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THE CONTRIBUTION OF ICT TO HEALTH CARE SYSTEM PRODUCTIVITY AND EFFICIENCY: WHAT DO WE KNOW?

Briefing paper

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CONTENTS

1. Information and ICT in health care

1. Traditionally the health sector has been perceived as lagging behind other industries with respect to its use of information and communications technology (ICT). This is surprising given the centrality of information exchange in the care process and for purposes of management, accountability, research and for financial transactions.

2. Health care provision is characterised by complexity and uncertainty. In most circumstances patients lack the ability to make an accurate diagnosis or to decide on an appropriate course of action on the basis of their symptoms. Instead patients usually seek diagnostic information from a health professional, to whom they also delegate decisions about how to organise and co-ordinate their care requirements. The successful outcome of such interaction depends (at least partially) on how information is shared between the patient and their delegated representative, and between different health professionals as they assume responsibility for parts of the care process. Any failure in communication between any of these parties may result in poor decisions being made which may impact adversely on the eventual outcome of the course of treatment. There is an obvious role for ICT systems in recording pertinent data about the patient and in facilitating data exchange among those involved in the care process, subject to necessary ethical safeguards.

3. Accurate information is also essential for the management, monitoring and regulation of the health system as a whole. Smith and Häkkinen characterise information as enabling three important functions in the health system (Smith and Häkkinen, 2006). First, information is essential to accountability, allowing politicians to monitor the performance of the health system and citizens to assess stewardship. Second, information facilitates research into general patterns of system and organisational performance, so that sound evidence can be obtained about best practice. Third, information enables management to undertake comparative analysis of organisations and individuals, and thereby assess the effectiveness and efficiency of how they are fulfilling their functions. Adding to this list, information also supports reimbursement and billing arrangements between payers and providers. Clearly ICT systems have the potential to support all four functions.

4. Given the centrality and diverse uses of information, ICT systems that ensure timely and accurate collection and exchange of information are likely to foster more efficient use of health care resources. But empirical evidence about the contribution of ICT to the productivity and efficiency of health care is limited. Identifying the impact of ICT on productivity is difficult for a number of reasons. A particular problem in the health sector is that there is no measure of performance analogous to profits for private sector firms, and health care organisations tend to pursue multiple objectives. Investments in ICT may be made to support any of these objectives. For instance, a computerised booking system may be implemented to boost patient throughput by optimising theatre use; financial performance may be improved via a reduction in transactions costs brought about by investing in technology to enhance billing arrangements. But other investments might be made to improve the quality of service provision and patient experience, and such objectives are notoriously difficult to measure and value.

5. This briefing paper outlines the methodological approaches taken to measure the impact of ICT on productivity, summarises the available evidence, and makes recommendations as to where future research effort might be best directed.

2. A brief overview of methodological approaches

6. Empirical studies into the impact of ICT can be subdivided into four broad categories:

- Aggregate analyses that take a macro perspective by looking at the economy as a whole;
- Industry- or sectoral-level analyses that focus on specific industries or sectors within the economy;
- Firm- or organisational-level analyses;
- Case studies that focus on specific examples of ICT.

7. A number of studies have used growth accounting methods to estimate the impact of ICT on the economy as a whole and in specific sectors. However, as yet, no study that employs these techniques has looked specifically at the health sector and a number of challenges have to be overcome before such a study can be undertaken. In section 4 we outline this methodology and discuss the challenges to be faced in section 5.

8. A range of techniques are available to examine productivity and efficiency at firm-level, and these are briefly reviewed in section 6. There are a handful of studies that employ these techniques to examine the effect of ICT in health care, which are reviewed in section 7. There is scope for further work to be developed in this area.

9. Case studies that examine the costs and benefits of specific ICT applications are the most common examples of empirical analysis in the health care sector, but published work is neither extensive nor comprehensive. A discussion of this analytical approach appears in section 8.

