AN ECONOMIC ANALYSIS OF SPILLOVERS FROM PROGRAMMES OF TECHNOLOGICAL INNOVATION SUPPORT

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The views expressed in this report are that of the authors and not necessarily those of the Department for Business, Innovation & Skills.

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Executive Summary

"Technology based innovations will be one of the key drivers of the private sector led economic growth that Britain so urgently needs… [and] requires innovation support that is strategically targeted at bridging the gap between idea generation and commercial success in global markets"[1]

Recognising the economic benefits that fostering technology can bring to the UK economy, technological innovation support programmes are a leading policy instrument funding emerging technologies and supporting innovative businesses to prosper. A spillover in this context refers to the indirect benefits earned by businesses as a result of the technology support to a business undertaking the initial activity (the primary beneficiary). The value of the spillover should be measured in excess of what the secondary beneficiary may have paid the primary secondary beneficiary to acquire the relevant benefit. In the example of business investment in technology innovation, the spillover is the benefit others receive beyond the returns made by the business making the investment. In contrast, where a business receives a benefit from others undertaking innovation activity (i.e. learning from the mistakes or using the knowledge generated by others), the business concerned can be considered to have benefited from spill-in innovation. The report defines three types of spillover resulting from a technology support programme:

- Market spillovers – the benefits received by society, as a result of the commercialisation of innovation by programme beneficiaries, in excess of the price paid for goods and services resulting from the innovation to acquire those benefits. Most support programmes will have explicit social welfare goals that would define the expected nature of market spillovers;

- Knowledge spillovers – the use of knowledge from the programme by non-programme beneficiaries, without full payment, to generate economic, social or environmental benefits. The greater the knowledge created, transferred and absorbed, and the related levels of commercialisation, the greater the scale of spillovers (for example through formal knowledge sharing, employment mobility, or through use of published research);

- Network spillovers – the effect of programme innovation on the development of a 'critical mass' of users, where the take-up of the innovation by additional users, increases the value of the innovation to existing users (for example, computer games).

When designing technology innovation support programmes the scope and value of spillovers should be examined in ex ante/post evaluation frameworks, ensuring that

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[1] BIS(2010): Blueprint for Technology, foreword by Prime Minister David Cameron, Department for Business, Innovation and Skills, November 2010; page 3-4, available at: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/32432/10-1234-blueprint-for-technology.pdf

spillovers are recognised by policy makers and promoted in support programmes to gain the maximum added value from interventions.

The purpose of this study was:

- to update the evidence from academic and grey literature on the nature of innovation systems and their propensity to produce spillovers; and
- to provide initial guidance on how to use this evidence in evaluation frameworks to assess the extent of spillover generation by technological innovation programmes.

The key findings of the report are summarised below and elaborated in the following text.

Summary of Key Findings

- ‘Open’ innovation systems are more conducive to the production of spillovers than closed innovation systems through the permeation of knowledge amongst those actors with an interest in the development and take-up of the technology;
- Open innovation systems which increase the tendency for innovation systems to generate spillovers are characterised by:
    - technologies with multi and general purpose attributes;
    - the presence of nascent and high value industries, the products of which have multi-purpose uses;
    - active presence of universities and research institutes;
    - strong relationships between actors and their close proximity in the innovation system (i.e. due to network ties, cooperative agreements and/or geographic clustering);
    - low costs of knowledge transmission and diversity of mechanisms to exchange knowledge (i.e. formal and informal); and
    - high levels of absorptive capacity.
- Testing of these identified factors using the TSB ‘Catapult’ programmes, the best approach to evaluating spillovers involved a four step process:
    - Step 1: Elaboration of the programme intervention logic to better define the innovation, by mapping out the policy setting, relevant actors, investments, presence of spill-in technologies, outcomes and impacts in a structured format;
    - Step 2: Use of the developed intervention logic to further define the wider range of actors and the possible flows (and types) of knowledge within the innovation system, presented as a framework model;

  - Step 3: Use of the model to define specific activities, outputs and outcomes that have the potential to generate knowledge spillover effects; and

  - Step 4: Using primary and secondary data to populate indicators of outputs, outcomes and impacts in the model, allows for a qualitative assessment of potential spillovers.

