RICHARD STONE'S CONTRIBUTIONS TO INPUT-OUTPUT ANALYSIS

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Abstract

This paper aims to highlight Richard Stone's contribution to input-output analysis.

The relevance, originality and effectiveness of Richard Stone's contribution to the development of input-output analysis is closely tied to the international and national positions he held during his fruitful professional life: internationally, by contributing to the United Nations programme for developing a standard system of national accounts; and nationally, through being Director of the Department of Applied Economics and of the Programme for Growth at the University of Cambridge.

Richard Stone's contributions to input-output analysis - as well as to economics in general - originate from his profound belief that economic analysis needs to be firmly based on quantitative foundations in order to make theory relate effectively to empirical data. 'My interest in economics' says Stone 'was from the beginning in its applications. I thought that the economics I was taught was insufficiently quantitative and that theory and facts were too widely separated. … The real difficulty is to combine the two so that theory can be used to interpret facts and facts can show what has to be interpreted.' [R. Stone and M. Hashem Pesaran, The ET interview: Professor Sir Richard Stone, *Econometric Theory*, Vol. 7, No. 1, 1991, pp. 89]. This methodological approach characterized all Stone's academic research and professional career.

The paper provides an overview of both the major theoretical and empirical contributions of Richard Stone to input-output analysis, as well as of less known essays.

Among the former we may mention Stone's studies on the integration of input-output tables within the Social National Accounts (SNA), his researches on the Social Accounting Matrices (SAM), the adjustment and updating of the technical coefficients (RAS method). Among the latter may be mentioned the attempt to apply the methods of input-output at the micro level.

In his later years Richard Stone became more interested in topics related to the social aspects of economic life, such as demography, health, education, and environment. In these fields also, his favourite approach was the application of input-output analysis.

For the convenience of researchers, a complete list of Richard Stone's works pertaining to input-output analysis is attached to the present paper

Keywords: Richard Stone, input-output analysis, econometrics history,

1. INTRODUCTION

Sir Richard Stone (London, 1913 - Cambridge, 1991), Nobel laureate in 1984, is probably one of the most influential economists of the 20th century, who helped to shape the rapid 'revolution' of economics after the end of World War II (Deaton, 1993). His academic interests were driven by his passionate concern about society as a whole, and by the desire, as a man of science, to contribute to its amelioration. Stone's extensive researches and publications range from national accounting to the modelling of consumer behaviour, covering a great number of topics and making extensive use of the available mathematical tools for applied research.

Stone's motivation has roots in his deep curiosity about the functioning of society, especially, but not exclusively, relating to its economic aspects. After attending Westminster School, he entered Gonville & Caius College, Cambridge, in 1932, achieving 1st class honours in the Law Tripos, part 1, in 1933. Not being interested in this subject, chosen to please his father, he changed to Economics. In his autobiography for The Nobel Prizes 1984 [192] [1], Stone explained his switch from law to economics in these terms: 'At that time the world was in the depth of the great depression and my motive for wanting to change subject was the belief, bred of youthful ignorance and optimism, that if only economics were better understood, the world would be a better place'.

The College had no teaching fellow in the subject but Stone was supervised by Richard Kahn and Gerald Shove of King's College, and J. W. F. Rowe of Pembroke College. He achieved a First in Economics Part II in 1935, probably influencing the College, as Pasinetti suggests, in its decision to appoint its first teaching Fellow in

[1] Quotations within parentheses report as usual name and year of publication of the referenced work. Quotations within brackets refer to Stone's works classification, provided by Stone himself and published in R. Stone and M. Hashem Pesaran, The ET interview: Professor Sir Richard Stone, *Econometric Theory*, Vol. 7, No. 1, 1991, pp. 85-123.

Economics, John Hicks, who joined the College in October 1935. But by then Stone had gone down (Pasinetti, 1992, p.113)[2].

From his earliest publications Stone's interest in applications of theory is apparent. Most of his work incorporates a variety of tools and methods and shows a steady determination to reconcile theory to empirical evidence.

It should be emphasized that Stone did not give specific attention to the development of input-output techniques. Indeed, in an interview with Pesaran, he observed: 'I have always thought that input-output techniques were an integral part of econometrics.' (Stone and Pesaran, 1991).

Therefore, Richard Stone's contributions to input-output analysis went hand-in-hand with his more general contribution to economics. Whenever he felt that a particular improvement to analytical techniques was required, Stone did not hesitate to try to develop new tools, more suited to his purposes.

