Unclassified **DSTI/STP/NANO(2012)12**

Organisation de Coopération et de Développement Économiques
Organisation for Economic Co-operation and Development

16-Mar-2012

English - Or. English

Directorate for Science, Technology and Industry
Committee for Scientific and Technological Policy

DSTI/STP/NANO(2012)12
Unclassified

Working Party on Nanotechnology

OECD/NNI International Symposium on Assessing the Economic Impact of Nanotechnology
Background Paper 1: Challenges for Governments in Evaluating Return on Investment from Nanotechnology and its broader Economic Impact

The Symposium is jointly organised by the OECD and the US National Nanotechnology Initiative and hosted by the American Association for the Advancement of Science

This paper has been prepared for the International Symposium on Assessing the Economic Impact of Nanotechnology

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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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JT03317970

English - Or. English

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BACKGROUND PAPER 1: CHALLENGES FOR GOVERNMENTS IN EVALUATING RETURN ON INVESTMENT FROM NANOTECHNOLOGY AND ITS BROADER ECONOMIC IMPACT

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Section 1: Introduction

1. Assessing the economic impact of any investment made by governments is a complex and challenging task; the OECD Science, Technology & Industry Scoreboard 2011[1] for example contains over 180 indicators resulting from more than 50 years of indicator development. This task becomes even more complicated when looking at nanosciences and nanotechnology investments due to a combination of complex factors. Nanotechnology is defined by the International Organization for Standardization as the '*application of scientific knowledge to manipulate and control matter in the nanoscale in order to make use of size- and structure-dependent properties and phenomena, as distinct from those associated with individual atoms or molecules or with bulk materials*'[2]. Nanotechnology is multidisciplinary and cuts across traditional industrial sectors allowing the realisation of many new products and processes. As such it overlaps with other key technologies such as Information and Communication Technologies (ICT), Advanced Materials, Advanced Manufacturing, and Biotechnology; each of which can (and does) exploit materials and processes operating on a nanoscale. Collectively these technologies are known as key enabling technologies (KETs), which are seen as critical to the transformation of industry and the creation of new products and services in this decade[3] and to address Grand Societal Challenges (such as sustainability, security, health) faced by all governments[4]. It is for reasons such as these that there has been huge investment over recent years in nanotechnology (and other KETs) and there is a growing interest in evaluation, to assist governments ensure optimum return from their investments.

2. Section 2 considers the various challenges faced by governments assessing the economic value and impact of nanotechnology. Section 3 provides an overview of the nanotechnology policy landscape in a number of OECD and non-OECD countries before Section 4 summarises and evaluates the economic indicators currently in use for nanotechnology economic impact assessment. Section 5 pulls together all the analysis and discussion to attempt to define the economic impact and how this may be measured most successfully. Finally, Section 6 provides a number of key conclusions.

Section 2: Key Challenges for Governments in Assessing the Economic Impact of Nanotechnology

3. Governments have in recent years become focused on identifying the impacts of their policies on key economic measures such as job creation, improved economic growth, sustainability, and improving the health of citizens. Such socio-economic objectives are rarely (if ever) addressed solely through investment in one or more technologies, but are subject to a number of different fiscal and legislative policies, and allied measures including communication and education. Investment in nanotechnology then becomes one of many options open to governments when considering specific socio-economic objectives. Taking this into account the first and largest challenge in assessing the impact of nanotechnology, and governments' investments in nanotechnology, is the lack of a broad framework which links applications and impacts of nanotechnology to economic data, or in other words, which allows governments to disentangle the impact of nanotechnology from a whole host of other factors. Although this paper will not examine issues regarding the nature of investment (such as direct versus indirect; capital funding versus research costs;

funding for basic research vs proof of concept), these issues also need to be taken into account when assessing the overall impact of a particular investment policy.

4. The second major challenge is a lack of understanding of the stages and roles of nanotechnology in present and future industries by those responsible for collecting and analysing economic data. This is largely due to the fact that nanotechnology can have a direct or indirect impact in the development or manufacture of a particular process or product. To illustrate this we will look at two value chains: the 'green' car, and the production of jam. The green car can include a number of different materials, components, and systems which have been enabled by nanotechnology, such as the battery, the tyres (reduced roll resistance), displays, the bodywork and chassis (light-weighting), and at the same time contain many that are not. The question is how to measure the worth of nanotechnology to the final car? Would it be possible to produce a green car without nanotechnology? What components are critical, and what incremental benefit do other nanotechnology enabled components provide? What if a component is produced through a nanotechnology enabled process, but contains no nanoscale features itself? The production of jam exemplifies this. Jam contains no engineered nanostructures; however, the efficiency of the production process may be improved by the inclusion of nanostructured coatings in the food processing equipment (reducing the build-up of food materials within the equipment, and therefore reducing the downtime for cleaning; or improving wear resistance and increasing the life-time of the equipment). The issue here is how to place a value on this improvement.

5. The economic impacts of government support for any technology can be both direct and indirect. Direct impacts from the products and processes that are created can include increased market share, growth of companies, new products, and wealth creation. The indirect impacts are more difficult to generalise as they depend on the nature of the technology development. In the next few paragraphs we will examine this in some more detail using the examples of early detection of cancer (aligned with health objectives of government), improved lithium ion batteries for electric vehicles (aligned with green transport and sustainability objectives), and novel display technologies (aligned with digital economy objectives).

Reduced deaths from cancer through earlier detection

6. According to the World Health Organization (WHO) '*cancer is a leading cause of death worldwide, accounting for 7.6 million deaths (around 13% of all deaths) in 2008*'[5]; early detection would improve both morbidity and mortality rates, as treatments would be more effective (e.g. before a cancer spreads). The direct economic returns for the technology leader here could be extremely large, given the global market for such a technology or device. Looking at the indirect economic impacts, these could include fewer deaths, fewer hospitalisations, lower treatment costs, lower state benefits to support patients undergoing treatment and unable to work, and the freeing up of resources to address other diseases. Measuring and quantifying these types of impact can be achieved, but extracting the contribution of nanotechnology is difficult, as there are many other influencing factors.

7. Strategies aimed at reducing the numbers of deaths from cancer focus on three stages: prevention, diagnosis, and treatment. Each of these stages is in turn influenced by a number of different factors both technological and otherwise (such as education, regulations, policy). For example, a change in lifestyle and diet would be expected to decrease the incidence of cancer, while a change of policy to increase the frequency of screening would also be expected to increase detection rates. From a technology perspective, different diagnostic systems based on different technology platforms (with different levels of nanotechnology input) could be implicated, each contributing to an increase in the early detection of cancer. It is clear that disentangling the impact of nanotechnology from all the other investments and interventions becomes extremely complex when assessing these indirect economic impacts.

