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The paper is intended to Inform discussion and debate at the symposium, and should not be taken as representing the views or positions of the OECD or its member countries, or of the co-organisers or host organisation.

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GLOSSARY

BRIC	Brazil, Russia, India and China
CBA	cost/benefit analysis
CNPq	(Brazil) National Council for Scientific and Technological Development
CV	consumer valuation
DOE	(US) Department of Environment
Defra	(UK) Department for Environment, Food and Rural Affairs
EPA	(US) Environmental Protection Agency
HGP	Human Genome Project
I/O	input-output [model]
IDA	Interchange of Data between Administrations
IT	information technology
MIT	Massachusetts Institute of Technology
NBIC	[the convergence of] nanotechnology, biotechnology, information technology and cognitive science
NIH	National Institute of Health
NNI	National Nanotechnology Initiative
NSF	National Science Foundation
OECD	Organisation for Economic Co-operation and Development
OSTP	Office of Science and Technology Policy
R&D	research and development
ROI	return on investment
S&T	science and technology
STAR METRICS	Science and Technology for America's Reinvestment: Measuring the Effect of Research on Innovation, Competitiveness, and Science
TBED	technology based economic development
TESTA	Trans European Services for Telematics between Administrations
USDA	United States Department of Agriculture
VOI	value of investment

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BACKGROUND PAPER 4 - MODELS, TOOLS AND METRICS AVAILABLE TO ASSESS THE ECONOMIC IMPACT OF NANOTECHNOLOGY[a]

By Katherine Bojczuk[b] and Ben Walsh[c]

1. Executive summary

1. Research and development, funded by both public and private investment, has a large role to play in the growth of the economy. Technology-based economic development strategies have become an increasing priority, with nanotechnology as one area of policy importance. The ability to evaluate the economic impacts of nanotechnology initiatives and investment is also becoming an increasingly essential part of the creation of optimum investment strategies.

2. Due to the relative infancy of nano-enabled technology there are few valuation models that are specifically focused on this technology area, and there is a clear lack of any definitive model. This report focuses on two main methodologies; (1) the Defra model based on performing a comparative valuation of a nano-enabled product against an incumbent product, and (2) the STAR METRICS database approach which utilises an Input/output (I/O) approach to perform an inter-industry analysis, attempting to develop an understanding of the outputs achieved by Federal funding in the Science and Technology sector. Both models have their merits, and both require assumptions to be made.

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3. The Defra model is comparative and as such requires an incumbent product to be identified. The model takes an ex-ante approach to value a nano-enabled product, and assumptions surrounding the way in which the technology will react in the market, including issues such as the diffusion and lifecycle of the product, are highlighted as considerations. The Defra approach is best used in a 'broadly defined market', in that it is intended for use at a product- or application-level rather than supplying sectoral outcomes or examining aggregate product groups. This is in contrast to the inter-industry approach of STAR METRICS which is more relevant and accurate on a macro scale. This methodology relies heavily on real-life case studies to populate the model and has a requirement for large datasets to generate high level data. The use of I/O models is, however, widespread and generally sets the precedent for this type of modelling. It should be noted, that the STAR METRICS approach is not nano-specific but encompasses all science and technology research areas across the US.

4. There are a number of models that attempt to value technological areas other than nanotechnology. These encompass a variety of techniques, from the extended cost/benefit analysis used in valuation of information technology, to the further use of I/O models in the biotechnology sector. The methodologies for each of these require a variety of assumptions to be made and proxy values to be used. The technological sectors studied can - to an extent - be compared to nanotechnology, in that any new, emerging or innovative industry will have similar data collection issues and lack of precedent. *The nature of nanotechnology makes the application of a single economic model difficult; nanotechnology can be described as both an enabling and a disruptive technology and also extends beyond a specific industry, but rather spans multiple applications.* The application of an economic valuation technique to nanotechnology in this way is an emerging research area and therefore, whichever methodology is applied, there will always be 'unknowns' to consider.

5. With factors such as economic growth, human welfare and international competition dependent on constant technological progress, convergence of technologies can be expected to be a primary area for innovation in the coming years. This is a factor which should be considered in the application of any economic model in the area of nanotechnology, as understanding of this will allow for better representation of the real interactions between technology sectors.

6. Developing a single model, incorporating all relevant aspects surrounding nanotechnology, is not likely to be achievable. *In order to continue with analysis of the economic factors of nanotechnology, it will be necessary to continue to collect data and develop metrics that can facilitate a rigorous analysis of nanotechnology in terms of economic indicators and socio-environmental impacts. The important factor in this is a consideration of how current models and methodologies could best minimise assumptions and use of proxy data.*

2. Introduction

2.1 Introduction

7. Research and development (R&D), funded by both public and private investment, has a large role to play in the growth of the economy. The quantitative research behind this is, however, thin (Griliches, 1995). Technology based economic development strategies have become an increasing priority, with nanotechnology as one area of policy importance, and there is an increasing need to develop an evidence base for science policy in this area (Armstrong, 2008).

8. A large volume of international research is underway to improve our understanding and implementation of nanotechnology. Evaluating the economic impacts of nanotechnology initiatives and investments is an essential part in the creation of optimum investment strategies.

9. Various methodologies have been developed to this effect, although there is a lack of any definitive model. This report explores the various models, tools and metrics available to determine current practices in the Science and Technology sector. Metrics and data collection methods for use in economic valuation methodologies are also discussed. These are outlined both in terms of nanotechnology and for other technological areas.

2.2 Report structure

10. The structure of this report is as follows:

- Section 3: Approaches to valuing technology: This section takes a broad based approach to outlining the common methods that are used for valuation purposes.

- Section 4: Review of existing methodologies: This section reviews the main methodologies currently in use to determine how estimates for returns on investments and evaluations of the economic impact of nanotechnology are made.

- Section 5: Indentifying key considerations: This section provides an overview and analysis of existing methodologies for technology valuation. The difference between these and the applicability to nanotechnology is discussed. Key considerations and uncertainties are also outlined, as it the possibility and scope of the convergence of nanotechnology with other technological fields.

- Section 6: Discussion: The discussion summarises the results obtained throughout the report. A discussion is outlined as to the need for a pragmatic approach to developing large scale models and metrics.

3. Approaches to valuing technology

11. To identify the tools, models and metrics that can be applied in order to value nanotechnology, it is important to provide an overview of the approaches that valuation techniques can take. To this effect, nanotechnology can be said to behave much in the same way as any other technology and the same broad approaches to valuation can be taken.

12. When considering nanotechnology valuation it is important to consider these approaches, as the strengths and weaknesses behind each will dictate to what extent any final valuation can be seen as robust. There is no definitive way to determine which of these approaches is superior, as each has its own merits in different situations.

13. This section summarises the broad approaches that can be taken with regard to the valuation of a new technology. These include:

- Costs approach: assumes that the value of an asset is based on the cost of constructing a similar asset, at current prices.
- Market approach: values an asset by determining the market prices paid for similar assets.
- Income approach: values an asset by calculating what the asset will earn in the future.
- Hybrid approach: combines any of the above approaches to value an asset.

14. It should be noted that most valuation approaches rely - at least in part - on market data. It is here that the problem lies in terms of valuing nanotechnology. Often, valuation for new products or innovations relies on the use of proxy data because direct market data are unavailable. The complexity in applying valuation techniques to these revolutionary new products stems from the ability to identify relevant, appropriate proxies (Potter, 2007).

3.1 Costs approach

15. The cost approach is based on the assumption that an investor will pay no more for an asset than the value of the corresponding cost to develop an asset of similar function or utility. Value is determined by aggregating the costs incurred in development of the asset (Drew, 2001).