At the time Stone started his researches, input-output analysis was a common technique among economists worldwide. Most of the input-output applications were based on the original model by Leontief and were especially used to analyse macro-economic flows within and between countries. The interest in input-output analysis was essentially driven by a practical purpose, in particular the increase in understanding of how the different elements of the economic system are interrelated.

2. INPUT-OUTPUT ANALYSIS AND THE DEVELOPING OF THE SNA

Input-output analysis became important to him when he was working on the development of the new Social National Accounts (SNA henceforth). This work began at the outbreak of war, when Stone was called to the Ministry of Economic Warfare, initially being asked to work on shipping statistics. In 1940 he was transferred to the Central Economic Information Service of the War Cabinet Offices at the request of

[2] More details on the life and work of Richard Stone can be found in: A. Deaton, 1987 and 1993; R. M. Goodwin, 1995; G. C. Harcourt, 1995; L. Johansen, 1985; L. L. Pasinetti, 1992; M. Hashem Pesaran and G. C. Harcourt, 2000; G. Pyatt, 1992; G. Stone, 1995; R. Stone and M. Hashem Pesaran, 1991; R. Stone, 1997; The Scandinavian Journal of Economics, 1985.

James Meade who was working on the financial aspects of the War and who needed someone to work alongside him on statistical computation. ‘That was the beginning not only of the British national accounts but also of a friendship that is still going strong’, said Stone in 1991 (Stone and Pesaran, 1991, p. 92).

In 1939 Richard Stone had married Winifred Jenkins, she too a young economist, but the marriage was dissolved in 1940 and in 1941 he married Feodora Leontinoff, who was Secretary of the National Institute of Economic and Social Research, where he had started to run a project on the interwar national accounts.

Pasinetti [1992 p. 114] comments that ‘these events were the prelude to the development of national accounting as a policy tool, not only for Britain, but for the world’.

After the end of the war, when his pioneering work had already provided the basis for the SNA, Stone realised a possible innovation to the whole framework of national accounting by making an industrial breakdown of the business enterprise sector, in such a way as to enable the construction of input-output tables similar to those obtained by Leontief. He addressed the issue at the end of a paper presented at the 26th Session of the International Statistical Institute, Berne, September 1949 [041], dedicated to sampling methods in national and social accounting.

Straight after that, in collaboration with J. E. G. Utting, Stone addressed the issue more specifically in an article, *The relationship between input-output analysis and national accounting*, that opens the series of his significant contributions to input-output analysis [042]. Stone aimed to complement the national accounts statistics with input-output statistics, in such a way as to make the input-output analysis more flexible and capable of extension to many other aspects of economic activity, in addition to the productive sphere. His contribution is both theoretical and empirical, and ranges from a redefinition of the methods of classification of economic activities to the study and estimates of changes in input-output coefficients.

Furthermore, in a subsequent article, *Simple transaction models, information and computing* [043], Stone discusses *transaction models*, that is models of economic interdependence which involve a *matrix of transactions* and a *matrix of response*. A *matrix of transactions* records the transactions between the different sectors of an

economic system. A *matrix of response* introduces particular hypotheses concerning technology or behaviour. Stone points out how many models used in economic analysis are particular cases of *transaction models*. As examples, Stone presents and examines some static and dynamic models, including: an elementary static model on Keynesian lines; the input-output model of Leontief; Goodwin's models. In Leontief's model, the *transaction matrix* coincides with the input-output matrix and the *response matrix* introduces the hypothesis of fixed technical coefficients.

In this period, Stone's increasing concern about the need to integrate input-output analysis into the SNA is witnessed by a further article, presented at the IARIW conference, Royaumont, 1951, on the topic in which he presents the system of national accounts as a suitable means to compare the economic structure and performance of different countries [046]. The paper also provides a brief account of the work of the National Accounts Research Unit of the Organisation for European Economic Co-operation. Among the issues considered by the Unit was the extension of the system of national accounts. Many countries had started working on more complex and larger national accounting systems, which included, for example, input-output tables, national balance sheets, purchases and sales of financial assets, etc. As regards input-output analysis, it is worth mentioning the work undertaken at that time in the United States (mainly by W. Leontief), Denmark and the Netherlands.