Improved lithium ion batteries for electric vehicles

8. The need for energy and transportation security through a lower reliance on fossil fuels (and at the same time limiting greenhouse gas emissions) is driving the mass manufacture of reliable and fit-for-purpose electric vehicles. One key component is the battery, which is currently limited by power density (electric vehicles have a range of approximately 100-200 km between charges) and charging rates (a full recharge can take up to eight hours), both of which limit consumer satisfaction. The direct economic impact of mass-producing a battery that addresses such issues could be significant. The indirect economic impacts are likely to include energy security (electricity used to recharge the batteries can come from a variety of sources including renewables), and lower pollution (reducing effects on human health, and the built environment). However, potential negative impacts also need to be considered, such as displacement of jobs from the oil and gas industry.

9. As with the example of cancer above, investment in nanotechnology does not operate in isolation and it will be necessary to extract its impact from those of other interventions. These can include: cost of batteries and the electric vehicles (will this limit market penetration?); cost of creating a viable infrastructure of charging stations; legislation (will this drive forward new solutions that may or may not include nanotechnology?); consumer acceptance of the electric vehicle (does it meet all requirements?); competing technologies including biofuels and hydrogen fuel cells (what are the fiscal incentives for these and where is large industry investing?). Understanding the influence of each of these is necessary to identify the impact of nanotechnology.

Novel display technologies

10. Displays communicate information to users and are found in a wide variety of devices, from mobile phones and computers to car dashboards and advertising screens. Their requirements for developing such displays are dependent on the application, and can include size, low power usage, flexibility, resolution, or operation in different environmental conditions. Investment by governments in such technologies may be motivated purely by direct economic objectives, such as technology leadership, boosting the manufacturing sector, securing jobs, or improving exports. Indirect economic impacts may arise through the replacement of rare or toxic chemicals within the display which in turn can reduce dependence on material imports and fluctuations in market prices, and facilitate recycling or end-of-life disposal of the device through reduced environmental risks. As with the examples above, other factors need to be considered when measuring the economic impact of nanotechnology. Would such a display technology be possible without nanotechnology? Has this led to new products or displaced existing ones? How much added value does nanotechnology provide over existing technologies?

11. The examples above also illustrate a number of specific issues which need to be fully understood in order to assess the direct and indirect economic impacts of nanotechnology.

Defining nanotechnology

12. Nanotechnology is, by its nature, multidisciplinary and therefore extracting reliable information regarding nanotechnology from the science and technology data categories, as currently defined, is difficult and uncertain. However, the definition of nanotechnology is itself somewhat unclear. Clear and consistent definitions provide the first step in gathering effective indicator data on investment. Indeed, how can an undefined quantity be measured?

13. From Table 1 we can see that the definitions utilised by a number of selected national and global organisations broadly cover similar aspects in terms of materials within a size range of 1 to 100 nanometres

(nm) that exhibit novel properties as a function of this size. However, inconsistencies can be found in the cut-off points selected. For example the European Commission (EC) defines a nanomaterial as including a certain percentage of nanoparticles which others (in particular the International Council of Chemical Associations) disagree with, instead favouring a weight distribution classification. Issues such as how to deal with agglomerated nanoparticles (should they be treated within nanoscale definitions if on the microscale and unlikely to disaggregate) further complicates the matter.

Table 1: Examples of definitions of nanotechnology or nanomaterials in use by organisations.

Organisation	**Definition**
International Standards Organisation	*nanoscale* size range from approximately 1 to 100 nanometres (nm) *nano object* material with one, two or three external dimensions in the nanoscale *manufactured nano object* nano object intentionally produced for commercial purposes to have specific properties or composition[6]
US Patent & Trademark Office **US National Nanotechnology Initiative**	Nanotechnology is the understanding and control of matter at dimensions between approximately 1 and 100 nm, where unique phenomena enable novel applications. Encompassing nanoscale science, engineering, and technology, nanotechnology involves imaging, measuring, modelling, and manipulating matter at this length scale.[7]
European Patent Office **Worldwide International Patent Office**	Formerly Y0N1 classification, now B82Y classification (adopted internationally under IPC)[8] "*nano-size*" or "*nano-scale*" relate to a controlled geometrical size below 100 nm in one or more dimensions; "*nano-structure*" means an entity having at least one nano-sized functional component that makes physical, chemical or biological properties or effects available, which are uniquely attributable to the nano-scale.[9]
European Commission	A natural, incidental or manufactured material containing particles, in an unbound state or as an aggregate or as an agglomerate and where, for 50 % or more of the particles in the number size distribution, one or more external dimensions is in the size range 1 - 100 nm. In specific cases and where warranted by concerns for the environment, health, safety or competitiveness the number size distribution threshold of 50 % may be replaced by a threshold between 1 and 50 %. By derogation from the above, fullerenes, graphene flakes and single wall carbon nanotubes with one or more external dimensions below 1 nm should be considered as nanomaterials[10].
International Council of Chemical Associations (ICCA)	Definition should be based on the size of particles within substances and not based on the on the hazardous properties of a substance its perceived risk. There must also be an appropriate cut-off criterion and choice of metric to allow for the use of globally standardised measurement. The chemical industry strongly advocates using weight concentration rather than particle number distribution to determine the cut-off criterion for nanomaterials.[11],[12]

Organisation	**Definition**
UK Royal Commission on Environmental Pollution (RCEP)	Nanotechnology is the manufacture, manipulation and measurement of materials with one or more dimensions in the range 1 to 100 nm[13].

Defining nanotechnology products and processes

14. Lack of a consistent definition can contribute to difficulties in assessing the contribution nanotechnology makes to specific products and processes; however, understanding and defining the nature of this contribution is just as important. For the purposes of this paper we will use the following definitions that align with those being used by the OECD's Working Party on Nanotechnology (WPN):

- Nanotechnology product: nanotechnology is fundamental, that is the key functionality would not otherwise exist e.g. novel batteries.
- Nano-enabled product, that is, those products whose key functions hinge on exploiting size-dependent phenomena underlying nanotechnology, but where nano-materials may constitute a small percentage of the final product.
- Products that utilise nanotechnology: nanotechnology has improved or enabled more efficient or cost effective production or processing, but the final product may not contain nanomaterials and its functionality may not have been enhanced by nanotechnology e.g. anti-fouling coatings for food processing equipment.