10. Before describing these analytical approaches in more detail, we first consider how studies define ICT resources.

3. Defining ICT resources

11. A key requirement for analytical work is a clear definition of what constitute ICT resources. First of all, international comparisons require appropriate price indices. ICT resources have been subject to continuous and rapid technical improvements over the last few years, which has led both to enhanced quality and to reductions in price. These technical improvements make it difficult to measure ICT resources over time, because it is necessary to estimate a "true" price change that is not contaminated by the change in quality. A number of methods are available to do this, and countries differ in the approach adopted (Schreyer, 2002). The US applies hedonic methods to measure the price of ICT resources, which consider how the mix of characteristics of a good change over time and identify the proportion of price change that is related to each of these characteristics. The alternative methods used elsewhere are thought to lead to underestimates of ICT output and investment growth in the countries that employ these methods (Inklaar et al., 2005).

12. Secondly, the ICT resources themselves need defining and measuring. The Groningen Growth and Development Centre's 60-industry database (http://www.ggdc.net) defines six asset types, of which three refer to ICT goods: computers, software, telecommunications equipment (Inklaar et al., 2005). (The non-ICT goods in the GGDC data are transport equipment, machinery, equipment, and non-residential structures (Inklaar et al., 2005).) In his study, Oulton also includes semiconductors (chips) though these represent a very small proportion of total ICT (Oulton, 2002). Clearly these broad categories contain a great deal of variation. For instance, while hardware (computers) may be fairly standardised, software is likely to be written for specific purposes and not easily transferred from one context to another. This finer level of detail will be missed when making international comparisons.

13. Some have argued that official sources of data on ICT, particularly those used to compile the national accounts, are likely to be preferable to private data, because the former are likely to be more representative and subject to consistent definitions of what constitutes ICT (Pilat, 2004). This is not assured, however, and there appear to be differences among countries in how they classify

telecommunications equipment in particular, which makes international comparison more difficult (Oulton, 2002). International comparisons are also hampered by differences in sources of information, particularly when there is reliance on surveys to generate the data. In many countries, ICT resources are poorly accounted for in official productivity statistics (Pilat, 2004). For example, Oulton argues that official Office of National Statistics estimates of the level of software investment in the UK during the 1990s is only a third of the actual level (Oulton, 2002).

14. Firm-level analyses usually rely on accounting returns by the organisations under consideration, and these returns may be subject to reporting error (Menon and Lee, 2000). The data advantage that firm-level studies have over aggregate or sectoral studies is that it is sometimes possible to identify the labour input associated with ICT as well as the capital input.

15. In theory, case studies should provide the most accurate information about ICT resources, but in their review Chuadhry *et al* found that ICT systems were incompletely described and data on costs or inputs were rarely reported, which makes it difficult to assess their net impact and to assess financial effects (Chaudhry et al., 2006).

4. Measuring productivity using growth accounting methods

16. A number of studies have employed growth accounting methods to investigate the contribution of ICT to productivity growth for the economy as a whole or for sectors within the economy. Taking the economy as a whole, the relationship between the growth in aggregate output and growth in inputs can specified as (Jorgenson and Griliches, 1967, OECD, 2001):

$$\Delta Y = \phi^{L}\Delta L + \phi^{nICT}\Delta K^{nICT} + \phi^{ICT}\Delta K^{ICT} + \Delta TFP \qquad (1)$$

17. Where ΔY is aggregate output growth, measured as the sum of growth for each type of output, weighted to reflect their shares in nominal GDP. Input growth measures the rate of growth for each input type, here defined as labour *L*, non-ICT capital resources K^{nICT}, and ICT capital resources K^{ICT}. These inputs are weighted by the proportion (ϕ) of income attributable to each input as a proportion of nominal GDP, under an assumption of constant returns to scale, $\varphi^{L} + \phi^{nICT} + \phi^{ICT} = 1$. Capital investments need to measured in real terms, hence the need to deflate (depreciated) capital stocks using a price index that corrects for quality change (Schreyer, 2002). Finally, the growth of total factor productivity (or technical progress), ΔTFP, is the amount by which output increases as a result of improvements in methods of production. TFP growth occurs when output increases for the same inputs.