16. This approach can, however, be useful in determining the relative inputs of participating parties into a joint venture (Potter, 2007). This could be useful when looking at the development of products, such as nano-enabled products, that require intense amounts of R&D before commercialisation. For early stage technologies, however, this method has some use as it requires minimum economic and market data. Conversely this is also the weakness of this method, as it does not consider revenue or profit data or any other interactions with the market (Drew, 2001).

3.2 Market approach

17. The market approach is routinely used to determine business worth. This approach determines value by comparison with a similar technology. Comparable transactions within industry can provide insight into what price a business would fetch in the market. This approach is often preferred as there is a degree of familiarity with the concepts that are being applied (Drew, 2001).

18. However, by definition nanotechnology is often unique and so identifying a relevant company and finding relevant data to use for comparison with the novel nanotechnology product is likely to require

a certain amount of assumptions to be built into the valuation methodology, representing a weakness in the market valuation approach (Potter, 2007).

19. Overall, the market approach to valuation can be a useful tool, including when applied to nanotechnology, but only when data are sufficiently available to provide an appropriate number of comparable transactions resulting in a comprehensive value estimate (Drew, 2001).

3.3 Income approach

20. The income approach is essentially focused on the ability of the company, or asset, to generate future cash flows. This involves discounting future economic benefits with the use of an appropriate discount rate. The greatest drawback of this approach in terms of its application to nano-enabled technologies is that there may be no market or sales data from which to predict these future revenues. This method also relies heavily on an understanding of the future risk of the technology. These risk estimates are crucial to this valuation approach but can often be subjective due to the nature of predicting how a future product will operate within the market (Potter, 2007).

3.4 A hybrid approach

21. In most situations, it is likely that combinations of the above valuation approaches may be used. No single valuation method is all-encompassing, and each has its own strengths and weaknesses dependent on its application and who undertakes the valuation. A hybrid approach makes use of a variety of techniques to derive the model that best fits the situation constructed. This will most likely utilize various methods under the three business valuation approaches (Potter, 2007).

4. Existing methodologies

4.1 Methodology for nanotechnology valuation

22. This section reviews methodologies and tools currently in use with the aim of understanding how estimates for returns on investments and evaluations of the economic impact of nanotechnology are made. Due to the relative infancy of nano-enabled technology, especially with regard to application in consumer products, there are currently very few valuation models or metrics that are specifically focused on nanotechnology. The focus of this section is therefore primarily on two models: Defra's comparative methodology model and the US-based STAR METRICS intra-industry study. Each of these takes a different approach to valuation; the Defra model focuses on a specific nano-enabled product, whilst the STAR METRICS approach can be used to give a broader view of the values that stem from R&D in the science and technology (S&T) industry. A broad outline of each of the models is provided, followed by a more in-depth analysis.

4.1.1 The UK Defra comparative methodology model[a]

23. The 2010 Defra project, entitled *A comparative methodology for estimating the economic value of innovation in nanotechnologies*, details a method for performing a comparative valuation between a nano-enabled product and an product that is currently on the market (Oakdene Hollins, 2010).

24. The Defra model for valuing nanotechnology was developed by a team of experts in the fields of economics and nanotechnology. It was designed to be used by non-experts and was tested and validated through a series of case studies. It is also highlighted that, although the methodology has been designed

[a] See Appendix A for further details of methodology

specifically with nano-enabled products in mind, it can also be applicable in valuing innovation in other emerging industries (Oakdene Hollins, 2010). The Defra methodology calculates the value of this nano-enabled product over a set timeframe, exploring the benefits to the consumer and producers as well as the wider benefits to society.

25. Throughout the use of the Defra model, there are a number of assumptions that may need to be made. The model uses a characteristic approach, which is based on the premise that goods can be defined as a bundle of attributes, and it is for these - rather than the product as a whole - that the consumer has preferences (Lancaster, 1971). To model new products within this framework, the new product can be thought of as embodying the characteristics of the incumbent product but in different quantities and proportions. It is by using this re-bundling of characteristics that the effect of new products can be analysed from a forward-looking viewpoint (Oakdene Hollins, 2010). To compare the nano-enabled product with an incumbent product, the value added of an incumbent technology is subtracted from the value added of the nano-enabled product as, ultimately, the nano-enabled product replaces the incumbent.

26. A key issue with this approach is that assumptions are likely to be made as to which characteristics are relevant. Furthermore, many characteristics cannot easily be measured due to their intangible nature. To use the characteristics approach, some characteristics must be removed in order to simplify the analysis.

27. Due to the difficulty of predicting radical innovations, the emphasis within the Defra methodology is predominantly on incremental innovations.[a] As such, the scope of radical innovations is limited and evaluation may only be possible if there is an incumbent product that performs the same function as the new product.

28. In dealing with the assumptions outlined above, the Defra methodology lays out where proxies or estimates should be used where data are insufficient or unavailable. Known data should always be used wherever they are available, but a pragmatic approach recognises that this is likely to be unrealistic for all nano-enabled products, especially those which have yet to be launched. Where data are unknown, or perhaps unavailable due to confidentiality issues, the Defra methodology suggests how approximate values could be used to compensate for these data gaps. The data and approximations for this are based on evidence from innovation literature.

29. The use of a sensitivity analysis, which is suggested in the outline to the methodology, also highlights which elements of the datasets used contribute most to the value of the nano-enabled product. This allows for transparency when using proxies or estimated data in outlining how inaccurate data can impact the final valuation.

4.1.2 The STAR METRICS programme[b]

30. In recognition of the need for measuring the impact of government funded research, the US has developed the STAR METRICS (Science and Technology for America's Reinvestment: Measuring the Effect of Research on Innovation, Competitiveness, and Science) programme. Started in May 2010, this programme aims to overcome the data challenges that are present in aligning the impacts of science investments with subsequent outcomes. The project is led by the National Institutes of Health (NIH) and the National Science Foundation (NSF) under the auspices of the Office of Science and Technology Policy (OSTP). More specifically, the programme recognises the need to 're-orientate' the current information

[a] A radical innovation is the creation of a wholly *new* product or process. Incremental innovation refers to making changes to improve *existing* products.

[b] See Appendix B for further details of the methodology of I/O models

within existing administrative systems to better achieve this purpose. As such, STAR METRICS is focused on developing a data infrastructure providing greater information on inputs and outputs (Lane & Bertuzzi, 2010).

31. The programme consists of two implementation phases (Lane & Bertuzzi, 2010) and involvement in these is voluntary. Phase I measures the initial impact of S&T funding on job creation. This entails collation of information on *who* is participating in scientific research and knowledge development, and requires capturing information and forming a database. This allows for the generation of measures which map the impact of S&T funding on job creation.

32. Phase II of the project is considerably more complicated and is expected to take up to three years to complete. This phase develops measures to determine the results of those involved in Phase I. The output of this will be varied and social aspects, which are difficult to measure due to intangible benefits, may be provided as qualitative data (Lane & Bertuzzi, 2010; Kramer, 2010).

33. Phase II will aim to measure the impacts seen by science investment in four principal areas (National Institute of Health, 2010):

- Economic growth measured through patent numbers and business start-up figures.
- Workforce outcomes measured by indicators such as researcher mobility into the workforce.
- Scientific knowledge as measured through publications and citations.
- Social outcomes measured through the impacts of funding on health and environmental factors.