15. Therefore in terms of economic impact assessment it may be relatively simple to determine a nanotechnology product at the 'material' or first stage of the value chain; however, at the later stages the grey area of definition outlined above makes assessment increasingly complex.

Lack of nanotechnology specific economic indicators

16. The sheer number of applications of nanotechnologies across all technology sectors, and their enabling nature, creates a complex and fractured landscape for analysis. Due to these difficulties, and the relatively short timeframe of nanotechnology investment, there has been little development of consistent and widely accepted nano-specific economic indicators. For example the EC, through its Framework Programme 7 (FP7), is currently funding a number of projects assessing indicators of nanotechnology impact (ObservatoryNANO[14], NMP Scoreboard[15], NanoIndicators[16]); however, no Europe-wide methodology has been developed.

17. This challenge must be faced on both a national level and, critically, as part of an international effort to ensure that indicators developed or refined can be compared on a global scale. WPN has been considering the need for nanotechnology related statistics and indicators since 2007[17]. In 2009 WPN published *Nanotechnology: An Overview Based on Indicators and Statistics (STI Working Paper 2009/7)*, and in early 2012 will publish a further report addressing the policy considerations of moving towards a statistical framework for nanotechnology, and report findings from a pilot survey of business activity in nanotechnology (In press).

18. In addition, the OECD's National Experts on Science and Technology Indicators (NESTI) is currently developing a conceptual and methodological framework for statistics on the development, application and impact of technologies. NESTI aims to formulate a common conceptual and methodological framework which can be used across the entire field of emerging and enabling technologies such as ICTs, biotech, nanotech, *etc.*

19. A selection of such indicators (that measure input, output, and impact) currently in use for assessing nanotechnology are described in Section 4 in terms of their performance against the challenges described here.

Data collection issues

20. Gathering data about the outputs, outcome or impacts of nanotechnology, for example the number of nanotechnology companies or value of nanotechnology products, is very challenging for a number of reasons. For example, companies may not see themselves as 'nano' despite their development or use of nano-enabled products or products that utilise nanotechnology. Further, even if companies acknowledge their involvement, it may prove a difficult task to dissect the aspects of a company's business and human resource which are 'nano' related.

21. In addition, impact indicators are largely reliant on the utilisation of survey methodologies and thus subject to a number of survey related uncertainties (scope of survey, response rate, targeting of respondents); however, the lack of a consistent definition for nanotechnologies (and nanotechnology products and processes), and the fact that nanotechnology can have both direct and indirect impacts introduces a further level of uncertainty in data collected. Some further difficulties, common to all impact assessments, and likely to be encountered in evaluating nanotechnology impact, include ensuring comprehensive geographic, organisation type, and technology sector coverage when collecting data. Furthermore, the availability of information is likely to vary on a country by country basis and this has the potential to skew results.

Industry sensitivity surrounding nanotechnology products

22. A further important difficulty adding to the challenges faced by governments in assessing the economic impact of nanotechnology is that some industry sectors, such as food and cosmetics, have become increasingly reluctant to divulge their activities in connection with nanotechnology development and incorporation into their products[18].

23. Their reluctance may reflect their concerns regarding market acceptance of nanotechnology in particular applications. For example, the EuroBarometer Survey (February 2010)[19] found that following increased levels of optimism (optimistic and don't know) for nanotechnology in 1999 and 2002, however there was a decline in 2010 with more respondents indicating nanotechnology may 'make things worse'. Safety was a major concern; however the survey also concluded that higher levels of engagement and familiarity significantly reduced concern.

24. There is also widespread variation in the development of regulations for nanotechnologies and materials; the EU has taken a strong stance on this issue, with a focus on 'responsible innovation' (encompassing safety, risk and regulation) being a key pillar of future nanotechnology development. In 2009 the European Parliament passed legislation on the use of nanomaterials in cosmetics[20]; introducing a further definition for nanomaterials. However, despite this progress an on-going debate on regulation of novel foods (including the use of nanotechnology) has yet to be resolved. With no formal reporting requirements, industry is less likely to respond to requests for information due to a number of reasons including confidentiality, lack of clarity on what is and what is not nanotechnology, and public perception.

Non-specific funding strategies and policies

25. The use of non-specific, rather than nanotechnology specific, funding strategies and policies is an important factor to consider when assessing specific economic impacts such as return on investment (ROI), but may be less important for measuring wider economic impacts (which as noted above are affected by multiple factors). The structure of governments funding of nanotechnologies is relevant to measuring value for money, i.e. how much funding and investment has gone into nanotechnology versus what economic impacts can be measured. Where a funding programme is not exclusively directed towards nanotechnology (for example a health programme focused on a Grand Challenge may not be technology specific, but include biotechnology or advanced materials) will it be easy to identify the final value derived from the 'nano' investment? If the result is a nanotechnology product or process, is the return due exclusively to the defined nanotechnology funding? Are governments over (or under) estimating the ROI as a result?

26. An example of a non-specific funding stream is the EU's FP7 'Nanosciences, nanotechnologies, materials and new production technologies (NMP)' that may fund research with no nanotechnology component. Other countries, such as the USA, have nanotechnology specific funding programmes.

27. There is also the issue of fragmentation of investment across funding bodies. Countries such as Germany have multi-departmental governmental strategies providing harmonised nanotechnology funding whereas in the UK and France there is a more complex structure of governmental funding for research and innovation. This fragmentation results in difficulty in accurately sourcing government investment data for such countries and reducing the validity of inter-country comparisons.

28. The nanotechnology funding policy landscape of selected OECD and other countries is discussed in Section 3.

Lack of indigenous industry producing nanotechnology products

29. Some consider that complete innovation chains are necessary for countries to fully benefit economically from a nanotechnology development, i.e. the means to research, develop and produce (or exploit) the fruits of its R&D. For example, if the underlying technology for a water treatment system was developed in country A, but manufactured in country B, the manufacturing country would reap a number of direct (such as market share, jobs, financial return) and indirect (such as improved water quality and reduced environmental burden) economic benefits from the original investment by the government of country A. Thus it is possible that without an existing indigenous nanotechnology industry base, countries may be unable to reap (and thus assess) significant economic impacts of their nanotechnology investments.

Section 3: Nanotechnology Investment Policy Landscape

30. In this section an overview of the nanotechnology investment policies and strategies in a number of OECD and non-OECD countries will be provided in terms of their goals for nanotechnology investment, total funding, and examples of funding programmes.

31. Table 2 provides an indication of the level of total investment in nanotechnologies and nanoscience showing the huge investment being dedicated globally. However, the table only provides details of the main funding programme in each country and therefore does not represent the full investment value being directed towards nanotechnology. Indeed this is due to the difficulty in determining a total value for each country as a result of the challenges of non-specific funding and fragmentation across funding bodies outlined in Section 2.