18. Instead of considering the contribution of ICT to overall output growth, a number of studies consider its impact on labour productivity (Timmer and van Ark, 2005, Inklaar et al., 2005). Studies of US labour productivity growth have ascribed virtually all of the acceleration that occurred in the late 1990s to investment in ICT (Jorgenson and Stiroh, 2000, Oliner and Sichel, 2000). But the US experience was not mirrored elsewhere, despite the fact that ICT products are traded internationally in competitive markets (Schreyer, 2002, Inklaar et al., 2005). These international comparative studies reach broadly consistent conclusions:

- Prior to the 1990s, there were lower levels of ICT investment in Europe than the US, hence ICT stocks were lower in Europe (Inklaar et al., 2005)
- During the 1990s, ICT-investment growth accelerated in both Europe and the US (Inklaar et al., 2005)

- The contribution of ICT capital deepening (ie the amount of capital available per unit of labour input) to labour productivity growth in Europe is about half the contribution that it is in the US (Inklaar et al., 2005)
- Unlike the US, Europe experienced a labour productivity slowdown after the mid-1990s which appears unrelated to ICT investment but may be partly due to declines in non-ICT capital deepening and a lack of acceleration in TFP growth (Oulton, 2002, Colecchia and Schreyer, 2002, Inklaar et al., 2005)
- TFP growth in Europe and the US has been similar for ICT-producing industries but is lower in Europe for ICT-using industries (Inklaar et al., 2005).

19. Provided that disaggregated data are available, equation (1) can be applied to industry-level analysis (Stiroh, 2002). Inklaar *et al* have used the GGDC database to explore the contribution of ICT to 60 industries and to make industry-level comparisons between the US, France, Germany, the Netherlands and the UK (Inklaar et al., 2005). The health sector is not separately identified in this database, but is incorporated within "Social and Personal Services" which also includes the education sector. Social and Personal Services is identified as a "non-ICT" industry in the database, reflecting low expenditure on ICT assets. In the next section, we consider the potential for application to the health sector.

5. Measuring the contribution of ICT to the productivity of the health system

20. There are a number of challenges in applying a growth accounting approach to identify the contribution of ICT to output growth or labour productivity in the health sector. In the past, for the purposes of compiling the national accounts, the output of the health sector – and the public sector more generally – was not measured at all. Rather, the output=input convention was used, in which the output of the public sector was valued simply by adding up expenditure on inputs. Among other criticisms of this approach, it obviously does not permit investigation of the contribution to output of expenditure on different types of input.

21. Some countries, such as the US and Canada, are likely to continue to apply the output=input convention to non-market services for the foreseeable future. But others, notably all member states of the European Union, are implementing "Direct Volume Measurement" (DVM) of non-market outputs for many services, including health and education (United Nations Statistics Division, 1993, OECD, 2001). This means that, as an example, instead of reporting how much was spent on the hospital sector, the accounts should measure how many patients were treated.

22. There are three fundamental challenges in applying the Direct Volume Measurement approach:

- The output of the public sector is often difficult to describe or measure.
- It is difficult to measure the quality of public sector output.
- Some means of weighting different goods and services is required in order to aggregate them into a single output index.

23. For the purposes of the national accounts, it is recommended that the output of the health sector is defined as the quantity of health care received by patients, in terms of complete treatments, adjusted to allow for the qualities of the services provided (OECD, 2001). In practice, it is not straightforward to apply this definition, particularly when patients require treatment from multiple agencies on an ongoing basis and because there is very limited information about the quality of health services. However, as an interim step, countries have made progress in measuring health service activities, these being the individual actions carried out by the health sector in delivering a completed treatment (OECD, 2001, Smith and Street, 2007). Assessing the quality of these activities remains a fundamental challenge, both in definitional and measurement terms.

24. For goods and services exchanged in the private sector, market prices provide an indication of their relative value to consumers. The absence of prices that reflect the true marginal social value is taken to be the fundamental defining feature of the 'non-market' sector. Direct volume measurement seeks to measure volumes of non-market outputs in the national accounts in an analogous fashion to that employed for the traded sector. This implies the need to infer values for each of the services under scrutiny. These are required so that the different non-market services produced can be aggregated together and also aggregated with market services. Current recommendations are to weight outputs by their costs (OECD, 2001).

25. Considerable progress has been made by EU member states in applying DVM methods for the 2006 national accounts (Smith and Street, 2007). At this early stage, of course, there are definitional variations across countries, incomplete coverage of parts of the health sector, and limited allowance for the quality of output. Nevertheless, progress has been made in moving toward better measurement of the output of the health sector, and this should provide a foundation for improved measurement in the future and for the construction of a data series. Contemporaneous information on input use would allow cross-sectional comparison of countries, which would make it possible to apply growth accounting methods to explore the contribution of ICT to output growth and labour productivity in the health sector. This is unlikely to be realised in the near future, however, and must remain a longer-term research ambition.