34. The STAR METRICS model uses an 'input-output' (I/O) modelling framework[a], a concept originally developed by Leontief (1941). The primary purpose of using this methodology is to model the interdependence among industrial sectors in an economic system (Stimson, 2002). The models produce a multiplier index that measures the total effect or impact of an increase in demand on employment or income. The reliability of these inputs will be high, although - as with any I/O models - there are often questions as to how the outputs directly relate to inputs. The transferability of this model to other fields is also a question that must be raised. The model looks at the industry as a whole, and so identifying the nano-specific technologies and end products may be something of a challenge.

35. The collaborative approach that STAR METRICS takes ensures the involvement of research institutions and those within the scientific arena whilst simultaneously creating a scientific data infrastructure based on real-life data. The spillover effect of investments is also captured in the STAR METRICS methodology. This effect can sometimes be seen as an explicit objective of investment in research, especially when related to Federal funding (Macilwane, 2010). Capturing this return from investment, to both other organisations and other parts of the economy, is an important function of any economic model that aims to fully measure these economic returns.

36. Spillovers are, by their nature, hard to capture and perhaps even harder to quantify. The use of I/O matrices, seen in the STAR METRICS approach, identifies routes by which knowledge might flow between firms and quantifies their likely scale providing a spillover estimate. This is known as a 'flow approach' (Nadiri, 1993). The ability to determine the value of these flows is perhaps an important factor when considering the suitability of an economic model to determine returns on investment: providing

[a] Broadly defined, an I/O model is a quantitative economic technique that represents the interdependencies between different industries within an economy, branches of national economies or competing economies.

estimates of spillover effects may be a factor in policy making. The long-term nature of the STAR METRICS project is, however, impossible to predict. There is no way of measuring how long it will take for basic research funding to result directly in societal benefits (Kramer, 2010).

4.1.3 Analysis of existing methodologies

37. There are a number of studies that aim to value nanotechnology using a variety of different methods. Each of these methods has been developed within the constraints of the industry it is trying to value, and reflects the large amount of assumptions that have to be made due to gaps in data and knowledge within emerging technologies.

38. As demonstrated through the above analysis of the models for technology valuation, there is little in the way of a definitive model or set of metrics for gaining an economic estimate. The approaches used in all the methodologies aim to determine the monetised value of a certain techno-enabled product/industry or aim to develop aggregate indices for policy decision making. The calculation of aggregate indicators relates to combining a number of factors to create an overall innovation score or indicator. This method does provide some means to measure innovation and has gained popularity from governments and policymakers (Stone, 2008). Even so, the monetisation approach offers greater potential towards understanding of the innovation process, and in many ways may seem more transparent as the aggregate indicator approach is highly complex (Stone, 2008). The issues with this approach relate to monetising intangibles and unknowns, where it is not always obvious which approach is best.

39. The following sections outline the inputs, process and outputs for the key models discussed in this report, and highlight where these difficulties lie in each.

Model inputs

40. In considering the inputs and outputs of models and metrics used to value both nanotechnology and other technological fields, an understanding can be gained of the overall complexities of the models, assumptions made and the overall efficacy of the valuation techniques.

41. The Defra model excludes fundamentally 'new' products due to its comparative approach; it can only value products in relation to an incumbent. The inputs require in-depth market knowledge of existing technologies to which the nano-enabled product is to be compared. However, with this model no complex database of information is required. Information to be inputted into the model is easy to obtain and directly relevant to the nano-enabled product and incumbent. Assumptions may have to be made due to a lack of available market data, but the Defra guide to the methodology explicitly states how proxy values and assumptions can best be used.

42. The Defra methodology is comparative in that the valuation of a nano-enabled product is derived by comparison with an incumbent. This does assume that an incumbent product can be found and that there are sufficient readily available data to allow for the comparison.

43. It is also worth noting that the methodology is time-sensitive in that its use will result in a valuation *at a point in time*. It may be, therefore, that any valuation figure needs to revisited periodically as changes such as new advancements in the market or technology may impact on the final valuation of the nano-technology product. For example, technological advances in existing products may render newly developed nano-enabled products obsolete.

44. This is in contrast to the STAR METRICS model where, once data streams and inputs begin, data collection can continue to flow over a longer time period with little additional oversight. Inputting data into the STAR METRICS model is voluntary although the incentive to do so is perhaps enhanced by the

low burden of participation. The STAR METRICS model does not require the construction or development of new databases but instead relies upon institutions providing their existing administrative data (National Institute of Health, 2010).

45. The success of the STAR METRICS model relies heavily on participation from S&T research organisations. The programme currently consists of five Federal S&T agencies (NIH, EPA, DOE, USDA and NSF) and more than 80 research institutions, primarily universities, providing enough participants to give a solid overview in determining the value outputs of Federal funding. It may be, however, that higher participation levels are required before the model can be fully used as a policy-making tool.

46. Criticisms of STAR METRICS include claims that it oversimplifies the inputs required in order to effectively determine valuation outputs. Measures of national R&D investment may only be one input required and in the longer term the model may require additional inputs focusing more on researcher competency, peer review, the tools available to the researchers and the wider business environment including data on infrastructure, government policy and government frameworks (Sargent, 2008).

Use of valuation methodologies

47. STAR METRICS and other I/O methodologies - such as the Human Genome Project (HGP) - rely on experts in order to obtain output information, and are often complex resulting in a lack of transparency. However, this type of model is considered the most widely accepted when determining the economic outputs within an industry, and so it may be that this model would be easiest to accept were a standard tool to be put in place.

48. The Defra model has specifically been designed for use by a variety of organisations, as demonstrated by the case studies in the methodology document, which suggests that the model can be used in a variety of different applications.

49. Both models could be described as incorporating elements of ‘freeware’ in that outputs are publicly available, and in the case of the Defra model it is freely available for use and application on the internet. Both models show a degree of transparency in their use, although it may be that the Defra model is clearer in the way the estimations are explained and laid out. It is likely that the development of nano-enabled products will require an increasing amount of public involvement and understanding, and so to this end it may be important that this is reflected in any economic model.

50. The Defra approach is best used in a ‘broadly defined market’, in that it is intended for use at a product or application level rather than supplying sectoral outcomes or examining aggregate product groups (Lancaster, 1971). This is in contrast to the inter-industry approach of STAR METRICS which is more relevant and accurate on a macro scale. As with the Battelle Report into both the bio-pharmaceuticals sector and the HGP, this model relies heavily on real-life case studies to populate the model. This model requires large data sets to even generate high level data.

51. In terms of development, all approaches to the economic valuation of technology, as discussed above, were developed by the public sector, although this does not limit their use to this sector. The public and private S&T sectors are co-operating on the development of STAR METRICS with the aim of developing bespoke STAR METRICS applications that meet the unique needs of participating institutions. As yet the STAR METRICS approach has not been tested with major companies in the S&T industry, but there is a possibility for it to be used in that context, enhancing participation and the overall levels of inputs and resultant outputs.

52. The Defra model has been specifically designed for use by policy makers and governments in order to perform cost/benefit analyses that comply with public sector accountancy and evaluation practices.

Private sector use has also been specifically stated as a possible use of the model. As with STAR METRICS, a key stakeholder in the development of the Defra model was the public research establishment. This use is specifically related to the evaluation of the outputs of possible research funding streams. Similarly, STAR METRICS specifically looks at the consequence of public sector research investment as opposed to directly measuring how private companies' investments have created returns.

Model outputs

53. The outputs of each of the models studies vary greatly. The STAR METRICS model gives a broad view of the S&T industry as a whole whereas the Defra model takes a more product- or process-orientated approach. Each model is intended to be used in different situations and so the outputs of these are different.