- The opportunity for using multi-criteria analysis exists. This involves scoring the presence of the above factors in the innovation system and weighting their importance. The sum of the weighted scores would allow comparison of technology innovation support programmes to generate spillovers across different sectors or topic areas.

- Quantifying the value of spillovers at a given point in time is notoriously problematic. Added to this, the literature provides little to no quantitative evidence on the linkages between the presence of factors in the innovation system/support programme and the scale of spillovers.

- However, the literature does provide some indication of scale with net rates of private return on R&D investment typically estimated in the region of 20-30% to the primary beneficiary and net social returns from spillovers (i.e. those incurred by secondary beneficiaries) of 20-100 % of R&D investment, with an average close to 50% return.

Establishing the innovation system

Innovation systems define the 'space' within which the intervention (technology support programmes) is taking place. The first part of the study attempted to better understand the notion of innovation systems and their features that would be expected to give rise to spillovers. Examples of Technology Strategy Board (TSB) support programmes were used to support this detailed examination.

A distinction should be made between support programmes commissioned in the context of closed compared to open innovation systems. The latter would by definition be more likely to produce spillovers, based on the findings of the inception phase of the study. This Report considers this distinction and uses a description of an open innovation system as the basis for structuring the findings of both the literature review and the evaluation framework.

This in turn placed the primary focus on knowledge and network spillovers, since these are the effects associated with the wider dispersal and take-up of knowledge beyond the boundaries of the support programme. Market spillovers associated with the direct programme beneficiaries would be identified through standard programme evaluation frameworks.

Findings from the literature review

An open innovation system provides the basis for the generation of knowledge spillovers.

The literature review confirms the view that support programmes characterised as 'open' within innovation systems are more likely to produce spillovers, because of their focus on building a community of interest around a particular technology and its development. It is within this community of interest that research and development is undertaken and in which findings are disseminated.

Open innovation systems are permeable to inflows and outflows of knowledge across boundaries, and thus are defined by the extent to which these boundaries are removed or mitigated as a community of interest develops around a particular technology. In contrast, a closed system is based on the idea that these boundaries are not always permeable, enabling knowledge to be contained or channelled through a defined group of actors. For example, Intellectual Property (IP) can be codified and held within a single firm or shared within a defined supply chain. Each innovation system is therefore defined by the technology, its related market applications, the actors with an interest in the technology and its take up. As knowledge is shared, knowledge spillovers occur, and form the basis for subsequent market and network spillovers.

Certain factors in an open innovation system can be identified that increase the tendency for knowledge spillovers.

There are a number of factors that can be identified from the literature that suggest the possibility of greater knowledge spillover effects from a technology innovation programme (given the type of innovation system within which it sits) (see Table ES1). There are also a number of factors which are understood to influence spillover generation, but where the evidence is ambiguous.

Overall, the literature on spillover effects is generally diverse and fragmented and has not examined in a systematic way the range and relative importance of different factors - and does not provide definitive evidence.

Table ES1: Factors in an open innovation system capable of increasing the tendency for knowledge spillovers

Characteristics of an open innovation system	Factors increasing the tendency for innovation systems to generate spillovers	Factors with ambiguous impacts on the potential for spillovers
1. Technology and nature of innovation	■ Multi and general-purpose technologies (in the long run)	
2. Market and industrial structure	■ High value added industries, with multi-purpose applications ■ Nascent industries	■ Higher level of competition ■ Higher capital/factor intensity ■ Higher market concentration
3. Institutional set-up		■ IP protection ■ Government funding for procurement / use of government owned assets / data
4. Actors	■ Active role of universities and research institutes	
5. Relationships between actors	■ Network ties and cooperative agreements among actors ■ Geographic clustering of programme beneficiaries	
6. Transmission mechanisms	■ Low costs of knowledge transmission – linked to types of	■ Interaction with international trade / foreign direct