Table 2: Funding schemes by country indicating the main current nanotechnology funding programmes and their value (values in currency of source and € equivalent in parentheses).

Country	Funding programmes	Nano-specific?	Period	Value
Brazil	Ministry for Science & Technology	no	Annual estimate	R$11.87 million [21] (€4.9 million)
China	Medium & Long Term Development Plan	yes	2006-2008	US$38.2 million [22] (€29.1 million)
European Union	Framework Programme 7	no	2007-2013	€3.5 billion[23]
France	Nano 2012 Programme	yes	2008-2012	€500 million[24]
Germany	Nano Initiative – Action Plan 2010	yes	2008-2013	€370 million[25]
India	Nano Mission	yes	2007-2012	Rs. 1000 crore[26] (€144.8 million)
Japan	MEXT	no	Annual estimate	€470 million[27]
Russia	Development of nanotechnology infrastructure in the Russian Federation for 2008 - 2011	yes	2008-2011	€693.3 million[28]
UK	Research Councils UK/Technology Strategy Board	no	Annual estimate	€256 million[29]
USA	National Nanotechnology Initiative	yes	2012	$2.1 billion[30] (€1.6 billion)

32. The socio-economic objectives for funding nanotechnology differ between countries; however, there are many commonalities such as: securing or maintaining leadership in a particular sector (especially advanced manufacturing); contributing to the resolution of societal Grand Challenges (such as health, sustainability, energy); and job and wealth creation. Data collection to evaluate the success of achieving each of these objectives needs to be considered in light of the challenges described in Section 2.

33. Germany is an example of a government focusing on key technologies, such as nanotechnology, to stimulate economic growth. In its 'Action Plan Nanotechnology 2015[31] the first goal is to seize the opportunities presented by nanotechnology to help combat the decline in Gross National Product (GNP) and exports that Germany has experienced during the ongoing global economic crisis. Some countries, such as Russia, have a greater focus on wealth creation, and essentially invest in companies and ideas through their nanotechnology programmes and anticipate a return on investment within a certain period. France is also looking at this aspect as one of the objectives of its large funding programmes (Investments in the Future Programme[32]) – equity share in new developments.

Brazil

34. Biotechnology and nanotechnology are one of eleven areas for strategic investment by the Brazilian government[33]. Between 2004 and 2008 the Ministry for Science & Technology (MCT) invested an average of R$11.87 million (€4.9 million) per year[34]. In common with most other countries there is an increasing focus on ensuring successful technology transfer from academia to industry[35]; this is likely in response to a low level of patenting compared to the relatively healthy publication rate (over 50% of nanotechnology publications in Latin America originate from Brazil)[36].

35. Brazil's Nanotechnology Programme has the objectives of promoting the generation of products, processes and services in nanotechnology, aimed at increasing the competitiveness of domestic industry in line with the targets set in the Plan of Action for Science, Technology and Innovation 2007 - 2010 (PACT). Programme actions have included supporting basic research, continuing the support for Nanotechnology Research networks and support the maintenance and creation of laboratory to promote integration between networks and research groups with industry, supporting training of teachers and doctors, and the implementation of the Brazilian- Argentine Nanotechnology Centre (CBAN) and also a virtual Brazilian-Mexican Nanotechnology Centre[37].

China

36. China has increased its investment in science and technology as a whole, from 1.5% of GDP in 1996 to 2% of GDP in 2010 and is expected to reach 2.5% by 2020 under the Medium and Long Term Development Plan 2006-2020 (MLP)[38]. Nanotechnology development has been given priority under this initiative and defined as one of twelve 'mega-projects'[39]. These 'mega-projects' and their associated implementation guidelines are intended to support industrialisation related to national socio-economic development within 3-5 years[40].

The European Union

37. Under the EC Framework Programmes (FP) the EU invested €1.4 billion in NMP in the 2003-2006 period rising to €1.1 billion in 2007-2008[41] with further growth expected until the end of FP7 in 2013. The objectives of the NMP programme are to secure global leadership in key sectors, and create added value such as improved safety, security, and sustainability. During FP7, industrial participation in funded projects reached 40%; however, there is an awareness of a very strong emphasis on basic research in EU programmes and in some Member States. This resulted in the formation of European Technology Platforms (ETP) which are industry led stakeholder fora with responsibility for defining research priorities in a wide range of technology areas[42]; out of 40 ETPs, 16 are explicitly related to nanotechnology and 16 are implicitly related. A further development is the NanoFutures[43] initiative which is a cross-ETP platform for all nano related technologies.

38. The High Level Expert Group (HLG) on Key Enabling Technologies (KET), which includes nanotechnologies, presented its policy recommendations to the EC in June 2011[44]; these include addressing the so-called 'Valley of Death', which is the gap between knowledge generation and commercialisation. The HLG has recommended a 'Three Pillar Bridge' strategy which should be adopted in the upcoming Horizon 2020 programme and also in the policy instruments related to EU's Regional Policy and the European Investment Bank. The three pillars are: technological research; product demonstration focused on product development; and production based on world-class, advanced manufacturing. The 'Competitive Industries' objective[45] and Horizon 2020 programme have developed these recommendations focusing on ensuring Europe is an attractive location for research and innovation investment. A budget of €5.89 billion has been assigned to developing European industrial capabilities in the Key Enabling Technologies sector; it can be noted that nanotechnologies is only one of a number of enabling technologies.

France

39. The first French nanotechnology specific funding was the 'French National Programme in Nanosciences' which ran from 2002 to 2004. During 2004-2005 five competence centres (C'Nano) were established and in 2005 the 'French National Programme for Nanoscience & Nanotechnology' was launched with a budget of €35 million[46].

40. The research and development strategy of France is currently undergoing considerable transformation, transitioning from a centralised to decentralised research and innovation system; this results in great difficulty in extracting the value and source of nanotechnology funding. Indeed government nanotechnology funding is distributed through four research organisations and a number of intermediary organisations[47].

41. Increased effort is being focused on stimulating private R&D to promote public-private collaboration and jobs/new companies through policy instruments. These include stimulus packages, tax credit and schemes such as the "pôles de compétitivité" to set up regional innovative districts and foster closer ties between firms, public research centres/universities and infrastructure. Prominent areas relate to nanotechnologies such as nanoelectronics; an example is the heavy investment of the French government in developing innovation clusters such as MINATEC[48] innovation campus in Grenoble bringing together academia, industry and technology transfer.