His intention to extend the application of SNA with the inclusion of a more disaggregated level of analysis comes to light also in a second paper [048] presented at the IARIW conference, Castelgandolfo, 1953. Stone opens this article by classifying models of social accounts on the basis of the methodology adopted for the consolidation of the variables included. According to Stone, there are basically two approaches. On the one hand, social accounts have been consolidated 'without much regard to the details of the commodity composition of production' [048, p. 29], as in the case of the models provided by Keynes and Harrod-Domar. The second approach is focused on the technological relationships which exist in the production sphere. Typical is Leontief's work on input-output analysis and the related activity analysis. Stone accurately surveys different types of models or parts of them.

Of particular interest is the historical reconstruction of the first input-output tables for the United States, the United Kingdom, the Netherlands, Denmark, Norway and Italy. Stone describes the huge efforts made by public-funded research groups to develop a very large matrix, in order to obtain more and more precise estimation of the national economy. The first tables were developed by Leontief based on the US economy, at Harvard University. In the UK, the pioneer attempts were pursued by Barna, for the year 1935, while in 1952 ‘a large-scale investigation relating to 1948 was started by the Board of Trade and the Department of Applied Economics in Cambridge’ [048, p. 59]. In the Netherlands the Central Bureau of Statistics developed original tables for the national economy, while there were also studies relating to Denmark and Norway in the same period.

Finally, according to Stone, ‘a most interesting study for Italy has recently been prepared and published by the Program Division of the M.S.A. Mission to Italy. An attempt is made to test the accuracy of the model and it is used to predict the probable structure of the Italian economy in 1956 and as a basis for regional analysis.’ [048, p. 60].

Although this paper is not noted for its original contributions to input-output analysis, it witnesses Stone's careful research into the state of the art, which has influenced the further development and application of input-output techniques. This should be seen as part of Stone's lifelong dedication to the development of quantitative tools for enhancing applied economics. In fact, input-output, as well as a broad set of different quantitative methods, is included in the final report that he wrote - together with Paul Samuelson and Tjalling Koopmans - to assess the development of *Econometrica*, as one of the areas to which more attention should be given. [050, p. 143]

At that time Richard Stone was the Director of the Department of Applied Economics – DAE – University of Cambridge. The establishment of the Department and the appointment of Stone as Director had been strongly desired by Keynes. Under his directorship, the Department had become one of the most prestigious research centres in the world in the field of applied economics and quantitative analysis.

His practical considerations were eventually condensed in a paper presented at the second International Conference of the Input-Output Association, held in Varenna (Italy) in 1954. In this paper [052], Stone explicitly highlights the relationship between input-output analysis and the national accounts. His transaction matrices now include financial transactions, financial and real asset balances and capital gains or losses on various types of assets. Sector classifications are also included, enabling construction of input-output tables based on the content of the national account matrix. Technically, Stone shows that both the national accounts and input-output tables can be derived from a more general social account matrix through pre-multiplication and post-multiplication by grouping matrices.

This innovation aims at obtaining a formal connection between two complementary methods for accounting transactions within an economic system. This formal connection leads to more homogeneous definitions and classifications of different accounts in both national accounting and input-output. Stone shows that once sufficient information is available, it is always possible to integrate the information provided in the table by including more complex forms of relationship between inputs and outputs. This paper constitutes an important contribution in the advance of input-output (and also national accounting), by allowing a widening of the perspectives and scope of these analytical tools.

Stone's focus on transaction models led to a further important work that constitutes a development of the forgoing analysis: *Transaction models with an example based on the British national accounts* [058]. Having shown that transaction models can serve as a major methodological tool to extend input-output analysis, he explores the short-term forecasting power of transaction models. Stone recalls that a transaction model can ultimately be defined as an analytical framework ‘in which each flow between accounts is expressed in terms of the total revenue of the paying account and certain other variables.’ [058, p. 202]. This technique had been applied by Leontief and other authors within the field of input-output analysis. In this paper, Stone demonstrates an original application to national accounts. Though based on rather rigid assumptions (about the relationships existing between different accounts), the model can be used as a powerful tool for short-term predictions. In the early sections the paper provides an in-depth

technical illustration of both a simple and an extended version of the model, highlighting the possibilities of extension and flexibility provided by this technique, once a simple baseline model has been set up. In the later sections, Stone illustrates an application of the model to the British national accounts from 1948 to 1953, showing that predictions based on the model are reliable, and can be improved further by increasing the precision of underlying data. In summary, this paper shows the breadth of Stone's interest in the field of national accounts measurement and estimation and his valuable contribution to the development of the study of this subject.