Characteristics of an open innovation system	Factors increasing the tendency for innovation systems to generate spillovers	Factors with ambiguous impacts on the potential for spillovers
	knowledge (tacit / codified) ■ Diversity of mechanisms	investment (FDI) ■ IP protection
7. Absorptive capacity	■ High levels of absorptive capacity	■ IP protection

These factors as a basis for an evaluation framework have been partially tested, using TSB 'Catapult' programmes

These factors are reflective of fairly broad concepts. For use in an evaluation framework, these concepts need to be translated into more tightly defined evaluation criteria and related indicators. The relevance and feasibility of these factors as evaluation criteria have been tested in discussion with managers of the offshore wind and the connected digital economy 'Catapult' programmes.

Feedback suggests that the factors do provide a credible basis for knowledge spillover assessment and are, in many cases, formally considered in current programme design. An attempt at a qualitative assessment of three programmes was undertaken, ranking the degree to which relevant features increased the likelihood of spillovers (see Table 4.2 in the main report). However, this approach was deemed insufficient for really understanding how and where spillovers are generated within given innovation systems and for establishing a robust evaluation framework.

A general framework for assessing knowledge spillover potential from technology support programmes

To assess the knowledge spillover potential of a technology support programme deemed to be operating in an open innovation system requires an expansion to the standard programme logic of the support programme. The programme logic describes the outputs, outcomes and the flow of future benefits of identifiable programme beneficiaries (within and across sectors) as appropriate to the programme (visualised in the usual horizontal flow from left to right in Figure ES1).

At each step in the flow of research and its commercialisation from outputs through to impacts, there is the potential for knowledge spillover, depending on the technology and the characteristics of the system (visualised as a vertical flow of spillovers from each step in the programme logic). The flow of spillovers is then a function of the seven factors identified in Table ES1 above. The potential scale of these spillovers can be assessed at each step by reference to indicators that seek to measure the presence of each of the seven factors in the relevant innovation system and hence the scope for spillover generation. Generally, high and positive values against each indicator would suggest the presence of spillovers from the support programme.

This framework of indicators is used for assessing the potential for knowledge spillovers – either ex ante or to review ex post - through the range of outputs, outcomes and impacts (Figure ES1 below). Given a benchmark (which will need to be established – using a reference programme), the indicator framework will allow an assessment of whether or not a proposed support programme will have a higher or lower level of spillover than the benchmark.

Figure ES1: A suggested framework for assessing ex ante the scope for spillovers

Core programme supported by govt. funds (Usual indicators)	**Outputs**	**Outcomes**	**Sector Impact**	**X-sector impact**	**Assessment of spillovers (relative to benchmark)**
Examples	Technical progress / testing / validation Increases in new partnerships / networks	Market testing and commercialisati-on	Market take-up and expansion Market spillovers	Application of new innovation in other markets / sectors	
SPILLOVER POTENTIAL					**HIGHER SPILLOVER IF:**
Sector level analysis:					
Technology and innovation	Multi and general purpose technologies: ■ Scope for multiple applications ■ Risk of technology being disruptive				Indicator: ■ High ■ High
Market and industrial structure	Size and value added of sector: ■ Potential market size (UK/global) ■ Scope for market pull ■ Capital intensity (Investment as share of sales) ■ Immaturity of sector (nascent / emergent / mature) ■ High / low GVA per worker				Indicator: ■ Large ■ High ■ High ■ High ■ High
Institutional set-up	Rules of the game vis-à-vis IP protection: ■ *Levels of IP protection and scope for imitation / learning* ■ Government funding and support ■ Impact on perceived risk to investors				Indicator: ■ *Context* ■ Positive ■ Positive
Actor level analysis:					
Actors	Number and type of actors: ■ Presence of research/technology organisations (RTOs)				Indicator: ■ High
Relationships between actors	Levels of networking: ■ Collaborations between industry and RTOs ■ Co-operation agreements between competitors ■ Scope for knock-on effects through supply chain ■ Scope for new industrial alliances				Indicator: ■ High ■ High ■ High ■ High
Transmission mechanisms	Types of knowledge (tacit / codified); (analytical, synthetic, symbolic): ■ *Dominant type* ■ Extent of distributed systems ■ Labour mobility with/across sectors ■ Exports/imports of sales/purchases as % of totals ■ FDI as % of sector investment				Indicator: ■ *Context* ■ High ■ High ■ High ■ High
Absorptive capacity	Characteristics of potential users of knowledge: ■ Levels of R&D amongst competitors and 'adjacent' sectors ■ Levels of human capital (share of workforce with given level of qualification)				Indicator: ■ High ■ High