Germany

42. Federal funding for nanotechnology research and development in 2010 reached around €400 million with the Federal Ministry of Education & Research (BMBF) increasing investment four fold since 1998[49]. The funding aims have moved forward from those of the 1990's, which focused on basic research, towards more application based funding. The Nano Initiative – Action Plan 2010[50] provided a unified framework across seven Federal ministries to speed up transfer of nanotechnology research results into innovations and industry, and remove innovation barriers.

43. The German government cites a number of socio-economic objectives for nanotechnology across these seven ministries, including: economic development, resource efficiency, environmental protection, innovative solutions for health problems, and international competitiveness of industry.

44. A specific example of an initiative in action is the InnoCNT[51] project, which has substantial government and industry funding, for carbon nanotubes that will have multiple applications across many industrial sectors. Since 1998 BMBF has also funded the set up of a number of internationally recognised competence centres to bring potential users and researchers in nanotechnologies together to promote industrial development; evaluation results suggest they have achieved an accelerated innovation process[52].

45. In the Nanotechnology Action Plan 2015[53] the federal government further focuses strongly on an intensive integration of science and economy, specifically in the areas of climate and energy, health and nutrition, mobility, security and communication, to ensure effective technology transfer and commercialisation using the following instruments:

- Collaborative projects;
- Lead innovations;
- Innovation alliances; and
- Excellence clusters.

India

46. In May 2007 the Indian Government approved the launch of a Mission on Nano Science and Technology (Nano Mission) with a budget of Rs. 1000 crore (€144.8 million) over 5 years[54] administrated by the Department for Science and Technology; this follows on from the more modest Nano Science and

Technology Initiative (NSTI) launched in 2001. In the Nano Mission programme equal importance is given to both fundamental research and the development of products and processes, through linking of research and industry and Public-Private Partnerships (PPP), particularly in areas highly relevant to challenges facing India, such as safe drinking water and drug delivery. Additionally, an important part of this funding is directed towards the development of the human resource required to facilitate a long term and competitive industry.

Japan

47. The bulk of nanotechnology funding in Japan is through the Ministry of Education, Culture, Sports, Science and Technology (MEXT) and the Ministry of Economy, Trade and Industry (METI). These Ministries support basic and applied research through the Japan Science and Technology Agency (JST) and the more industrially focused, including funding of demonstration activities, programmes of The New Energy and Industrial Technology Development Organization (NEDO)[55].

48. In 2009 nanotechnology represented 5.2% of the budget of the 3rd Science & Technology Basic Plan. Under the 4th Science & Technology Basic Plan, instigated in 2011, fields, such as nanotechnology, will no longer be prioritised in favour of the two broad areas of Life Innovation and Green Innovation[56].

Russia

49. A federal nano-specific programme, run across a number of governmental departments, is the "Development of nanotechnology infrastructure in the Russian Federation for 2008 - 2010 years". This programme focuses on infrastructure and the training required to make use of it[57].

50. In 2011 RUSNANO, an open joint stock company, was formed to develop a Russian nanotechnology industry through the reorganisation of the Russian Corporation of Nanotechnologies; the Russian government owns 100% of the shares. The aim of the company is to bridge the gap between product development and market entry through early stage investment, and also commercialising existing developments funded by federal investment[58].

United Kingdom

51. Government nanotechnology investment is largely funded through the UK Research Councils (EPSRC, BBSRC, STFC, NERC, ESRC and MRC); however, there is not a common funding pot but rather each council funds aspects of nanotechnologies and nanosciences relevant to their goals[59]. In March 2010 the UK Nanotechnologies Strategy was launched[60] with the aim of co-ordinated approach across government departments to develop a nanotechnology industry that would contribute to an innovative and competitive UK manufacturing base. The vision of the UK strategy is that '*the UK's economy and consumers will benefit from the development of nanotechnologies through Government's support of innovation and promotion of the use of these emerging and enabling technologies in a safe, responsible and sustainable way reflecting the needs of the public, industry and academia*.'

52. The Technology Strategy Board (TSB), funded through the Department for Business, Innovation & Skills (BIS) funds nanotechnology commercialisation activities. Most funding is aimed at basic and applied research; however, the EPSRC, as the main funder of NMP, also funds 12 universities to exploit technologies arising from research through Knowledge Transfer Accounts (KTAs). It also provides follow-on funds to exploit the commercial potential of promising results (since 2004 £15 million (€18 million) has been awarded to 159 projects).

The United States of America

53. The US 2012 Federal Budget provides $2.1 billion (€1.6 billion) for its National Nanotechnology Initiative (NNI) representing continuing growth in investment; since the inception of the NNI in 2001 there has been a cumulative investment of greater than $16.5 billion (€12.6 billion)[61]. The NNI is an interagency initiative supporting nanoscale science and engineering at member agencies, such as Department of Energy. The NNI's vision is '*a future in which the ability to understand and control matter at the nanoscale leads to a revolution in technology and industry that benefits society*.'[62] It also looks to develop a skilled workforce, improve education, and develop nanotechnology responsibly.

54. The US is also addressing the 'Valley of Death' by ensuring US leadership in advanced manufacturing. The President's Council of Advisors on Science and Technology (PCAST) made a number of recommendations to address this, including the launch of an Advanced Manufacturing Initiative, in its report of June 2011[63]. From this it appears clear that the US perceives that manufacturing is key to future development and effective competitiveness and, although they remain committed to funding a nano specific programme (NNI), nanotechnologies will also be increasingly incorporated into programmes such as the Advanced Manufacturing Initiative.

Balancing investment and returns

55. The evolving policy landscape of most countries, both OECD and non-OECD, reflect a shift in focus from a concentration on funding basic research towards initiatives focused on improving the links between innovation and the value chain for nanotechnologies. There is also a move to more challenge driven, research, addressing key societal challenges, and manufacturing driven strategies by a number of governments; Germany's early adoption of manufacturing focused strategies, and also development of competency centres, has contributed towards its resilience to the current global economic crisis. With funding being spread across the innovation and value chain it is important that the impact of nanotechnology is evaluated at each stage.

56. Assessments of the economic impact of nanotechnology, and of government's investments in nanotechnology, also needs to consider the original objectives set out in government policy, and the framework in which these policies operate, and should account for both the direct and indirect economic impacts identified in section 2.