Soon after the publication of this paper, Stone's second wife, Feodora, increasingly ill for some while, died, leaving him to look after their only child, Caroline: there was inevitably an hiatus as regards his work output for the best part of the two years 1956 and 1957. Indeed it was not until 1960 that his publications demonstrated substantial further advances in his thinking in the area transaction models. By this time he had been appointed Director of the Cambridge Growth Project.

The problems tackled so far partly relate to Stone's concern that more precision and detail is needed in the presentation of national accounting tables. Recalling the idea he illustrated in *Transaction models*, Stone proposes, in a paper presented at the ISI conference, Paris, 1961, a further development of social accounting, by addressing the issue of the classification of all the agents involved in the economic system [077]. The problem, then, is mainly practical as Stone points out: 'A complete system of social accounts must be able to handle transactors in all their aspects: as producers, consumers and accumulators. To reduce the number and variety of transactors to manageable dimensions it is necessary to classify them, but experience shows that it is impossible to find a single classification which will be equally suitable for each aspect.' [077, p. 230]. In the international standard systems of national accounts this classification is generally achieved by what Stone calls 'the limited solution', by which classification is reduced to a minimum, such as for instance 'private' and 'public'.

However, Stone proposes a broader system of classification (which he defines as 'the proper solution') to be applied to social accounting as well. According to this method, as many classifications can be chosen as thought useful by the model-builder. Then, in order to transpose different classifications to different transactors it is necessary and

sufficient to introduce some appropriate classification converters, which, as Johansen puts it (Johansen, 1985), are merely 'matrices with different types of proportional constants'. As Stone himself stresses, his model is based on the distinction between real and financial economic activity and focuses mostly on the former, rather than the latter. The concepts postulated by Stone reflect directly the Programme for Growth at Cambridge. In fact, as was usual in his later publications, the final part of the paper provides a detailed examination of the provisional results of the computational model developed at the Department of Applied Economics of the University of Cambridge, which serves as a sort of test for the concepts expounded in the paper.

The extensive work on the inclusion of input-output tables in national account models led to the publication of a report issued by OEEC in 1961, *Input-Output and National Accounts*, intended as a sequel to two previous reports issued in, respectively, 1952 (*The Standardized System of National Accounts*) and 1956 (*Quantity and Price Indexes in National Accounts*). The purpose is to further the examination of some conceptual problems arising in the previous reports. In particular, the 1961 report deals 'with the sub-division of the national accounts on an industry basis so as to provide a detailed picture of industrial structure.' [076, p. 5]. Again, Stone illustrates the application of input-output analysis to national accounting, in order to provide a more complete framework for the economic system. In this way 'input-output tables are viewed as a bridge between statistics that can actually be collected about the productive process and the requirements of applied economic analysis.' [076, p. 11]. The methodology adopted shows Stone's concern for a re-positioning in economics based on a reconciliation between theory and empirical methods. According to Stone: 'all models must be capable of being checked by observation.' [076, p. 11]

3. THE SOCIAL ACCOUNTING MATRIX (SAM)

It is well known that Richard Stone spent most of the first part of his professional career in fostering the development of a consistent system of national accounts. At the end of the 1950s, his efforts culminated in a book, *Social Accounting and Economic Models*, co-authored with the talented and charming Roman intellectual Giovanna

Croft-Murray [Pasinetti, 1992, 117], who was to become his third wife shortly afterwards and who until his death helped him in all his work. The book provides a comprehensive exposition of the framework of national accounting. As explicitly stated by the authors, it is intended ‘as a more advanced sequel to Meade and Stone’s *National Income and Expenditure* [016].’ [067, p. 7]. The purpose of the book is to provide a more complete model of the economy as a whole, starting from the analysis of national income and expenditure. This objective was the focus of most of Stone’s work from the late 1950s to the early 1970s. As Deaton points out: ‘As always, the vision is of a framework of accounts each of which opens a window on the operation of the economic system, supplemented with models that describe the processes revealed through those windows. … The book sets forth the principles of national accounting, shows how the various transactions can most conveniently be laid out as matrices – social accounting matrices, inevitably known as SAMs – and then discusses the various models of behaviour: an input-output system for production, a linear expenditure system for the demand for non-durable goods, and dynamic demand functions for durable goods. (The last was based on his work with Deryck Rowe where he had introduced the simple stock-adjustment model, another lasting contribution to the empirical arsenal.) This remarkable little book gives what is in effect a skeletal model of the economy, and this was to be progressively filled out and expanded in Stone’s next enterprise, the Cambridge Growth Project’ (Deaton, 1993, p. 486).