Note: Context indicators – significant but ambiguous implications for levels of spillover – but should be examined on a case by case as to whether the levels are 'optimum'

Continuing challenges and ideas for the measurement of knowledge spillovers

The need for qualitative assessment of knowledge spillovers

The indicators described in Figure ES1 have been examined in relation to the possibilities of populating them from primary or secondary data. Only a small number of indicators can be populated from secondary data, and even then the data needs careful interpretation. The remainder of the indicators can only be populated on the basis of a qualitative assessment, using detailed information of actors that define and operate the innovation system.

The qualitative assessment will need to consider whether factors that increase the likelihood of knowledge spillovers are present and to what extent. In doing so, the analysis will need to develop the essential narrative, explaining the interactions within the specific innovation system and the spillover potential.

This approach is akin to scenario development, and the approach could make use of related techniques such as workbooks and workshops. Since these techniques are used in producing technology 'roadmaps', the approach should be familiar to many of the actors.

Use of multi-criteria analysis

The requirement to establish the relative significance of spillover potential of a proposed support programme / intervention, in the absence of quantitative data and using a scenario based research approach, suggests the possibility of developing and applying a multi-criteria analysis. This would be based on the seven factors and related indicators already defined. For a given programme the presence of each factor would be scored, with a higher score the greater the presence. Each criterion would be weighted according to the relative importance accorded to individual criterion.

The sum of the weighted scores would provide the basis for comparison with previously scored interventions or between a range of planned interventions. This would allow a ranking of, for example, the different Catapults on the basis of potential to generate spillovers.

The scope for quantification of spillovers

Some studies have sought to quantify spillovers from the perspective of supply chain and market impacts (which tend to assume that the business users of the knowledge are close to identical to the producers of the innovation and/or that existing inter-industry linkages are stable and provide a reasonable proxy). Using these assumptions, these studies have used econometric methods to quantify the value of spillovers for particular industrial sectors.

In a review of the economic literature, the net rate of private return on R&D investment is estimated to be in the region of 20-30% with the indirect or social rate of return estimated to be in the range of 20-100% from R&D investment, with an average close to 50% return. However, the literature does not differentiate between sources of the R&D investment; therefore it is not possible to measure the spillover impact from only technology innovation support programmes. Equally, it is not possible to attribute the presence of individual factors in the innovation system to the scale of impact.

Based on a range of 20% to 100% rate of social return relative to the private rate of return (20-30%) there is a wide variation between the direct benefit and the indirect benefit of R&D, which makes it difficult to suggest using the direct benefit as a proxy for the spillover effect.

This argument is supported further given that knowledge spillovers are likely to be at their greatest when innovation leads to market disruption and the realignment of demand and supply relationships. Since the econometric approaches invariably assume these relationships are stable, it seems unlikely that the results of such models could provide even a rough approximation to the social value of knowledge spillovers. The literature would, however, tend to support a conservative position that spillovers add a minimum of 20 percentage points to the private rate of return.

Moving towards monetisation of knowledge spillovers generated by support programmes

As a basis for decision-making, and determining investment priorities, especially across competing policy areas, establishing the monetary value of spillovers is clearly desirable.

A bottom-up approach would seek to estimate the number and value of individual spillovers in the form of a conventional impact assessment methodology – with due reference to the risks and benefits of deadweight and market displacement effects.

An alternative or complementary approach is to scope trends in the potential future total global market value of the knowledge produced by the support programme. Possible actual market shares could be assessed through the development of market scenarios.