Section 4: Currently Available Data and Needs for Successful Future Investment

Input, output and impact indicators

57. For the purpose of this report we identify data using three indicator sets: input, output, and impact indicators. Input factors can be thought of as the instruments of governments or public investment (regional, national, and pan-national) such as funding schemes, innovation strategies, public-private partnerships, pilot lines, pre-commercial procurements, and researchers employed in nanotechnology but also include venture capital and other private funding. Output indicators include data such as publication and patenting activity, and number of new products; while impact indicators measure aspects such as company and market growth, and job creation.

58. These indicators, amongst others, are common to all areas of science and technology impact assessment and some of their advantages and limitations are outlined in Table 3a (input), Table 3b (output) and Table 3c (impact); limitations which are particularly pertinent to nanotechnologies are highlighted in bold italic.

Table 3a: Advantages and limitations of common input indicators

Input indicator	Advantages	Limitations
Public investment	Information publicly available and accessible	***Fragmentation of funding across departments/agencies*** Little data on the recipients of public funding ***Comparison between countries requires an agreed definition***
Infrastructure	Considerable publicly available information Good indicator of capacity for development & growth	The availability and level of detail of available infrastructure varies considerably between countries ***Fragmentation of activities across infrastructure***
Number of graduates	Provides an indicator of skills available at a country/region scale Information on courses (BSc and MSc level) is available through public sources	Little literature or governmental analysis available Available data is user (student) focused rather than policy driven ***Definition of course to be included is problematic and definitions may vary on an institutional or country basis*** Does not provide information on the post-graduation path of students No central database of relevant courses available ***Difficulties of defining contribution of course content***

Table 3b: Advantages and limitations of output indicators

Indicator	Advantages	Limitations
Publications[64]	Publications are closely linked to research activity They have been subject to peer-review for quality control They cover a broad range of scientific disciplines Publication data are available as long time series They are publicly available at a low cost	Publication databases are biased in favour of English-language journals as the mainstream outlets They combine different journal-specific databases whereby targeted searches are cumbersome Publication data only cover the codified aspects of scientific research Citation data may not only reflect genuine interrelationships and quality of research ***Publication behaviour and propensities may vary significantly across disciplinary fields*** ***Largely relevant to results of basic or applied research***
Patents[65]	Patents are closely linked to inventions They cover a broad range of technologies on which there are sometimes few other data sources The content of patent documents is a rich source of information Patent data are available as long time series and across many (most) countries They are readily available from patent offices	The value distribution of patents is skewed as many patents have no industrial application (and hence are of little value to society) whereas a few are of substantial value Many inventions are not patented because they are not patentable or inventors may protect their inventions using other means The propensity to patent differs across countries, industries and companies Differences in patent regulations make it difficult to compare counts across patent offices Changes in patent law over the years make it difficult to analyse trends over time
Product sales	Provides an indication of the spread of nanotechnology products within industry in general rather than just 'nano' companies. Provides an indication of nano related wealth generation	Lack of data standardisation between sources ***Existing data is largely survey based*** Regional, sectoral, and organisation size bias ***Industry reluctance to disclose participation in research/production*** ***Difficulty in determining what is a nano-product within a wider product range***

Table 3c: Advantages & limitations of impact indicators

Indicator	Advantages	Limitations
Number of companies	Provides an excellent indication of innovation success and measure of developments reaching the market	Limited literature and company reports Lack of data standardisation between sources ***Existing data is largely survey based*** Regional, sectoral, and organisation size bias ***Industry reluctance to disclose participation in research/production*** ***Lack of clear definition on what is a nano-product***
Number of jobs	Job creation is a key aim of many innovation strategies and an important indicator of innovation policy/funding success	***Existing data is largely survey based*** ***Lack of clear definition hampers categorisation*** Data is aggregated and per country No distinction between research & technical staff ***In many cases only a proportion of an individual employee's time will be related to nanotechnology, hampering the derivation of total impact***
Growth of market volume/share	The key indicator of innovation success showing the contribution of scientific/technological development	***Existing data is largely survey based*** ***Industry reluctance to disclose participation in research/production*** ***Lack of clear definition on what is a nano-product***

Performance of indicators in nanotechnology impact assessment

59. From the highlighted issues in Tables 3a, 3b and 3c, it is clear that the lack of a consistent definition of nanotechnology is a key issue affecting many of the indicators. As discussed in Section 2 there is clearly a strong risk of a mismatch between definitions used for input indicators (public investment) and output and impact indicators, which is likely to result in erroneous and incomplete information on the real impact of nanotechnology investment.

60. Publications and patents are the most commonly utilised output indicators due to their quantitative nature and the development of sets of nanotechnology specific definitions; examples of their use include EC funded projects such as EC projects ObservatoryNANO[66], NMP Scoreboard, and NanoIndicators; the US National Science Foundation funded Nanomapper[67]; and the French Observatoire des Micro et Nano Technologies (OMNT)[68]. The results can provide an interesting insight into scientific activity and output, of the development of new products, and provide a basis for international comparisons.

61. No such quantitative methods have been developed for impact indicators for nanotechnology such as the number of companies or nanotechnology related jobs. Surveys are the main collection tool used, however, these bring associated issues and uncertainties. An example is the EU's NMP Scoreboard and ObservatoryNANO, both of which are examples of the EU's approach to the collection of information on the return on its nanotechnology investment.

62. Box 1 provides an example of the indicators utilised in the ObservatoryNANO highlighting where the challenges described here, and in Section 2, may affect the results of its assessment of the impact of nanotechnology investment.

Box 1: FP7 ObservatoryNANO - an example of nanotechnology impact assessment

During 2010-2011 the FP7 ObservatoryNANO conducted a company census to firstly identify companies involved in nanotechnology using three key quantitative indicators; FP7 NMP funding (input), publications, and patents (output). Secondly an online company survey was initiated to glean further, qualitative, details including number of jobs and percentage of activity related to nanotechnology (impact). Some issues encountered included:

- It was found that companies may patent in different countries, such as head office location, from where the research or development has taken place;
- FP7 NMP funding is only applicable to the early stages of the innovation chain and also covers technologies outside of nanotechnology;
- Out of 1540 companies identified as making use of nanotechnology from publications, patents or FP7 NMP funding, only 100 were willing to take part in the survey, with the food industry found to be particularly reluctant.

63. One of the widest exercises in mapping nanotechnology activities was undertaken by the German Federal Ministry of Education & Research (BMBF) with the Nano-Map[69] resulting in a detailed map of nanotechnology competency in Germany. One of the outcomes was the determination of the number of nanotechnology companies present, evaluated by BMBF as representing half of the European total of nanotechnology companies[70]; however, this statement may be exaggerated due to the fact that few European (or other) countries have completed such a detailed assessment. This example highlights the difficulty in assessing the impact of nanotechnology investment on an international basis due to the wide variation in both level and available methods of analysis.