After a detailed description of social accounting from a conceptual point of view, the book provides two chapters on economic models, representing details of relationships within the framework outlined in the first part. The book is important in the context of dynamic models of consumer behaviour, as well as for the introduction of a technical arrangement to allow for the inclusion of the effect of price on the demand of commodities.

In 1962 Richard Stone and Alan Brown published *A Computable Model of Economic Growth* [085], the first of a series of twelve volumes issued by the Department of Applied Economics and known as the "Green Books."

The volumes present the results of the extensive research project, directed by Stone and called *A Programme for Growth*, in which the best researchers and scholars of the DAE took part.

The most important result of Stone's work on SAM can be found in *A Social Accounting Matrix for 1960* co-authored with Alan Brown and others and published in *A programme for Growth* [086].

The advance of the SAM was also due to Stone's colleagues at Cambridge, especially to Graham Pyatt, who carried on this work also after the end of his co-operation within the Cambridge Growth Project. In particular, Pyatt contributed to the development of SAM at the World Bank, which eventually produced a worldwide standard version which, with further extensions and modifications, has been widely used up to the present.

Once the SAM was developed, it turned out to be a very flexible and extensible analytical tool. In a 1967 paper presented at the ISI conference, Sidney [125], Stone explores the possibility of extending its application to the dynamics of income distribution, accounting for a number of different forms of redistribution, including healthcare related expenses: the health sector was indeed his next target to be included in input-output analysis.

A Programme for Growth aimed to demonstrate the building of a model to study British economic growth prospects. One remarkable aspect of the project was related to the construction and use of input-output tables. Great effort was put into the estimation of input-output coefficients and their possible variation over time. Stone and his colleagues developed a special method of updating the technical coefficients, known as the RAS method. The acronym indicates that the updating of the coefficients is made by pre-multiplying and post-multiplying the matrix of technical coefficients A by two suitable matrices R and S. The problem of variation of technical coefficients had been illustrated by Leontief in his early work, but it is Stone who provided a computational technique to be adopted at the international level.

4. INPUT-OUTPUT ANALYSIS APPLICATION: EDUCATION, HEALTH AND ENVIRONMENT

Since the early 1960s Stone's interest in social and demographic aspects of society became more and more accentuated. He began to conceive and develop a system of national accounts which incorporated these factors. It is a system that goes beyond the SNA and broadens the economic analysis to include also social and demographic dynamics. Early research in this direction was undertaken at King's College Research Centre and appeared in *Toward a System of Social and Demographic Statistics* published by the United Nations in 1975.

In the paper *The analysis of economic systems*, presented at the 7th conference held by the Pontifical Academy of Sciences in Rome, in 1963, Stone had set out his view of the way economic modelling should be pursued, essentially by taking into account the complex inter-relations between the economic system and its environment. However, in this paper he is even more explicit on the role he attributes to economic modelling: by recognising the imperfections of the economic system when *laissez-faire* is its ruling principle, the paper aims 'to discuss how economic models might help us to reconcile the advantages of central planning with those of individual initiative.' [097, p. 4]. The core issue is the availability of information, the feasibility of decision-making being undermined if it is inadequate or absent. Therefore, since information is costly, a thorough examination of the sources of information should be made, in order to understand when it is possible and convenient to transfer it to a central authority and when it is not. Once again, Stone's purpose is to present the philosophy underlying his model, stressing its practical scope (as a tool to allow policy-makers to plan the economy accurately) and then proceeding with the illustration of the model itself, which represents the bulk of the work of the Cambridge Growth Project.

This presentation offers a broader view of the whole project, since Stone suggests some possible extensions in the near future to more complex fields of economic activity, not necessarily directly related to the real side of national economy. In fact, as Stone argues: 'we believe that the main motive forces of economic growth are to be found in human abilities and attitudes: organising capacity, acceptance of education and training,

response to innovation, labour mobility, and so on. However, we could hardly have begun with these indefinite and on the whole badly documented areas of interest; and in any case it would have been useless to do so until we could embody them in a coherent picture of the socio-economic system. So, naturally enough, we decided to build out from the familiar and to use our working experience as the starting point for our work.' [097, p. 84]

The paper does not add any new contribution to the model of growth, nor does it introduce particular original features to input-output analysis. However, it clarifies further Stone's view on the need for balanced intervention by a central authority to control the economy, in order to progress towards socially-agreed objectives: this aim needed a more accurate and detailed picture of the economic system, a task that input-output tables could substantially contribute to achieving.