6. Methods to conduct firm-level analyses: efficiency analysis

26. In addition to difficulties in quantifying the output of the health system, evaluative challenges in assessing the impact of ICT include isolating its impact from other, perhaps contemporaneous, technological improvements and organisational initiatives; and recognising that there may be lags between ICT investments and benefit realisation (Devaraj and Kohli, 2000). It is difficult to address these challenges using aggregate statistics and firm-level analyses offer the potential to go some way to overcoming these difficulties (Hempell, 2005).

27. Since the 1970s there has been a significant increase in the amount of research devoted to analysis of the relative efficiency of different organisations. Typically these efficiency analyses treat a "decision-making unit" – for example, a hospital – as the locus of production, converting inputs into valued outputs.

28. Roughly speaking, firm-level analyses fall into two groups. The first group of studies are based on the standard economic theory of the firm, and comprise regression (econometric) models to estimate either a production or cost function. These studies attempt to identify the contributions of specific factors of production, such as labour, capital or ICT input, to observed levels of output or cost. The production function describes the relationship between output y and inputs (L, K^{nICT},K^{ICT}) of a firm i at time t, such that:

$$y_{it} = y(L_{it}, K_{it}^{nICT}, K_{it}^{ICT}) \qquad (2)$$

29. The cost function is specified as:

$$c_{it} = c(y_{it}, w_{it}, r_{it}^{nICT}, r_{it}^{ICT}) \qquad (3)$$

where c measures cost, w measures wages, and r represents the rental price of capital resources. For these equations to be considered equivalent (*ie* the dual of one another), cost minimising behaviour must be assumed, which may not be the case when analysing organisations in sectors where competitive pressures are weak (Intriligator, 1978).

30. The second group of studies attempt to estimate the relative efficiency of organisations, and these studies can be sub-divided into those that use the regression based technique called Stochastic Frontier Analysis (SFA) and those that employ a linear programming technique known as Data Envelopment Analysis (DEA). SFA involves either estimation of a production or cost function, as in equations 2 and 3, or analysis of output by considering exogenous constraints on the production process (Jacobs et al., 2006). DEA involves the estimating the ratio of output to inputs (including ICT resources), under the straightforward assumption that the higher this ratio, the more productive the organisation (Farrell, 1957).

31. The fundamental challenge in analysing organisational-level efficiency is that the true production possibility frontier is generally unknown, certainly to external observers such as researchers, but also probably to the organisations themselves. This information deficit is particularly acute in the production of health care, most of which is complex and individually-tailored, and where urgent provision is often required. Health care does not lend itself to being thought as a "production-line" technology. Rather, a standardised production process is difficult to identify, and there is considerable variation among organisations in how and what outputs are produced, and what type and mix of inputs are used to produce them. Contributions to care processes are often made by multiple agents or organisations, a "package" of care may be delivered over multiple time periods and in different settings, and the responsibilities for delivery may vary from place to place and over time. All of this makes it very difficult to assess the contribution of a single type of input, such ICT, to the efficiency of the production process.

32. These caveats notwithstanding, SFA and DEA hold promise. To apply either technique, a fundamental prerequisite is that the organisations are engaged in similar production processes. For instance, it would not be appropriate to compare general hospitals with specialist hospitals without taking account of the more specialised care requirements of patients treated in the latter type of hospital.

33. As the true "technically feasible" production frontier is unobservable, both SFA and DEA infer an "empirical" frontier based on the observed behaviour of the sample of organisations. SFA and DEA differ in how they establish the location and shape of this frontier, and in determining where each organisation is located in relation to the frontier. This means that often the two techniques will generate different estimates of organisational efficiency and of the contribution made to efficiency by different inputs.

34. The differences between the techniques are best illustrated diagrammatically. Figure 1 plots the relationship between the disability adjusted life expenditure (DALE) and health expenditure *per capita* for countries analysed in by the World Health Organisation in their World Health Report 2000 (World Health Organization, 2000). In effect the WHO treated each country as a "firm", with health expenditure being the main input to produce the primary output of health. There is considerable variation among countries in the health status enjoyed by their populations and in their level of health expenditure. Efficiency analysis is based on the idea that some organisations (countries) are better at utilising their inputs than others, and that there is a "frontier" of best practice.