Value chain assessment and required indicator development

64. In terms of assessing impact along the full value chain (material, component, system and final product) we again return to the issue of a lack of clear definition for nanotechnology in general, and more specifically in terms of defining a product affected by or resulting from nanotechnology investment (nanotechnology product, nanotechnology enabled product or products that utilise nanotechnology) once again hampers the assessment of the impact of government investment. There is also a need to consider the indirect impacts described in Section 2.

65. Starting materials can be more easily defined and are likely to be identified as ‘nano’ in publications and patents. However, collection of data regarding nanotechnology in later stages of the value chain becomes reliant on less quantitative methods. For example, a food processing facility utilising a nano-enabled coating in its processing machinery is unlikely to identify or declare itself as a nanotechnology company in a survey, and will not, itself, have filed a patent or submitted a publication. Nevertheless it manufactures a product in which the process is enabled or improved by nanotechnology. Current methods and indicators cannot easily meet the challenge of identifying and quantifying the resulting economic impact.

Section 5: Defining the Economic Impact of Nanotechnology

66. From the discussion in previous sections it is clear that there are many challenges facing governments in assessing the contribution of investments in nanotechnology to addressing key societal and economic objectives. A clear path, or structure, for resolving at least some of these challenges will allow for a greater degree of confidence in future investments. The problem of defining a nanotechnology product will require both consistent and agreed definitions. Definitions and perhaps other mechanisms

(such as a clarified regulatory landscape) should assist nano-enabled products, or products that utilise nanotechnology to be easily identified and thus included in economic impact assessment. Here the international efforts of both ISO and the OECD are vitally important.

67. Given a clear set of international definitions, and consistent regulatory landscape, issues such as the mismatch of definition between government input indicators and output and impact indicators would be partially addressed. However, the evolution of the policy environment in many countries towards a more challenge driven or manufacturing focused approach to innovation funding, may re-introduce difficulties in comparing data collected about input, investment and economic impact related to nanotechnology.

68. Standardised definitions, and a clearer regulatory landscape, would also likely improve the quality of survey data (the most commonly utilised methods for gathering impact indicators at the later stages of both the innovation and value chains). However the uncertainties intrinsic to survey methodologies would, however, remain.

Value chain examples

69. In order to illustrate the issues and challenges facing governments and to suggest how these may be overcome we shall use two value chain examples; the ‘green’ car and food processing. In each illustration, nano-products are outlined with a solid line, nano-enabled products with a dashed line, and products that utilise nanotechnology with a dotted line.

70. The first example, shown in value chain 1, is the 'green’ car; reducing the environmental impacts (climate change, air quality and land use) of vehicle transport is high on the agenda of all governments. The green car is, however, a complex product encompassing many different value chains on which the impact of nanotechnology could be seen. Taking the power storage and release system as an example, the material ($LiFePO_4$), component (electrode), and system (battery) are nano-products with the final product (green car) being nano-enabled; that is, its performance is enhanced by the use of nanotechnology. The question to be addressed here is how much added value the nano-battery adds to the final product. Additionally how this can be combined with the nanotechnology input in many other systems and components of the green car; other nano-enabled developments include light weighting, decreased roll resistance, and energy scavenging which will contribute towards complying with ever stricter regulations for reduced CO_2 emissions. Below the value chain illustration Tables 4a and 4b summarise the potential components of economic impact and identify further the challenges in assessing the economic impact of nanotechnology on a ‘green’ car.

Value chain 1 – nanotech-battery in a ‘green’car

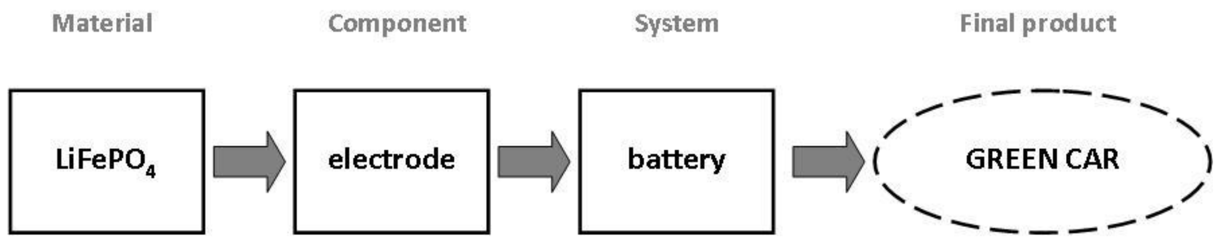

Table 4a: Summary of the potential components of economic impact and overall economic impact for the 'green' car value chain example.

<table>
<tr><th colspan="2">Potential component measures of economic impact</th></tr>
<tr><td>Material</td><td>Component</td></tr>
<tr><td>Low cost
High availability of raw material
Safe as thermally/chemically stable</td><td>Increased energy density
Increased power density
Reduced costs
Non-toxic</td></tr>
<tr><td>System</td><td>Final product</td></tr>
<tr><td>Skilled job creation
High value industry expansion
Many other potential application areas
Addresses critical design issues of conventional technologies, in terms of size and capacity</td><td>High expected market growth due to improved performance creating mass market.
Job creation, and retention, within existing industries at number of skill levels and also in development of associated infrastructure.
No use of fossil fuels and no emissions from product itself.</td></tr>
<tr><td colspan="2">Overall economic impacts
Improved market growth of ‘green cars’ leading to employment retention and growth within the existing car industries.
Reducing greenhouse gas emissions to help meet challenging national and international targets.
Improved air quality in many urban areas improving health.
Reduced dependency on fossil fuels.
Electricity required in electrode and battery manufacturing can be sourced from renewable sources.</td></tr>
</table>

Table 4b: Summary of the challenges regarding economic impact assessment and overall challenges for the 'green' car value chain example.