As the proceedings of the conference reveal, the actual presentation of the paper gave rise to a lively debate during the conference itself. Most of the participants agreed with Stone's philosophy of model-building, demonstrating a common approach to the issue by economists in the 1960s. The most interesting aspect of the discussion relates to the possible application of the model for planning purposes. For this to be possible, as Pasinetti observed (Pasinetti, 1992), it is essential to understand which relations in the economic system are independent of the institutional set-up and which are not. This point is important in highlighting the danger of a misunderstanding of the background of the economic system of a country, a problem that Stone himself realises.

The first technical contributions concerning the extension of input-output tables to education appeared in the late 1960s. In *A model of the educational system* (1965) [111] Stone tries to include education and manpower in the Growth Model developed at Cambridge. From a technical point of view, this paper provides two different approaches. The first one is the application of input-output analysis to the educational system. The second is the use of Markov chain methods for formalising the hypothesized relationships. The focus is on improvement of the growth model. In fact, as Stone explains: 'The purpose of calculating these activity levels is to enable us to calculate the requirements for economic inputs: teachers, buildings, equipment and supplies.' [111, p. 105]. A number of papers along these lines followed. However, in the

words of Stone: ‘My work on demographic accounting was prompted by the desire to put education and manpower into the Growth Model. This never happened in the way I intended.’ (Stone and Pesaran, 1991, p. 109)

Work in this area became more and more intense in the following years. In *Input-output and demographic accounting: a tool for educational planning* [115], Stone set the basis for the development of an input-output model to be applied to the less familiar field of demography. The usual input-output matrices present stages of individuals’ lives in rows and columns. The categories, rather than industries and products, are age-groups and occupations. When input-output analysis is applied to demography, a further difference occurs, as output coefficients, rather than input coefficients, are fixed. In this case, the model is more properly defined as an ‘allocation model’.

The further development of this model was pursued in later works [127 and 128] aiming for the consolidation of a comprehensive model of socio-economic growth which accounts also for education. These ideas were also presented at an OECD meeting held in Paris in 1966 focusing on educational planning [116], where Stone acknowledged that a large part of the scientific community involved in the study of these topics was moving towards similar aims, although adopting different techniques. Moreover, Stone stressed the common aim of the participants in the conference to promote ‘the formulation and control of educational programmes.’ [116, p. 285]. Stone continued by adding that: ‘They saw a number of new areas where research is urgently needed, and commended these alike to those engaged in research and to those who support research. They expressed the hope that, even at this early stage, the papers presented in this volume would come to the notice of educators, educational administrators and educational planners, without whose understanding and help educational model building could easily become separated from the very activity it was designed to assist.’ [116, p. 285].

The very practical issues raised by the participants at the conference opened up also the debate on the planning itself with reference to education, as in this realm individuals’ freedom of choice ought to play a fundamental role. Stone’s great interest in demography is also witnessed by his participation in a number of international conferences on the subject. In 1967 Stone attended an international conference in

London where, after highlighting what he considered the most important issues in economic model building, he offered an example of the way computational model building should be pursued in order to be fruitful and effective.

In *An example of demographic accounting: the school ages* [127], Stone (with co-authors Giovanna Stone and Jane Gunton) points out that: 'Demographic, educational and manpower statistics are usually treated as three separate subsystems in the statistical universe. Here an effort is made to connect them, and to do it in such a way as to enable us to trace through time the gradual transformation of human stocks and flows.' [127, p. 301]. The purpose is mostly practical, in order to provide demography, like economics, with an accounting framework for comparing and organizing information.

The starting point is a population matrix in which the units of analysis are characteristics of human individuals. According to Stone, this matrix can be further developed to analyse education, demography or any other social science of interest, to provide more detailed information on the functioning of the social system. Stone's aim is the possibility of intervention. In fact 'one can try to use this knowledge, in combination with data on costs, educational technology and available resources, to bring about desirable changes in the circumstances.' [127, p. 301]. In this paper, as well in [115], the focus is on the education system. In particular, the paper illustrates the formal construction of a population matrix and in the final part it provides an extensive application to school age groups in Britain in 1963-64.