35. In DEA, the frontier is established by the data themselves, as illustrated in figure 1. The uppermost observations, those with the highest level of output given their scale of operation, are deemed efficient. The frontier is located by connecting up these uppermost observations, and the frontier then "envelopes" the remaining observations.

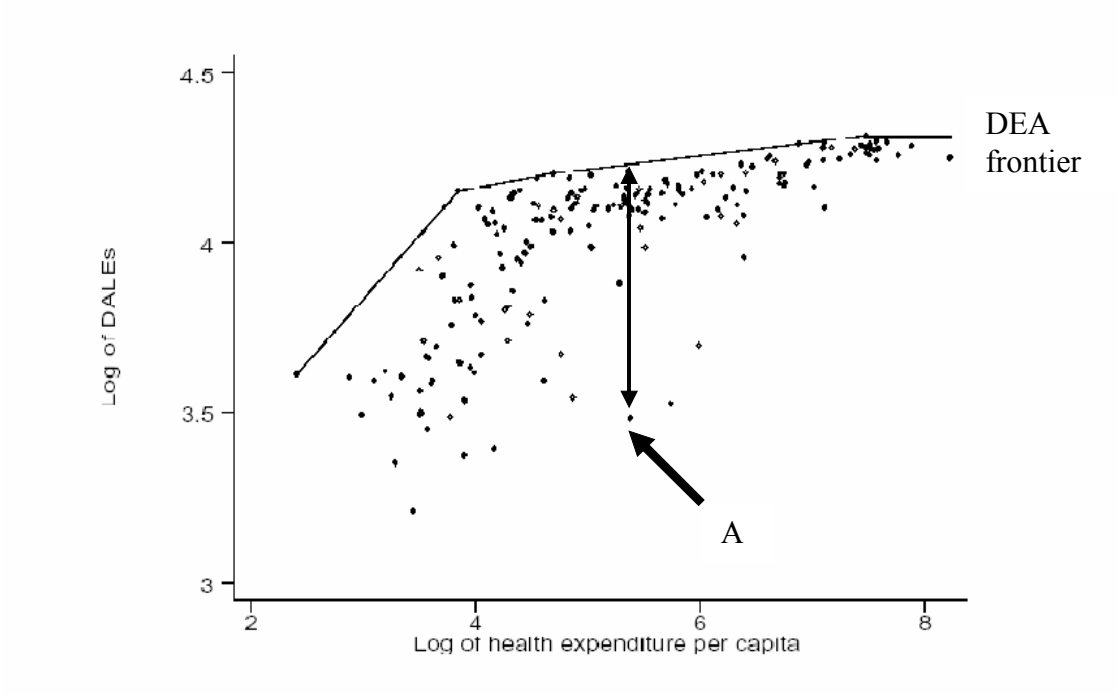

Figure 1: DEA efficiency frontier

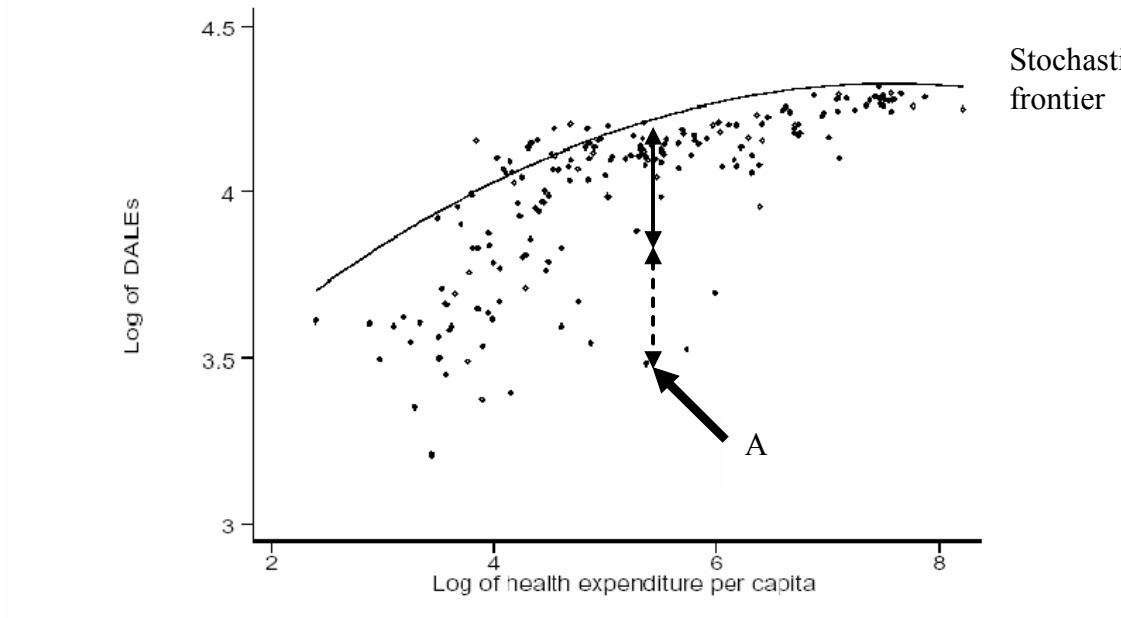

Figure 2: SFA efficiency frontier

36. The SFA frontier is illustrated in figure 2. SFA is an adaptation to standard regression analysis. A straightforward regression analysis would plot a line of best fit through the centre of this cloud of

observations, from which inferences about the average relationship between the variables can be made. In standard regression, deviations from this line of best fit are interpreted as reflecting measurement error and statistical "noise". In SFA, the residual comprises two components: the standard statistical noise and inefficiency. SFA involves separating these two components, and locating a frontier above the line of best fit. Note that, unlike in DEA, the SFA frontier need not be at the upper extremity of the data. If observations lie above the frontier, as depicted in figure 2, this is due to statistical noise.

37. Once the frontier has been located, the efficiency of any particular organisation can be estimated by considering its distance from the frontier. But, even if SFA and DEA yield an identical frontier, they differ in their interpretation of the distance from the frontier. First, DEA assumes correct model specification and no measurement error. This means that for observation A in figure 1, its entire distance from the frontier is due to inefficient conversion of health expenditure into health output.

38. In contrast SFA interprets only a portion of the distance from the frontier as being due to inefficiency. This is illustrated for country A in figure 2, where the shortfall is divided into both statistical noise and inefficiency.