<table>
<tr><th colspan="2">Challenges regarding assessment of economic impact</th></tr>
<tr><td>Material</td><td>Component</td></tr>
<tr><td>Key indicators are patent and publication data but are reliant on a non-conformant definition.</td><td>Key indicators are patent and publication data but are reliant on a non-conformant definition.</td></tr>
<tr><td>System</td><td>Final product</td></tr>
<tr><td>Identification of nanotechnology input at this stage is largely reliant on survey generated data based on manufacturers reporting.</td><td>Determining the total added value provided by the nano-battery, and also other nano-enabled developments such as light weighting, decreased roll resistance and energy scavenging.</td></tr>
<tr><td colspan="2">Overall challenges
Assessment of the impact of the nano-enabled green car on market growth, job creation, and emissions over other technologies.
Identification of the role of nanotechnology along the landscape of car components is highly complex, heightened further if aiming to identify cumulative cost benefit of investment to the final impact.</td></tr>
</table>

71. Jam production is our second example, shown in value chain 2. The product itself, jam, contains no nanomaterial and its functionality is unaltered by the use of diamond-like carbon coating in the processing equipment; however, the abrasion and corrosion resistant coating on the metering pistons for filling jam jars allows for reduced maintenance and therefore delivers the economic impact of lower operating costs. Tables 5a and 5b summarise the potential components of economic impact and the challenges in assessing the economic impacts of nanotechnology in this value chain

Figure 1. Value chain 2 – nano-coated processing equipment used to make jam

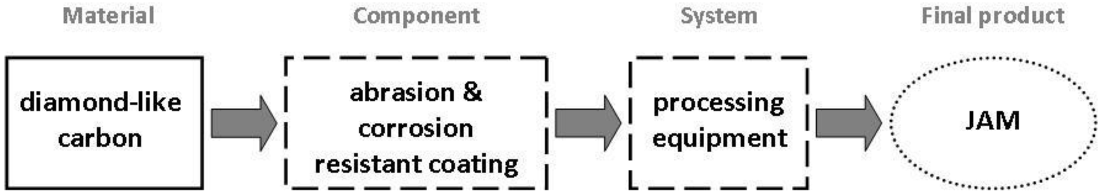

Table 5a: Summary of potential components of economic impact and overall economic impacts for the jam production value chain example

Potential component measures of economic impact	
Material	**Component**
• Completely safe (utilised within healthcare applications) • Can be applied to a variety of metals and alloys, technology is well understood	• Additional initial capital cost for coating of equipment. • Creation/expansion of high value industry. • Requirement for highly skilled jobs.
System	**Final product**
• Reduced energy consumption. • No alteration/modification required to incorporate nano-enabled coating. • Improved performance and operational reliability[71] • Improved equipment lifetime • Potential job losses due to decreased maintenance required. • Reduced operating costs.	• Lower carbon footprint of product. • Potential cost reduction due to savings in processing. • Reduced investment risk of machinery failure impacting production.
Overall economic impacts	
• Improved energy efficiency in jam manufacturing reducing energy consumption and emissions. • Increased processing output, manufacturing capacity and profitability.	

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Table 5b: Summary of the challenges regarding economic impact assessment and overall challenges for the jam production value chain example

Challenges regarding assessment of economic impact	
Material	**Component**
• Key indicators are patent and publication data but are reliant on a non-conformant definition.	• Key indicators are patent and publication data but are reliant on a non-conformant definition.
System	**Final product**
• Nanomaterial/nano-enabled component/material represents a very small proportion of total system and is unlikely to be highlighted in patent, publication or industry reporting. • No regulatory requirement for food contact materials containing nanomaterials to be declared by processors/manufacturers.	• Final product contains no nanomaterial and functionality is unaffected by nanotechnology. • No regulatory requirement for final product to indicate involvement of nanotechnology at any stage.

Overall challenges

- Determining the impact of nanotechnology investment when the final product contains no nanomaterials and its functionality is unaltered by its involvement.
- Developing an appropriate framework of economic indicators across all stages of the value chain to highlight nanomaterial or nano-enabled product involvement.

72. These two value chain examples illustrate both the challenges faced in terms of assessment of the economic impact along the value chain, but also emphasise the importance of assessment of the full value chain, rather than of individual stages. For example, considering only the final product - jam - would not identify any economic impact of nanotechnology. Conversely, looking at the nanotechnology 'value' in a green car, ignores the economic value of the individual material, components and systems that are each a result of nanotechnology. The picture is further complicated by whether the valuation of economic impact should be cumulative (along the value chain), be confined to the value of the final product, or represent some combination. Without an understanding of these issues by those collecting economic data, the full economic impact of nanotechnology, and ROI of government investments will be difficult to quantify and to compare across sectors and countries.

The future for nanotechnology economic indicators and impact assessment

73. The policies of many countries (described in Section 3) are moving towards more challenge driven and manufacturing focused research and innovation funding policies. Nanotechnology then becomes an option from one of a number of different approaches and technologies to address specific socio-economic objectives. As discussed in Section 2, identifying the impact of nanotechnology is further complicated by other contributing factors such as regulation.

74. Therefore it could be suggested that effort directed at the development and improvement of nanotechnology specific indicators may not be required in the longer term. However, in the short term a number of countries (USA, India and Germany) are continuing with nano-specific funding programmes and here, at least, the need for improved economic indicators of the impact of nanotechnology will remain. The value chain examples highlight the need for those collecting economic data to fully understand the impact of nanotechnology at each stage of the value chain and also across multi-disciplinary/multi-application value chains which can arise from the 'enabling' nature of nanotechnology and its potential to contribute to solutions for many global challenges.

Section 6: Conclusions

75. Nanotechnology is developing in a complex policy environment; however, it remains a critical component of public investment to help address the grand challenges facing all countries, and to ensure an innovation led, and manufacturing based, economic recovery. Different countries have adopted a variety of funding policies and strategies which makes international comparison difficult. In the following we provide some key conclusions on the challenges facing governments in evaluating their investment in nanotechnology and in assessing the impact of nanotechnology on wider economic, societal and environmental challenges:

- Nanotechnology operates alongside other interventions (such as other enabling technologies, regulation that 'forces' an issue, or guidance recommending a change in approach, e.g. greenhouse gas emissions), each of which can influence the successful outcome of government strategy. It is necessary to understand the contribution that each intervention makes in achieving a specific objective and the other factors that might influence the outcome (such as regulations or public opinion).

- The nanotechnology policy landscape is evolving as a number of countries move from technology driven to challenge driven and manufacturing focused policies and strategies, which make use of all enabling technologies. This may change the focus away from nanotechnology specific economic impact assessment.
- Agreeing consistent international definitions of nanotechnology and nanotechnology products will assist in ensuring that data collection between countries is comparable and comprehensive enough to understand the role of nanotechnology at various stages.
- As surveys are the only method for gathering data on certain indicators it is important for the evaluation of nanotechnology that there is further development and improvement in survey methodologies, and supporting infrastructure such as expert working groups. This will allow for a broader framework to link the applications and impact of nanotechnology to economic data.
- Value chain assessment should be included in impact evaluation to determine the full economic value and impact being derived from nanotechnology investment by governments, and to help address the problem of defining the involvement of nanotechnology in a final product, where economic value is most commonly assessed.

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