The technical issues related to the extension of input-output analysis to demography and education are addressed in *Demographic input-output: an extension of social accounting* [128]. This paper provides an extension of the framework being developed in [115] and [127], with an application to demographic data. In the former papers the focus was on the education system, with the objective of analyzing flows and stocks of human individuals across different stages of education. This paper shows a similar possible application to population flows, such as intra- and inter-national migration. As Stone stresses in the introduction, his purpose is to extend the application of social accounting according to the proper meaning of the concept, as introduced into economics by J.R. Hicks in 1942. In fact, Stone notes that 'Social accounts are still thought of mainly if not exclusively as statements connecting economic flows and

stocks expressed in money terms. […] In other words, what we have been doing so far is no more than economic accounting.' [128, p. 293]. The paper presents some practical examples of British figures which allow Stone to construct demographic matrices analogous to those presented in [115] and [127]. He then addresses technical issues concerning the development of Markov-chain models for demography in the same way already attempted for education.

In a paper entitled *A system of social matrices* [140], Stone followed up the explorations started in [115], [127], [128]. As previously, attention is mainly given to the construction of the social matrix, illustrating all the methodological issues and difficulties arising. In particular, the presentation provides two possible interpretations of the main analytical tool (which is a set of equations), one relating to input-output analysis, and another related to Markov chain methods. The paper provides some examples of 'life sequences' (in Stone's terminology) to which this analysis could be applied. Further technical explanations were provided in the further papers, *Transition and admission models in social demography* [143], *Random walks through the social sciences* [148] and *Life profiles and transition matrices in organizing sociodemographic data* [185], mostly focusing on probabilistic models related to the development of input-output extensions to demographic variables. Most of this work was summarized in the OECD report *Demographic Accounting and Model Building* issued in 1971, one of the most comprehensive attempts of to put into practice Stone's extensions of SNA and input-output analysis [134].

Stone's efforts to extend SNA and input-output beyond the previous confines of economics was directed also to the financial sector. In *The Social accounts from a consumer's point of view* [114], Stone explored the possibility of including financial transactions within national accounting. This investigation was based on the revised version of the SNA which, as Stone puts it, 'has done something to correct a serious imbalance in the development of social accounting: the concentration on flows to the exclusion of stocks.' [114, p. 249]. Therefore, the inclusion of balance sheets in social accounts offers expanded possibilities for construction of economic models. In the paper, Stone illustrates a few simple examples. As Johansen summarises: 'On the basis of input-output analysis, he extended purely computational methods in an attempt to

construct models of financial circulation which could be used in practice. After constructing extreme models with certain fixed proportions derived from the borrowing and lending sides of the markets, respectively, a (hopefully) more realistic model is then established as a compromise between the two.' (Johansen, 1985, p. 12).

Another interesting field of tentative application of input-output techniques was to the environment. The first paper on the subject, *The evaluation of pollution: balancing gains and losses*, [141] reflects the climate in the late 1960s regarding human development, expressing severe concerns about what we would now refer to as 'environmental sustainability'. In the opening sentences of the paper, Stone acknowledges that: 'The market system has proved itself to be a practical means of regulating the production and consumption of goods.' [141, p. 412]. However, the market system has failed to provide a solution for 'externalities', especially pollution. As Stone notes: 'The goods accounted for in the market system, are intended for sale and expected to yield a profit; but the accompanying evils do not show up in the accounts if the producer can dispose of them without cost to himself. Thus, for instance, a textile mill prospers if it can sell its textiles at a profit, although in producing them it may foul the local river so that the community must either suffer a loss of amenity or spend its own money on cleaning up the mess. In such circumstances the mill-owner has no incentive to adopt less polluting processes or to spend money on waste-purifying equipment. It is therefore difficult, if not impossible, to calculate what the textiles really cost, and the allocation of resources will be distorted as a consequence.' [141, p. 412].

As Stone recognizes, the problem is not new in itself, rather in its 'scale, rate of growth and diversity of pollutants' [141, p. 412]. Interestingly, according to Stone a solution can be achieved only through further improvements in science, rather than from a denial of science. In fact: 'The anti-pollution campaign is generally associated with a campaign against science. But the fact is that, in order to control pollution, a great deal of scientific, engineering and economic research will be needed. The back-to-nature movement, which seems to have a certain vogue among modem youth, is acceptable only to affluent people who have no conception of what it entails. Those who live under primitive conditions look with hungry eyes on what they conceive, rightly in my opinion, to be the marvellous scientific and economic achievements of the West. It is

cruelly frivolous to deny them the fruits of these achievements.' 141, p.412] As an economist, Stone provides his contribution to the solution of the problem by suggesting an application of input-output analysis with a view to understanding how to sustain the costs of reducing pollution within the productive process. The paper is indebted to Leontief's previous work on the same topic.