54. The STAR METRICS model is based around the creation of a database which will build on this information in future to allow for measurement of science impact on economic outcomes such as job creation, on scientific outcomes such as the generation and adoption of new science, often measured by citations and patents, and on social outcomes such as public health (National Institute of Health, 2010). However, there is criticism that, although the STAR METRICS output will be used as something of a basis to justify economic spending in the S&T sector, there is no evidence to suggest that increased spending will result in an increase in innovation (Macilwane, 2010).

55. The initial product from the STAR METRICS model is a report documenting the number and types of jobs created through S&T grants, and will allow for a rigorous analytical approach to understanding the complexities of research investment, ultimately with the ability to develop descriptive results of the S&T sector (Lane & Bertuzzi, 2010).

56. The outputs of the STAR METRICS model will be varied; from in-depth quantitative estimates of the industry to more qualitative understandings of the S&T industry. The generation and adoption of new science that the STAR METRICS project aims to measure as one of its outputs is calculated through a measurement of the number of new patents and citations. Patent numbers is widely used as a proxy of innovative output, although there is a difficulty in constructing firm datasets that contain patent data (Griliches, 1995)[a]. The STAR METRICS model allows for an analysis of direct, indirect and induced outputs that flow from S&T funding.

57. The Defra model differs in that it studies the economic effects on innovation ex-ante[b] and produces a valuation based on a specific nano-enabled product or process. The issues and assumptions that arise with this approach are further discussed in Section 4.2. It should also be noted that the Defra model is comparative, thus the output of the model represents the benefits of the nano-enabled product assessed against an incumbent, rather than its absolute value.

58. Even so, the Defra methodology offers an approach that enables both funders and other industry observers to attempt to at least part-way rationalise their investment in nano-enabled products. The levels of investment in nanotechnology are high, and it is necessary for both companies and other investors, both public and private, to be able to monitor and understand resultant economic benefits, a process which the Defra model enables.

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[a] Section 0 looks further at the use of patent data as an indicator

[b] Ex-ante is 'before an event,' for example a forecast. Ex-post, or 'after an event', includes measures of past performance.

4.2 Methodologies for other technological fields

59. The following section provides an overview of alternative economic metrics and models currently in use in other technological fields. An understanding of the practicalities and limitation of applying these methodologies to nanotechnology is also provided.

4.2.1 The biotechnology industry

60. Biotechnology can be defined in a number of different ways but it is principally centred on the use of living organisms by humans in order to create products or to perform tasks. This industry can be said to draw a number of parallels with the emerging nanotechnology sector, mostly in terms of the radical way in which it can be applied to transforming existing industries (David, 2008). A note of caution should be drawn with regards to these comparisons, however. By definition, 'radical' technologies represent an area of focus that has not been studied before and as such may not follow the same patterns of expansion of previous technologies or innovations. Section 4.2 of this report looks further into some of the factors that may create differences between how these technologies develop, including the rate of diffusion and product lifecycle.

61. Several studies have been undertaken which outline similarities between the biotechnology and nanotechnology industries, drawing parallels by comparison of technology innovation and through the study of regulatory issues arising with biotechnology that could be applicable as 'lessons learnt' for nanotechnology (Rothaermel & Thursby, 2006; Mehta, 2004). Although there are similarities between the complexities, unknowns and possible development of these two technologies, comparisons are difficult as nano- and bio-technology are at different stages in their lifecycles: it is impossible to predict whether nanotechnology will follow the same trajectory, represent similar benefits or have to overcome similar hurdles as biotechnology.

BioEconomy 2030

62. The continued commercial application of biotechnology has resulted in a rapid development of the sector, and highlighted the need for rapid development of policy frameworks and a greater understanding of future uncertainties and potentials. The BioEconomy 2030 report takes an evidence-based approach to providing a broad analysis of future developments in the sectors where bio-technology has the greatest potential impact: agriculture, health and industry. Biotechnological developments to 2015 are estimated through quantitative analysis of existing data, past trends, field trial data, company reports, and R&D expenditure figures. The role of additional factors, including regulation and social factors, and possible future developments are also outlined. The developments of fictional scenarios to 2030 are also developed to explore the impacts of a variety of factors on the BioEconomy of the future (OECD, 2009).

63. The report is focused on developing a policy agenda and encompasses the economic and social factors that may develop in these sectors (OECD, 2009). Even though the report aims to be as comprehensive as possible in outlining the future potentials and challenges of the 'BioEconomy', there is still recognition of the limitations of this. The report highlights that biotechnology is undervalued as there are a number of factors, including potential for future development of currently unimaginable products, which are not measurable in monetary terms and often not included in analysis. The impacts of these could have wide-reaching benefits to health and the environment, but it is not feasible to estimate this to an appropriate level of accuracy (OECD, 2009). The main challenges for biotechnology draw parallels with nanotechnology and relate to a lack of supportive regulation and public opposition to the introduction of this technology.

The Human Genome Project (HGP)

64. The HGP began in 1990 and was planned to last for 15 years, although rapid technological advances across this time period led to an early finish, with a completion date of 2003. The aim of the project was not only to identify the 20,000-25,000 genes and categorise sequences that make up the chemical base pairs of human DNA, but also develop methods of storing this information and improve tools for data analysis (BERIS, 2011). A recent report suggests that between 1988 and 2010 the initial Federal investment of $3.8 billion in the HGP has driven a return of $796 billion in US economic output, creating 310,000 jobs. A large part of the HGP was to allow for the transfer of related technologies to the private sector, providing the medium for which the multi-billion US biotechnology industry and new medical applications could be developed (BERIS, 2011).

65. The investment in the HGP has, no doubt, had a lasting impact on this field of research and allowed for a foundation for progress in the biosciences. There are, however, criticisms that can be made of the methodology used to calculate the return on initial investments for this project (Drake, 2011).

66. In measuring the economic output of the HGP, the Battelle (2001) report uses an I/O model, common practice in such studies to calculate the return on initial investments (Drake, 2011). In the case of both nanotechnology and the use of I/O models in biotechnology research, these models can be used for forecasting and predicting potential future performance and economic output from a level of input.

67. In some ways, the HGP methodology is comparable to STAR METRICS, especially with regard to the initial approach. Both develop a ‘from the ground up’ database of individual companies or researchers involved in the industry and use employment as a base for an I/O analysis. The HGP report analysis includes a separate assessment of post-HGP expenditure and impacts on the genomics-enabled industry as a whole. These far-reaching impacts, outside of the initial scope of the data collection space, are analogous with the impacts that STAR METRICS is aiming to measure through its database.

4.2.2 The Biopharmaceutical sector

68. In 2011 a further report, *The US Biopharmaceuticals sector: Economic Contribution to the Nation*, also utilising an I/O analysis, aimed to quantify the economic impacts of the biopharmaceutical sector, with specific reference to the US economy and job creation. Through the use of the I/O methodology, an attempt is made to quantify what impacts would occur if revenues from the biopharmaceutical industry were to increase or decrease (PhRMA, 2011).

69. In this report the outputs valued include a wide variety of factors including jobs, personal income, and tax revenues. In addition, the report highlights some of the ‘functional impacts’ of the sector; essentially the wider-ranging benefits that the biopharmaceutical sector provides. This includes contributions to enhancing human health, improving life spans and sustaining high quality of life. Also included in the report is an assessment of how the biopharmaceutical sector enhances key aspects of the US economy; innovation, product exports and the quality of jobs produced (Battelle, 2011).

70. A measure that is outside the scope of the biopharmaceutical I/O model is the impact on productivity in other industry sectors. Although positive impacts are likely to occur, quantifying these is complex and therefore not covered in the report (Battelle, 2011). This report is another example of the use of an I/O model to estimate the economic contributions that flow from research investments.