39. DEA and SFA also vary in their use of information. DEA uses only a selective amount of information in estimating each organisation's efficiency score. Each organisation is compared only to "peers" that produce a comparable mix of outputs. This has two implications. First, if an output is unique to an organisation, it will have no peers with which to make a comparison, irrespective of the fact that it may produce other common outputs. An absence of peers results in the automatic assignation of full efficiency.

40. Second, when estimating the efficiency of an organisation that lies below the frontier, in DEA only its peers are considered. SFA appeals to full sample information when estimating relative efficiency, thereby making greater use of the available data and making the estimates more robust in the presence of outlier observations.

7. Studies of the impact of ICT in health care organisations

41. Despite the very large number of studies that have estimated production or cost functions or applied SFA and DEA in the health sector, I was able to find only four studies that look specifically at the impact of ICT in the health care industry. Three of these studies use the same dataset.

42. Devaraj and Kohli estimate a production function to analyse the effect of implementing a decision support system in eight US hospitals, with data covering three years available on a monthly basis (Devaraj and Kohli, 2000). A number of performance measures were considered, including proxies for profitability and quality, and ICT expenditures were subdivided into labour, capital and support costs. The authors conclude that ICT investments have a positive but not immediate effect on both profitability and quality.

43. Menon and Lee use a panel data set spanning 18 years (1976-1994) for 54 general and surgical hospitals in the US state of Washington (Menon and Lee, 2000). They employ panel data techniques to estimate hospital costs as function of ICT capital input, ICT labour input, non-ICT capital input and non-ICT labour input. They find that ICT investment increased following the change from cost reimbursement to DRG-based funding, and that ICT enabled efficient production and substituted for other inputs.

