1.00a	0.94a	0.70a	0.64a	0.56a	-0.16	-0.16	-0.12
	1992															1.00a	0.55a	0.54a	0.52a	-0.18	-0.18	-0.12
Cuello β FL	1966																1.00a	0.89a	0.77a	0.06	0.06	0.03
	1979																	1.00a	0.95a	0.07	0.08	0.02
	1992																		1.00a	0.05	0.04	0.02
Jones FL	1966																			1.00a	0.86a	0.62a
	1979																				1.00a	0.65a
	1992																					1.00a

[a] Correlation is significant at the 1 percent level (two-sided test)
[b] Correlation is significant at the 5 percent level (two-sided test)

Table 2: Pearson correlations between knowledge weighted linkage measures and 'traditional' linkage measures (117-industry classification)

		Knowledge BL (γ)		Knowledge FL (γ)	
		1979	1992	1979	1992
Rasmussen BL	1979	-0.10	-0.08	-0.10	-0.08
	1992	-0.10	-0.08	-0.10	-0.08
Cuello α BL	1979	0.08	0.07	0.08	0.07
	1992	0.09	0.08	0.09	0.08
Cuello β BL	1979	0.17	0.13	0.17	0.13
	1992	0.19	0.14	0.19	0.14
Knowledge BL (γ)	1979	1.00a	0.99a	1.00a	0.99a
	1992		1.00a		1.00a
Rasmussen FL	1979	0.21b	0.15	0.21b	0.15
	1992	0.22b	0.16	0.22b	0.16
Cuello α FL	1979	0.08	0.07	0.07	0.07
	1992	0.09	0.08	0.09	0.08
Cuello β FL	1979	0.17	0.13	0.17	0.13
	1992	0.19	0.14	0.19	0.14
Jones FL	1979	-0.14	-0.13	-0.14	-0.13
	1992	-0.07	-0.06	-0.07	-0.06
Knowledge FL (γ)	1979			1.00a	0.99a
	1992				1.00a

[a] Correlation is significant at the 1 percent level (two-sided test)
[b] Correlation is significant at the 5 percent level (two-sided test)

Table 3: Minimum and maximum values of the different linkage types

		Minimum	Maximum	Standard deviation
Rasmussen BL	1966	0.9999989	1.0000042	0.0000011
	1979	0.9999997	1.0000009	0.0000003
	1992	0.9999998	1.0000007	0.0000002
Cuello α BL	1966	-0.5580640	51.8445790	5.04101
	1979	-1.4041910	19.1028550	3.17238
	1992	-6.2461080	19.5913640	3.33249
Cuello β BL	1966	0.0080498	20.4505540	2.19629
	1979	-0.0377110	12.5458290	1.79981
	1992	-0.0270240	13.1905850	1.93266
γ BL	1979	0.00000004	32.4643000	3.55769
	1992	0.0066173	36.5074810	3.70203
Rasmussen FL	1966	0.9999989	1.0000133	0.0000018
	1979	0.9999997	1.0000044	0.0000006
	1992	0.9999998	1.0000026	0.0000003
Cuello α FL	1966	-0.5581470	51.8448040	5.04104
	1979	-1.4041920	19.1028730	3.17238
	1992	-6.2461110	19.5913720	3.33249
Cuello β FL	1966	0.0080475	20.4506310	2.19630
	1979	-0.0377120	12.5458440	1.79981
	1992	-0.0270260	13.1905950	1.93267
Jones FL	1966	0.9999995	1.0000022	0.0000005
	1979	0.9999999	1.0000005	0.0000001
	1992	0.9999999	1.0000005	0.0000001
γ FL	1979	0.0000000	32.4643200	3.55770
	1992	0.0066173	36.5074309	3.70203