4.2.3 Information technology valuation[a]

71. A 2003 report by the European Commission's Interchange of Data between Administrations (IDA) programme studies information technology. The methodology for the report focused on the TETSA (Trans-European Services for Telematics between Administrations) network which provides an infrastructure for business needs and information exchange requirements between all EU Member States and institutions (European Commission, 2005). The study was based around a cost/benefit analysis (CBA) of TESTA, in order to determine the benefits and costs that flow from this network.

72. This project differs from a traditional CBA of cost and revenues in that it not only focused on the direct financial benefits resulting in a return of investment (ROI) figure, but also aimed to include many of the information technology (IT) benefits that are hard to quantify, such as access to information, customers' satisfaction and facilitation of an enhanced decision-making process (DG Enterprise, 2003).

73. This methodology, the 'IDA Value of Investment (VOI)', notes that for models used in the public sector there is a need to include qualitative benefits that are normally left out of CBA, and the use of this methodology ensures these benefits are included where feasible (Europa Press Release, 2003).

74. As with the other models for economically assessing technology, the IDA VOI methodology highlights the difficulties of making ex-ante estimates and recognises that a certain level of assumption should be made. The recommended division of 'verified costs', including known costs based on contracts and facts, and 'unverified costs', including estimations or assumed future costs, is practical as it allows for transparency where assumptions of the unknown have occurred. It is also mentioned in the report that, as time goes on and the TESTA initiative develops, uncertain estimations may become clearer and the overall valuations can be updated (DG Enterprise, 2003). This is a similar recognition to that which the Defra methodology outlines, in that a model such as this can only value a point in time. The more developed and further integrated in the market a product is, the more accurate the economic estimates can be.

4.2.4 The value of health research[b]

75. In 2008, a UK-based study commissioned by the Academy of Medical Sciences, the Medical Research Council and the Wellcome Trust was compiled with the aim of comparing the cost of UK medical research with the economic benefits accruing from this (Health Economics Research Group, 2008). This study takes an initial approach to looking at returns from investment in health research but finds that there are a number of limitations at present. These are centred on a lack of available information and data, specifically with regard to the lack of a standardised way of mapping and classifying research funding.

76. Spillover effects are also highlighted as an area that needs more research. These include questions such as: To what extend are benefits from UK health research felt on a global scale, and how can knowledge flows and influence of UK research best be identified? The applicability of this report to nanotechnology may not, therefore, be in applying the same methodology but in recognising that a comprehensive valuation model must consider all of these factors.

4.2.5 Overview of methodologies

77. It is clear from this overview of methodologies, that the use of I/O models is widespread. This same model is used in the STAR METRICS approach to valuing nanotechnology and may command a

[a] See Appendix C for further details of methodology

[b] See Appendix D for further details of methodology

certain amount of credibility due to its ‘tried and tested’ status. The use of an I/O analysis is attractive in part because it provides relatively straightforward results. The use of the multiplier effect to calculate the total impact and wider effects on the economy also yields far larger values than would be obtained by any direct ‘head-count’ approach[a] (Wisconsin Centre for Cooperatives, 2009).

78. The difficulty in comparing nanotechnology with other industries stems from an uncertainty into how the ‘nano’ sector will evolve. Although parallels have been draw with the biotechnology sector, nanotechnology differs in that it covers more than just one sector and therefore has the possibility of creating an impact on a larger scale.

4.2.6 Alternative value indicators

79. The following section highlights some of the key indicators that are often used when estimating technology valuation. These are often factors which are included in the economic modelling process although they can also represent broad valuation techniques in themselves.

Modelling consumer valuation (CV)

80. Consumer valuation (CV) is defined as being the consumers’ willingness and ability to pay for a particular product. By definition, CV is subjective; i.e. the value of the product and ‘service’ that it provides is dependent on the preferences of the consumer. This relationship can be modelled and estimated. Indeed in some instances it may have already been determined and this information can be directly used. Depending on what data are available, there are a number of methods for assessing this variable, such as focus groups, using proxy variables, survey questionnaires (stated preference surveys), revealed preference surveys and analysing purchasing patterns of different products. CV is difficult to apply for many nano-enabled products, mostly because there is little precedent for these products in the market. CV is also a difficult concept in itself, and often techniques for determining this are insufficient or simply unable to produce accurate estimates.

81. CV is also related to the ‘hype’ surrounding a product when it is introduced to the market. The term ‘hype’ generally implies a degree of exaggeration about new technologies and products. ‘Hype’ need not be formal advertising, but is often the more informal ‘talk’ (at conferences and in the business press) about the potential capacity of a new technology to transform customer experiences or business processes. The literature on demand and consumption makes a distinction between various customer types and these will react to hype in different ways. Some will accept hype because they are keen to make the most of the potential of a new technology. Others will be unforgiving, and if they see themselves as victims of ‘hype’ will start to spread negative messages.

82. Due to these complexities, it is not possible to offer a simple framework which adequately captures the full effects of hype on demand. The Defra methodology notes that, if the user of the model had the desired expertise, the effects of ‘hype’ could be included, but the complexities of this fall beyond the scope of the methodology as it is presently.

[a] The “head count” approach essentially creates an inventory of size, sales revenues and other factors between cooperative organisations in an economy. This gives a broad idea of the scale and type of linkages between those organisations studied, but does not capture the multiplier effect and specific industry-to-industry linkages.

Supply and value chains

83. The value chain approach to understanding nanotechnology essentially aims to map how technology (or nanotechnology) investment impacts the wider economy. A Lux Research (2006) report maps the nanotechnology value chain from nanomaterials (un-edited nanoscale structures) to nanointermediates (products such as coating with nanoscale features) to the end of the value chain; nano-enabled products (the end goods that incorporate nanotechnology). This approach looks at nanotechnology not as an industry, but as a set of tools and processes across industry, from basic materials to finished goods and applies forecasts to each section of the chain.

84. As with any economic model, precisely defining what is to be valued is an important first step. Using this value chain model as a way of valuing final nano-enabled products may be problematic in that it looks at the product as a whole and does not consider how much of the product is actually ‘nano-derived’ (Berger, 2007). This represents an argument for the use of a comparative methodology (such as the Defra model) when valuing nanotechnology as it allows an understanding of the value added of the nano-enabled product.

85. Even so, this method of categorising nanotechnology has been widely cited and utilised and can allow for a clear definition of the parameters of the nanotechnology that is to be valued, by determining at which stage of the value chain the product lies.

Use of patent data

86. Patent-based indicators are widely used as a proxy for innovation activity and as a tool to estimate the value of new technologies. There is also an increasing use of patent citations as ‘output measures’ for the impacts of S&T funding (Stone, 2008). The STAR METRICS model uses patent data in this way.

87. There is a strong literature base that supports the use of this patent data as a proxy, and empirical evidence to suggest that there are links between patent citation (i.e. the citation links from a patent to other patents and scientific literature) and companies with high market value (Stone, 2008). Even so, the weaknesses of this method are apparent.

88. In order to utilise patent data as a measure of innovation or output, it is necessary to create datasets that encapsulate the required patent information. This in itself can be problematic - although the widespread use of electronic data storage techniques has facilitated this to a great extent. To fully make use of patent data it is often merged with other datasets containing information such as accounting and financial measures. Problems also arise here, as matching different data sources can provide inaccuracies and resultant measurement errors (Thoma, 2010).

89. There is a level of subjectivity involved in assessing the quality and value of a patent. Each patent differs considerably in its technical and economic significance. Many new developments will not be patentable and many that are patented may not achieve any level of commercial success (Desrochers, 1998). It may be, therefore, that the use of patent data in this way will not provide the best estimates of value of nanotechnology. Instead, patent data can be used to provide an overview or indicator of general increases or decreases in innovation throughout the wider economy.