44. Ko and Osei-Bryson re-analysed the data used by Menon and Lee, arguing that ICT investments had a positive impact on productivity in the health care industry (Ko and Osei-Bryson, 2004). However, this study does not improve on that by Menon and Lee and, in fact, contains two fundamental flaws. First,

the authors estimated a production function, according to which hospital output is described in terms of patient days. This is a poor descriptor of hospital output, because it implies that hospitals with longer lengths of stay are more productive, whereas reductions in length of stay have long been identified as sources of efficiency gains. Second, they fail to take account of the fact that they observe each hospital numerous times over an extended period, instead treating every annual observation as independent. This means that the estimates of the impact of their explanatory variables, such as the contribution of ICT, will be biased, which undermines any inferences that might be drawn about their impact.

45. Menon *et al* also analysed their data using SFA techniques, using a similar model specification as in their companion paper (Menon and Lee, 2000) but with a simpler functional form (Menon et al., 2000). Like Ko and Osei-Bryson, though, they also use patient days as a measure of output and do not account for the panel nature of their data.

8. Case studies of specific examples of ICT

46. The final type of analytical approach into the impact of ICT investment takes the form of a case study of a particular type of ICT. These studies might be either retrospective evaluations that measure the actual impact of the ICT investment or prospective assessments, which are more akin to "business cases" which set out the assumptions on which investment might be justified. The strength of case studies lies in their specificity, offering the promise of detailed information about costs and benefits and about the environmental conditions in which the ICT investment has been made. But case studies suffer two weaknesses. First, it is difficult to attribute ICT investment to observed effects, because it is usually not possible to apply randomisation or case-control design to the evaluative study. Second, it is difficult to generalise from the particular study to the broader context.

47. Chaudhry *et al* reviewed 257 studies that explored the impact of ICT, most of which considered decision support systems or electronic health records (Chaudhry et al., 2006). Three main benefits on quality were found: increased adherence to guidelines, better surveillance and monitoring, and decreased medication errors. ICT was not found to have any clear impact on labour input, but did appear to reduce utilisation of care.

48. An alternative approach is based on making projections about the future costs and benefits of particular ICT initiatives, which is a feature of the study by Stroetmann *et al* (Stroetmann et al., 2006). But it may be the case that some of the expected impacts are not realised in practice. This is a weakness of the evaluation of NHS Direct Online, where benefits were expected to come from this service substituting for visits to GPs and other health professionals, and to calls to the NHS Direct telephone service. The national evaluation of the NHS Direct telephone service found no evidence of substitution (Munro et al., 2000), and it is even less likely to have occurred for the online service. Rather, NHS Direct appears to have stimulated previously unmet demand, the value of which is difficult to establish.

49. The main drawback of case studies is the ability to generalise. Chaudhry *et al* highlight this problem, noting that a quarter of the studies they identified emanated from just four institutions, and all sites were more likely to be "leaders in the field" and therefore less representative of usual practice (Chaudhry et al., 2006). On the plus side, the advantage of focussing on exemplar projects is that they may foster replication elsewhere. But there is a bias against reporting unsuccessful applications, consideration of which may alter the conclusions drawn about the contribution of ICT to productivity. The ambitious but controversial attempt to introduce an electronic patient record in the NHS is a high-profile example, which had already cost the NHS £12.4bn (€18.3bn) by December 2006 (Brooks, 2007). The need for electronic patient records is not clear-cut, and the programme has provoked opposition from health professionals and patient groups who are particularly concerned about confidentiality. The installation of the new hospital administration systems is behind schedule, and there is growing evidence that the transfer from old to new

systems has compromised patient care. It is an open question whether this system will ever be subject to formal evaluation, and when and how its impact will be accounted for in official statistics. Examples such as this suggest that Solow's productivity paradox, whereby ICT investments are not observed to lead to productivity gains, may not have secured universal resolution (Solow, 1987).

9. Conclusions and recommendations for future research

50. The health sector has traditionally been a low user of ICT but there appears to great potential for wider use of ICT resources in the health care sector, given the central role of information in the care process and for governance, management, research and financial purposes.

51. With regard to the care process, paper-based records have been the normal method of recording details of patient contact with health professionals and personal contact via letters or phone calls has formed the predominant method for data exchange among those involved in caring for patients. It has been argued that the "advantages of health information technology over paper records are readily discernible" (Chaudhry et al., 2006), but implementation of electronic records runs the risk of cost inflation and needs to be sensitive to ethical concerns particularly around patient confidentiality (Smith and Häkkinen, 2006). It is also unclear whether electronic records substitute for or are additional to traditional forms of data management and data exchange. If there is limited substitution, implementation will add to costs without substantial net beneficial impact. There appears to be a major research task in determining the optimal form in which electronic data are held and how access to this information is circumscribed.