For example, in the digital economy it may be possible to quantify the spillover from initial software or hardware innovation by assessing the proportion of sales the new innovation might take from an existing market (i.e. personal computer sales, content sales of music/ entertainment, etc.) This can be problematic in new markets where the potential scale is unknown and the technology is unproven in this respect, hence markets characterised by highly innovative or fast changing technologies can be harder to quantify.

In the context of programmes (such as Catapults) where impacts are largely in the form of spillovers, the extent to which spillover estimates might be justified will depend on the scenarios used and the credibility of the underlying intervention logic.

Application of the general framework to inform policy choices

The scope to use the framework across TSB programmes

The framework is most useful when seeking to inform investment choices between different sectors and technologies, where there is some expectation of significant knowledge based spillovers.

Where technology support programmes are essentially active in a ‘closed’ innovation system characterised by investment in knowledge protection and highly focussed on a set group of beneficiaries interested in private rates of return (i.e. a specific supply chain, or within a single firm), then the nature and context of the intervention works against spillover generation.

Review of the range of TSB programmes suggests that the framework has the greatest utility in monitoring and supporting investment choices in the Catapult programme. It would also have relevance in the context of Knowledge Transfer Networks (KTNs) which are explicitly directed to facilitating an open innovation system.

The framework is not designed for use in individual project appraisals. However, it could be used to assess the relative potential for spillovers of the various sectors, topic areas and technologies which frame these project level interventions.

Using the evaluation framework to inform investment decisions

The evaluation framework described above provides the potential to indicate the relative propensity of different programmes to generate knowledge spillovers, ex ante and ex post.

However, it does not automatically follow that the programmes with the greatest propensity for spillovers will necessarily provide the greatest return. It may be that closed programmes operating in a closed system with a very specific objective and innovation context could offer higher returns than an open programme.

The investment decision can then perhaps be separated into two choices: the first between innovation programmes that are essentially closed, and those which are essentially open; and, secondly, between competing open programmes.

Deciding between closed and open innovation programmes

The choice for a closed programme might depend upon, inter alia:

- The nature of the technology (is it well defined and discrete?)
- The desired nature of innovation (is it largely incremental?)
- The clarity as to the innovators and methods of research (are these readily identifiable?)
- The planned use of results (is it the intention that innovators are the primary users of the results of innovation?)
- The required levels of certainty and timing of benefits (is the benefit stream to be applied in the nearer term?)

Situations that meet the above criteria and where spillovers are of limited interest would be funded on the basis of standard rates of return; and would not be subject to the spillover assessment framework.

To the extent that there is a choice between a closed and an open programme, then the current approach of requiring the demonstration of a minimum level of return of any programme reduces the risk that the open programme may be ineffective or inefficient compared to the closed programme.

On the other hand, concerns over deadweight loss that might be significant in a closed programme would be less of an issue.

Deciding between different open programmes

The evaluation framework is essentially focused on this choice. It enables some degree of the relative ranking of different programmes. Further development might consider the use of scoring and weighting of factors as described in the context of a multi-criteria analysis.

Ex post, the framework is useful for understanding the greater potential impact of investment programmes of innovation support which were not justified on the basis of spillovers. Ex ante the framework can establish (relative to a specified benchmark or counterfactual) whether a proposed support programme has the potential to generate relatively high spillover activity.

The framework could also be used to help design the support programme in such a way as to maximise the opportunity for spillovers, by identifying strengths and weaknesses as the basis of adjusting the design and operation of the support programme.

Deciding between innovation support and other policy choices

In the more strategic case where there is a choice between defending current, or pursuing increased future, investment allocations between innovation support programmes and other policy choices, some quantification of the impacts of spillovers is likely to be required. Nevertheless, that spillovers may still be identifiable, but not quantified, could still help to inform decisions.

The scope for quantification could be explored on the basis of extending the ex-ante assessment into a more detailed assessment of market opportunities and possibilities for given market shares.