5. Identifying key considerations

90. Through studying the available methodologies for the valuation of a wide range of technologies, it is clear that there are a number of considerations that need to be outlined. Each model reflects a certain amount of uncertainty and requires proxies to be used and assumptions to be made.

91. These issues are perhaps amplified with nanotechnology valuation, as ‘radical’ innovations compound issues such as lack of information and datasets and uncertainties with how these technologies will react in the market. The following section outlines these issues, with the aim of determining how these will affect any comprehensive model or metric used to value nanotechnology.

5.1.1 Lack of information

92. The analysis of economic models in use to value both nanotechnology and other technological sectors has highlighted the difficulties in developing a comprehensive model. If one model were to cover everything it is likely to be un-workable and be supported by a vast number of assumptions. Simply put, any model must select the features that are necessary to consider and must disregard the rest.

93. The Defra model can be described as an incremental metric, in that it excludes radical innovation due to a lack of data and a level of uncertainly about this type of nano-enabled product. Essentially, there are issues in valuing radical innovations as, before they hit the market, there is a lack of data and understanding of how they will act. The difficulty in this is implicitly highlighted in the Defra methodology, although is also implicitly reflected in an I/O model approach such as that taken by STAR METRICS.

94. One of the broadest issues with using a model to estimate, ex-ante, the value of nano-enabled products is the uncertainty surrounding these. It is only possible to observe the outcomes that follow research investment and development, not the results of what may have happened were the research not to be implemented. This essentially results in a situation in which establishing unequivocal links between research and its output will always be a difficulty (Health Economics Research Group; Office of Health Economics; RAND Europe, 2008).

95. Two widely recognized problems with investing in nano-enabled products are the long time-frames and high development costs required to bring a product to the market. A great deal of money is needed for a long period of time until the investors may get any compensation for their investment. This highlights the element of risk that is present when investing in a technology for which the future applications and adoption are unknown. This is a similar problem to that which faced biotechnology - especially in the earlier stages of development - when industries, supply chains, and regulatory frameworks were less established (David, 2008).

5.1.2 The replacement of current technologies

96. Part of the issue with defining nanotechnology is due to the way in which the technology can be deemed incremental (i.e. enhancing the functions of an existing product) or radical (i.e. creating an entirely new product). Nanotechnology has the ability to create new products, the value of which are not quantifiable until the product has reached the market, as well as replace current technologies through incremental or radical developments.

97. The 2006 Lux Research report noted that, through the development and application of emerging nanotechnologies, improving nanotechnology products will drive second and third order disruption across the industry (Lux Research, 2006). So, for example, the introduction of a nano-enabled product that reduces the maintenance requirement of a product will result in a decrease in demand for those who are employed in this area. This may, however, be offset by the benefits associated with the production of this nano-enabled product. Essentially, the impacts of nanotechnology becoming more widespread are hard - if not impossible, to predict. Like other technologies that can be classified as disruptive or enabling, nanotechnology will likely lead to the simultaneous destruction and creation of jobs (Committee to Review the National Nanotechnology Initiative, National Research Council, 2006).

98. It is difficult to understand to what degree nanotechnology has the ability or scope to replace existing technologies, and to what extent it can collaborate with existing industries to improve existing product functions. The convergence of technologies may also result in the creation of new products, or at the least impact the existing industries, but this does not necessarily mean the displacement of current technologies.

99. The enabling aspects of nanotechnology result in a potentially large range of applications. The threat of nano-development to existing companies may not be that of displacement, but rather of difficulties for organizations - especially smaller companies - to opt for and pursue the most viable application on nanotechnology. For these smaller companies, access to a relevant market may also present an issue.

5.1.3 Investment in nanotechnology

100. It is likely that any all-purpose models for valuing nanotechnology cannot be comprehensive as each circumstance will have different parameters, scope and issues arising and will be formulated under different contexts. For example, venture capitalist (VC) and private equity models may have a different scope to other methodology types.

101. VC investment relates to that provided to early stage, high potential, high risk and high growth start-up companies. These are attributes shared by many new technological industries, including nanotechnology. A VC investor will place a high emphasis on the likelihood of market acceptance of a product or process in deciding investment potential. In this case a model that identifies the prospects of a product, such as the Defra methodology, would be beneficial.

102. Governments are also likely to invest in high gross value added products and sectors, although this is often more focused on achieving socio-economic goals rather than return on investment. The use of models by governments is also in order to determine the wider commercialization potential of public investments in a particular technology. This is to specifically ensure Actions to leverage private investment in technology (ObservatoryNANO, 2010).

5.1.4 Measuring spillover effects

103. Spillover benefits from R&D are a particular type of positive externality[a], which can be seen as those accruing to an innovating firm's customers or to its competitors.

104. By their nature, spillovers are hard to capture and quantify - although attempts have been made. There two methods by which spillovers might be measured: 'flow approach' and 'cost-function approach' (Nadiri, 1993). The flow approach is based on identifying routes by which knowledge might flow between firms and then quantifying their likely scale. This is done using I/O matrices such as the STAR METRICS model. More complex, flow-type models seek to better quantify the 'distance' between firms and industries by including the use of patents and other measures of technological distance.

105. The problem with all measurements of R&D spillovers is setting the boundaries; spillovers can be inter-industry as well as intra-industry. The literature produces a wide range of values for the spillover effects of R&D on a firm or sector's output. However, given the problems with measurement of these, it is perhaps surprising that they are not even more variable.

[a] A positive externality is linked to the spillover effect. It refers to a positive effect or benefit realised by a third party resulting from a transaction in which they were not directly involved.

106. There is a variety of factors that influence the scale of these spillover benefits, including the competitiveness of the market, regulatory structures, technological innovations, knowledge sharing and co-operation between innovators and other players in the market (Jaffe, December 1996).

5.2 Uncertainties in economic nanotechnology valuation

107. The development and commercialisation of nano-enabled products faces a variety of challenges and uncertainties. These include the questions of risk and more dynamic issues. Any model that seeks to value ex-ante a technology that is radical, innovative or just new to the market must make a number of assumptions about how the product will react one it becomes commercialised. This section outlines these issues and develops an understanding of how (or whether) it is possible for methodologies, such as the Defra model, to value a nano-enabled product by resolving these issues of uncertainty.

5.2.1 The diffusion of nanotechnology

108. The diffusion of nanotechnology relates to how, and at what rate, this technology spreads through the market. For the purposes of understanding this issue, it is assumed that the introduction of nanotechnology will produce the same reaction as that of other technologies. Although there are a number of different models of diffusion, it is widely accepted that adoption follows a Normal frequency, or an S-shaped cumulative curve. There is, however, little to suggest which model is most accurate in terms of understanding the diffusion of a technology (Baptista, 1999). There is a wide range of factors that have been shown to influence the rate of adoption, and diffusion rates are complex to predict and are sensitive to a wide range of forces. Estimating the rate of diffusion of nano-enabled products can therefore be difficult (Rogers, 1995; Bandiera & Rasul, 2006).

109. The Defra model aims to consider the rate of diffusion during the stage where the economic value of the product is estimated. It suggests that the relative immaturity of the nano-enabled applications and products means that the full commercial success of these technologies is likely to be in doubt. The risk associated with these in-development technologies is taken into account through the use of empirical discount rates, which reduce the value of a technology in proportion to its distance from market. The further the product is from full commercialisation, the lower the value of the technology. Therefore for products that have not yet been launched onto the market, a higher discount rate is used to reflect the higher risk associated (Oakdene Hollins, 2010).