52. Applications of ICT to further other forms of information exchange in the health system are probably less controversial. Moreover, with many countries tending toward greater decentralisation of decision-making, the need for accurate and timely information for monitoring purposes is increasing (Smith and Häkkinen, 2006). Information allows an appropriate balance to be struck between local autonomy and system governance, and ICT has a major role in supporting these arrangements.

53. This briefing paper has categorised the analytical approaches that are available to study the impact of ICT on productivity and efficiency, and provided a brief overview of these analytical approaches. A summary of the key advantages and challenges associated with each analytical approach is provided in the table below.

Study type	Advantages	Challenges
Industry-level analyses	Offers insight into impact of ICT on industry as a whole. Permits international comparisons.	Health care output is poorly measured, though recent improvements where direct volume measurement has been introduced. Quality of output is not taken into account. ICT resources may be poorly measured.
Firm-level analyses	May be able to identify multiple objectives to which ICT investment is directed. Can identify variation among firms.	Need to compare like-with-like sample of firms engaged in same production process. Results sensitive to choice of analytical technique.
Case studies	Highly specific assessment of particular forms of ICT investment.	Difficult to attribute effects to ICT. Results may not be generalisable. For prospective studies, assumptions of impact may be ill-founded.

54. Research into the impact of ICT resources in the health sector is currently limited. No studies have been conducted that explore the impact of ICT on the health system as a whole, which is unsurprising given the difficulties in measuring the output of this sector. However, as Direct Volume Measurement becomes the established technique to measure output for the purposes of the official statistics, there is increased potential to explore the relative contributions of different types of input to output growth and to variations in output levels across jurisdictions. At present, though, this must remain a longer-term research ambition in the health sector where the immediate priorities in this area are to better understand and measure the output of the health care sector. Many countries have not yet adopted Direct Volume Measurement and, among those that have, there is considerable diversity in practice. This makes it difficult to make valid international comparisons of output levels and growth, let alone of the factors that contribute to output.

55. There have been few firm-level analyses that focus explicitly on the impact of ICT in the health sector. This is an area of significant research potential, notwithstanding the challenges involved in specifying production processes, choosing among analytical techniques and making secure inferences about the relative efficiency of organisations. In the first instance, it may be more appropriate to estimate more traditional production (or cost) functions, rather than applying techniques of SFA and DEA that are designed to estimate relative efficiency. The production function expresses an explicit formulation of the relationship between output and input types and, consequently, lends itself to investigation of the importance of ICT investment. In practical terms, research along these lines requires a dataset about organisations engaged in similar production processes with data about their outputs and input use, including ICT, preferably measured over several time periods.

56. Case studies offer the greatest potential for specific learning about particular cases of ICT investment, although much published work makes it difficult to draw conclusions about the cost-effectiveness of implementation because reporting tends to focus on measures of benefit without consideration of the financial effects. Case studies offer the best opportunity to gain detailed insight into particular forms of ICT investment, which may be particular in the health system, where software is often designed for specific purposes in particular contexts.

57. The main drawback of a case study approach is that it is difficult to apply rigorous evaluative study design. For instance, randomisation of organisations to particular levels of ICT is clearly not possible, and it would be difficult to formulate a “case-control” study. Case studies of single technologies in single sites make it difficult to attribute observed effects to ICT input and to make generalisations. Caution should also be exercised in drawing conclusions from published case studies, particularly if poor examples of ICT investment are under-reported.

58. This review suggests that adopting a single analytical approach is inadvisable and that insight into the overall effects of ICT is best gained from consideration of a mix of study types. An initial way forward may be to consider a specific example of ICT, rather than ICT in aggregate. The introduction of the electronic patient record appears a pressing example of where international evaluative effort might be directed, particularly given ethical concerns about this technology, the difficulties in determining whether it substitutes for or adds to existing technologies, and its high cost. Those health systems that are considering the implementation of electronic patient records would likely benefit from experience elsewhere, in the identification of both best practice and potential pitfalls. Such shared learning may help avoid the electronic patient record (or other forms of ICT) contributing to a “productivity paradox” in which high levels of investment insufficiently enhance the efficiency of the health system or patient experience.

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