Some time later, Stone observed: ‘The SSDS contains very little that is relevant to the environment but I did write a paper intended to show how far a country should divert resources from the production of regular goods to cleaning up pollution [141]. Meade produced in *L'industria* (1972, pp. 145-152) a better version of this model, in which it was recognized that the consumer is interested not so much in the amount of cleaning up as in the state of the world after the cleaning up has been carried out. I have always maintained that environmental statistics, along with the national accounts and socio-demographic statistics, were one of the three pillars on which the study of society should rest’. (Stone and Paseran, 1991, p. 110).

Expanding the frontiers of input-output analysis was indeed a challenging task, as Stone was perfectly aware. In the paper *Direct and indirect constraints in the adjustment of observations* [155], he addressed some technical problems related to accounting matrices. These problems arise almost always in applied economics, but are particularly relevant when exploring ‘virgin’ fields of research. In particular, Stone is concerned with a practical problem that, as he says, has bothered him for long time: 'It is the question of what we can do to improve the economic and social matrices we construct from basic data which in some degree are inevitably incomplete, inaccurate and inconsistent.' [155, p. 42]. The essay, written in honour of Odd Aukrust, focuses on this subject mainly in relation to input-output analysis, a technique he had by then mastered fully.

In the next few years, there were many examples of recognition of Stone’s immense contribution to Economics: among many other honours, in 1978 he was appointed Knight Commander of the British Empire and became President of the Royal Economic Society; he was awarded the Nobel Prize in 1984. He lived a further 7 years, well cared for by Giovanna who continued publication of his work after his death.

5. CONCLUSIONS

This brief review of some of the work of Richard Stone has identified how Stone, a regular user of mathematical and statistical techniques, developed new methodologies to implement its models. In particular, this is true for input-output analysis, which he used as a tool, but also extended in its theoretical formulation.

A further extremely innovative application is worth here mentioning. In a 1973 paper *Process, capacity and control in an input-output system* [138], Stone explored an application of input-output analysis at an intra-firm level, introducing processes instead of branches of production. The intention was to explore possible application of input-output analysis to help business decisions. The rather simplified illustration provided in the paper highlights a possible new stream of development for input-output analysis. This application to a highly disaggregated level of analysis was essentially new at the time and offered a further example of Stone's eclectic and enquiring approach to economic analysis.

While attempting to extend input-output analysis to new sectors, Stone provided a number of in-depth surveys of the state of the art. In the '70s, he published three excellent reviews of the then latest developments in input-output analysis: *The expanding frontiers of input-output analysis* [152], *Input-output analysis and economic planning: a survey* [168] and *Where are we now? A short account of the development of input-output studies and their present trends* [172].

Richard Stone contributed to economics in a large number of fields, usually pushing forward the limits of applied research. Some of the new developments introduced by Stone were made possible by the concurrent technological innovations he witnessed during his life. In particular, as Stone recalled later in *Computer models of the economy* [102], the development and improvement of electronic computers had a significant role in fostering applied research. Presenting the advantages of computer modeling in economics, Stone provides a simple description of a 'toy model' of the economic system which summarises in outline the relationships included in the complex model of growth developed by him at Cambridge. Stone's purpose here is to show that by knowing with increasing precision a large number of parameters it would be possible to

compute quantitative models that would be ‘detailed enough and reliable enough to play an important practical role in government and business planning.’ [102, p. 604]. The effort made by Stone and his colleagues to construct and develop the computational model was huge, but was made possible (and worthwhile) by the fast growing introduction of digital computers into scientific research. Stone offers an interesting example (referred to the growth model being developed in Cambridge), which helps to clarify the technological context in which he was working at the time: ‘The whole economy is represented by the entries in a set of 253 balancing accounts. Each account shows the incomings and outgoings of some branch or sector of the economy. The numerical inputs (parameters and conditions) needed for a computer-run number between 5000 and 6000. A run involves about 30 million multiplications: on a desk calculator this is equivalent to 60 man-years of work; on the Atlas computer it takes 22 seconds.’ [102, p. 604]. Clearly the introduction of computers opened possibilities for economic modelling that had been impossible even to imagine only a few years before. The stress on computational devices is driven by Stone’s practical-minded approach. In fact, as usual in his works, Stone’s aim is to obtain as much ‘ready-to-use’ information as possible. However, even the most detailed information must be regarded by decision-makers as only a tool for improving decisions: ‘Computers do sums, men take decisions.’ [102, p. 605]

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