5.2.2 Product lifecycle

110. Product lifecycle relates specifically to the trends that are expected to occur across the lifetime of a product, especially in terms of price and value changes. A product is assumed to follow the stages of introduction, growth, maturity and decline, although the length and even certainty of these stages is hard to predict. The literature does, however, suggest that the prices of new products fall every year after a product's launch, although the steepness of this price fall is unclear.

111. The Defra methodology takes account of this factor when determining the sales price of the nano-enabled product. As the speed of price decreases across the product lifecycle cannot often be easily determined, the methodology suggests an assumption is made that the sales price of the nano-enabled product decreases linearly towards the cost of production. However, this is suggested only when there is a lack of evidence and the user of the methodology cannot determine more appropriate measures for the nano-enabled product being valued (Oakdene Hollins, 2010).

5.3 Non-OECD economies

112. In the period 1990-2009, OECD countries accounted for over 82% of the 17,133 nanotechnology patents and corporate publication entries. This is expected to change over the course of the next twenty years, however, as research suggests that research and innovation in nanotechnology is heavily dependent on the 'general technology development strength' of each nation (Rocco, Harthorn, Guston, & Shapira, 2010). The BRIC countries (Brazil, Russia, India and China) are projected to rapidly outpace OECD countries in terms of growth over the next two decades, and it could be expected that research and innovation in technology will also rise considerably

113. China is already the third largest nation by number of nanotechnology patents, accounting for over 11% of total patents and corporate publication entries. India, Brazil, Chinese Taipei and Russia also make considerable contributions to the total (Rocco, Harthorn, Guston, & Shapira, 2010). This rise is a result of both general increased economic strength and investment and an increased focus on scientific R&D within the BRIC economies.

114. This wider R&D investment includes the development of scientific knowledge based networks. The Brazilian National Council for Scientific and Technological Development (CNPq) has been central to the development of the Lattes CV System. This is a network, not dissimilar to STAR METRICS, that is designed for use by government to evaluate both scientific projects and oversight and to influence funding decisions. As a tool it enables research funders to monitor the subsidy of research by outcome. The tool follows international research funder best practice and is also freely available to non-governmental academic partners.

115. In Russia, specific evaluative metrics are beginning to be developed by Rusnano, a private sector entity with strong support and influence of the Russian government and research establishment. Rusnano has developed partnerships with organisations such as MIT with a view to importing funding and research best practice to Russia. Funding is perhaps provided in a more 'venture capitalist' sense than traditional government research funding, in that money is provided to private firms operating within Russia from an investment perspective (MIT World, 2010).

116. These examples of knowledge-based networks demonstrate the approaches being taken in BRIC countries, where innovative collaborations between traditional governmental funders and the private sector often require unique approaches to funding evaluation and monitoring. These networks are similar to the STAR METRICS model and are, with the exception of Rusnano, industry-wide and not specific to nanotechnology as a sector. It is likely that as investment increases in line with future economic growth projections, specific models - similar in nature to the Defra model - will become more common in these nations.

5.4 Converging and enabling technologies

117. Convergence of technologies refers to the ability for different technological systems to evolve towards performing similar tasks, creating materials, devices and systems. With factors such as economic growth, human welfare and international competition dependent on constant technological progress, convergence of technologies can be expected to be a primary area for innovation in the coming years (Bainbridge, 2007). Understanding of this in any economic model will allow for better representation of the real interactions between technology sectors. Driven by the announcement of the National Nanotechnology Initiative (NNI) in 2000, nanoscale technology has increasingly been recognised for its ability to revolutionise science and technology (Roco & Bainbridge, 2005; Bainbridge & Roco, 2007). Much of this is thought to occur through its convergence with other fields, predominantly the synergistic combination of nanotechnology, biotechnology, information technology and new technologies based on

cognitive science; categorized as the 'NBIC' fields, each of which is advancing at a rapid rate (Roco & Bainbridge, 2005).

118. The principles behind NBIC convergence are that new approaches will be brought to currently diverse areas of research, the combinations of which will yield huge potential. Revolutionary progress in improving human performance through improving sensory, cognitive or physical appearance has often been cited as one key application (Roco & Bainbridge, 2005; Gordijn, 2006).

119. It should be noted that, to an extent, nanotechnology can already be seen as somewhat inter-disciplinary in nature, demonstrating links to a vast range of subject matters (Porter, 2009). Convergence of NBIC technologies is, however, more focused on enabling this synergy which is likely to require fundamental change and the requirement of new technologies, industries, processes and capabilities supported by new skills and knowledge. Comprehensive convergence may, however, also require the introduction of measures to prevent the disruption of existing industries or the current working practices between existing societal institutions (Roco & Bainbridge, 2005).

120. The convergence of nanoscale science is an increasingly recognised field and as the trend for this increases, so should the scope of science policy decisions (Roco, 2003). Incorporation of NBIC technological convergence into strategic R&D is increasingly becoming a priority, although as yet very little exists in the way of a comprehensive framework to facilitate this. There are suggestions that, by its complex nature, nanotechnology itself may spur collaboration. Within many new industries, a patent holder of a technology is likely to be a participant in that market. With nanotechnology, however, a patent holder is likely to own rights across all of the NBIC fields (Nanowerk, 2006).

6. Discussion

121. The review and assessment of both models relating directly to the economic value of nanotechnology and models focusing on other technological areas has highlighted the often speculative approach that is necessary in order to determine value. The importance of developing measurable relevant indicators is clear (National Research Council, 2006).

> *In order to continue with analysis of the economic factors of nanotechnology, it will be necessary to continue to collect data and develop metrics that can facilitate a rigorous analysis of nanotechnology in terms of economic indicators and socio-environmental impacts. The important factor in this is a consideration of how current models and methodologies could best minimise the assumptions and use of proxy data. The more data collected on nanotechnology, the better these models can be. Nanotechnology can be described as both an enabling and a disruptive technology and also extends beyond a specific industry, but rather spans multiple applications creating further challenges* (National Research Council, 2006).

122. It is clear that the paucity of data and the nature of nanotechnology itself are both issues. Developing a sufficient baseline and clear datasets, as are currently attempted through the use of the STAR METRICS model, are important steps towards tightening the evidence base that is required.

123. Through studying the models outlined in this report it is clear that developing a single model, incorporating all relevant aspects in order to estimate the economic value of nanotechnology, is not likely to be achievable. The STAR METRICS model takes an industry-wide view in attempts to develop an understanding of the outputs achieved by Federal funding in the S&T sector, whilst the Defra model takes a more product-orientated approach. Both models have their merits and both require assumptions to be made.

124. A comparative model, such as the Defra methodology for estimating the economic value of innovation in nanotechnologies, takes a forward-looking approach to nanotechnology valuation, and may provide for more useful and accurate outputs for private investors or research funders faced with budget constraints. This does not, however, mean that the model would be less useful for public-sector bodies. In fact, it may provide a clearer evidence-base as to the likely return from research funding in the area of nanotechnology. I/O models such as STAR METRICS do, however, go a long way to establishing the required collaboration between institutions and creation of data frameworks that will allow for an inter-industry approach; good for policy makers and key with nanotechnology due to its multi-faceted role in the market.

125. There are a number of models that attempt to value technological areas other than nanotechnology. These encompass a variety of techniques from an extended CBA used in IT valuation to the use of an I/O model sharing similarities with STAR METRICS. The methodologies to each of these require a variety of assumptions to be made and proxy values to be used. The technological sectors studied can, to an extent, be compared to nanotechnology in that any new, emerging or innovative industry will have similar data collection issues and lack of precedent. In applying these models to nanotechnology these are, therefore, present. The nature of nanotechnology as an emerging research area means that whatever methodology is applied there will always be a certain amount of the unknown to consider and attempt to model in any economic valuation technique.

APPENDICES

A: Stages of the Defra methodology

The Defra methodology calculates the value of this nano-enabled product over a set time frame, exploring the benefits to the consumer and producers as well as the wider benefits to society. The methodology itself consists of twelve steps:

1. Select the nano-enabled product
2. Define the functionality
3. Identify the incumbent product(s)
4. Select scenario
5. Market definition
6. Identify data requirements
7. Determine production costs
8. Determine sales prices
9. Establish market size
10. Determine externalities
11. Calculate surplus
12. Estimate economic valuation (Oakdene Hollins, 2010).

Each of these stages is supported by a document entitled *A comparative methodology for estimating the economic value of innovation in nanotechnologies*, which guides the user through the process of applying the model.

B: An overview of the I/O methodology

An I/O model can be used as a descriptive tool in understanding flows of an economy, a forecasting tool for estimating the impacts of events or policy changes and for assessing specific scenarios or goals.

The three basic components of an I/O model are:

1. Transaction tables; these are essentially ‘spreadsheets’ of the economy containing data on the monetary flow of goods and services.

2. Direct requirement tables; these tables are derived from the transaction tables and show the resources, or input of commodities, that an industry requires to produce a dollar of output. The value-added component that an industry requires to produce a dollar of output is also shown.

3. Total requirements tables; this table is the ultimate goal of the I/O analysis and requires transaction tables and direct requirement tables to first be compiled. This table shows the monetary flows between industries in the production of output for a given sector.

Table 1 outlines and defines the type of multipliers used in I/O analysis. Multipliers are used to analyse the 'ripple' effect of changes in certain factors.

Table 1: Types of multiplier for I/O analysis

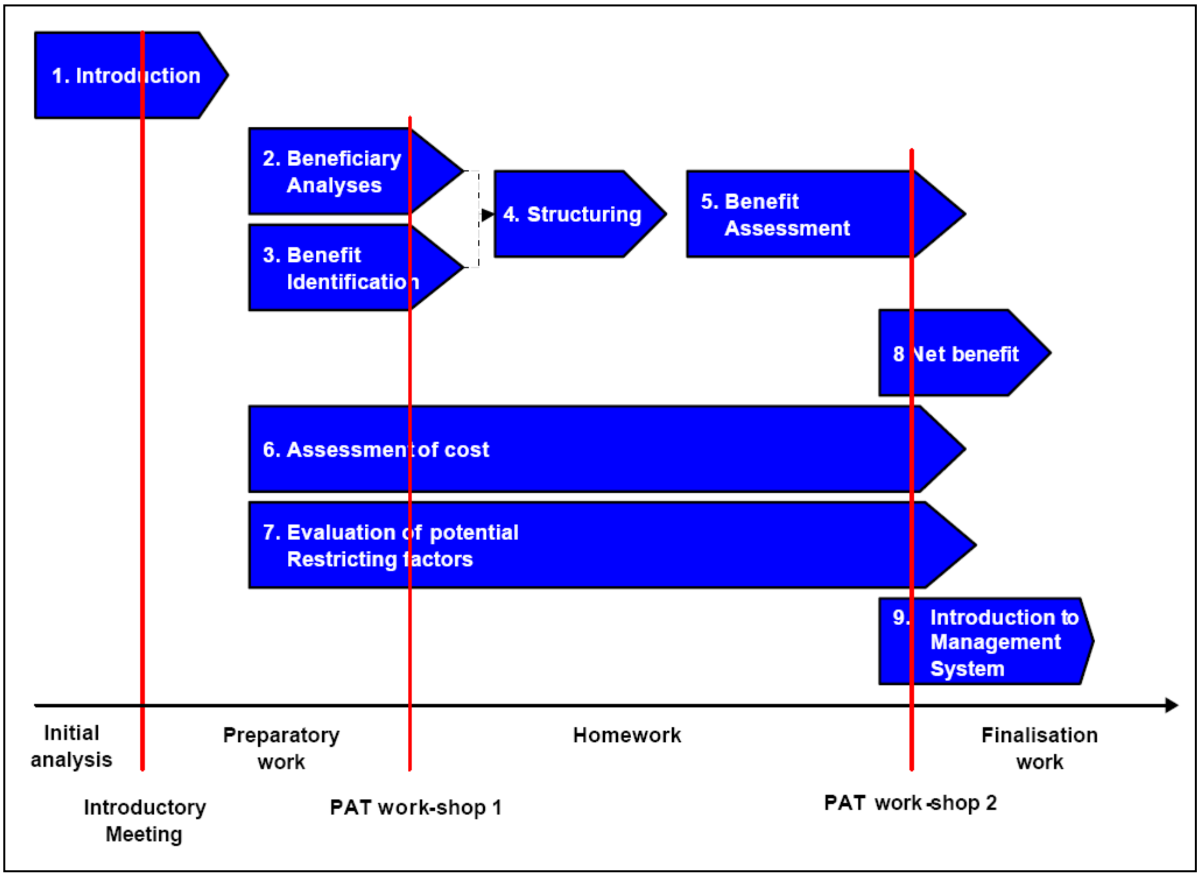
Type	Definition
Output multiplier	The output multiplier for industry ***i*** measures the sum of direct and indirect requirements from all sectors needed to deliver an additional dollar-unit of output of ***i*** to final demand.
Income multiplier	The income multiplier measures the total change in income throughout the economy from a dollar-unit change in final demand for any given sector.
Employment multiplier	The employment multiplier measures the total change in employment due to a one-unit change in the employed labour force of a particular sector.

Source: Input-Output multipliers, Available at: http://reic.uwcc.wisc.edu/implan/

C: The IDA VOI methodology: Evaluation of information technology

Figure 1 represents the nine key stages of the IDA VOI methodology, from initial analysis to end valuation result.

Figure 1: IDA VOI methodology stages



Source: IDA VOI methodology, Available at: http://ec.europa.eu/idabc/servlets/Doc676e.pdf?id=18194

As well as outlining the stages of the methodology, the diagram also shows where meetings and workshops would need to take place in order to utilise the model through collaboration with experts and developers. The *IDA Value of Investment* report outlines these and further details how the methodology is carried out in practice.

D: Stages of the UK Value of Health Research Methodology

Throughout this methodology, economic returns to medical research comprise were assumed to consist of two elements:

1. Health gains net of the health care costs of delivering them
2. GDP gains (UK national income that results directly and indirectly from the medical research and the further activity stimulated by it) (Health Economics Research Group; Office of Health Economics; RAND Europe, 2008).

A 'bottom up' approach is taken is that detailed analyses of specific disease areas is studied. The summation of estimates for each disease area provides a value for returns to medical research as a whole. Initially, returns to public and charitable research from cardiovascular disease was estimated and then tested in the area of mental health.

To estimate the net value of health gains the following steps were taken:

1. Economic literature was reviewed to obtain published figures for the Quality Adjusted Life Years (QALYs; a widely used measure of quality and quantity of life) gained per patient from specific patient group or intervention combinations.
2. These figures were multiplied by estimates of the numbers of users of each intervention, to give an estimate of the total QALYs gained from each intervention.
3. QALYs gained were monetised by multiplying the estimates from stage two with published figures on the opportunity cost of a QALY within the current NHS budget.
4. A review of existing economic literature provided estimates of the incremental health care costs associated with each intervention. These were multiplied by the numbers of users, to quantify the incremental health care costs of each intervention.
5. Estimates of the impact of health research on UK GDP were estimated through an extensive literature review into the 'spillovers' from public and charitable research, between both organisation and sectors.

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