1 Introduction

1.1 Purpose and objectives of the project

The purpose of this study has been to develop an evidence base that will assist BIS (Department for Business, Innovation and Skills) to further improve the design of innovation support programmes based on a better understanding of the nature of spillover benefits. The study sought to distil the available literature to identify the factors that influence the likelihood of spillovers occurring, and their nature and scale. Using this evidence, the study aimed to develop an evaluation framework that can be used to better assess the value for money of innovation support programmes.

The Study had two specific aims, each with a set of sub-objectives:

- To provide an update of the most recent literature on spillovers covering any advances in the years since Jaffe (1996) was published. Achieved through a literature review this should:
    - Include the impact of any advances in technology which have enabled quick and cheap knowledge dissemination, together with consideration of the effect(s) of open innovation methods on the magnitude and range of spillovers;
    - In light of the social objectives of the technology Strategy Board (TSB), consider social spillovers from technological innovations, such as environmental and quality of life impacts; and
    - Identify the factors that influence the size, range and likelihood of these spillovers with a view to helping BIS categorise TSB and other innovation support programmes.
- To develop a monitoring and evaluation framework which could be used in future evaluations of innovation support programmes to measure spillover impacts. This framework should:
    - Inform programme development (i.e. what should be established in business cases) in order to identify potential features of a given innovation programme that may be conducive to spillovers;
    - Establish the case for government intervention in the relevant technology areas;
    - Provide quantitative and qualitative methods for measuring the potential for spillover impacts; and,
    - Provide an ex post methodology for measuring spillover impacts that can be applied as part of future programme evaluations.

1.2 Context

The 21st century has witnessed rapid innovation and technological change which have, in turn, allowed greater commercialisation to take place across different market and industry sectors worldwide. From increased cost-effectiveness to more job creation, technological progress is now seen as an important contributing factor to increased efficiency gains and higher growth rates. The growing acceptance that technical progress is a necessary condition for sustainable growth has subsequently led to increased support from the public sector for the implementation of technology programmes.

Technology programmes, designed to foster and stimulate innovation, specify the type and eligibility of programme beneficiaries (for example, businesses and other organisations such as the public sector). They are often targeted to different technology areas (for example, stem cells and regenerative medicine, internet technologies, plastic electronics, software and technologies addressing renewable energy and climate change, satellite communications, advanced manufacturing, amongst many others). This specification is driven by the purpose of the programme (for example, to increase productivity and economic growth, to improve resource efficiency, or to improve social outcomes).

The innovations funded by the programme deliver benefits to the programme beneficiaries, but (usually by design but also by accident) the innovations also impact on non-beneficiaries. Where these impacts on non-beneficiaries are not (fully) reflected in financial transactions between beneficiaries and non-beneficiaries these impacts become spillover effects. These spillovers can be positive (and/or negative), thereby increasing (and/or reducing) the social welfare benefit of the technology programme. The scale of such R&D spillovers will depend on the transfer mechanism pathway, the number of potential non-beneficiary users, the ability of users to make use of the knowledge (for example, direct or in the form of new products/processes), and the extent to which the benefits are internalised in the payments to knowledge providers. The effects on users are normally defined in economic terms, but could be defined using social or environmental indicators depending on programme objectives.

1.3 Method of approach

Our method of approach for this project comprised:

- A review and summary of the literature and evidence base on spillovers. A full reference list is provided in Annex 1 and the search strategy used is detailed in Annex 2;

- Interviews with TSB programme managers to better understand the context and nature of current support programmes in which to apply findings and inform the development of an evaluation framework; and

- Meetings with programme managers in which to test and revise evaluation framework proposals.

1.4 Structure of the report

The report continues in the following sections:

- Section 2 – provides an understanding of spillovers (in the context of open innovation systems);
- Section 3 – provides a summary of the main evidence relating to the factors that influence the occurrence of spillovers;
- Section 4 – outlines the process of developing the required evaluation framework, including an approach to establish the likelihood of spillovers, and then to define, track and measure specific spillovers; and
- Section 5 – provides conclusions.

2 The capacity of innovation systems to generate spillovers

2.1 Understanding spillovers

A broad body of literature exists on what spillovers are and how they might be generated from economic activity, specifically in relation to investment in and support for technology programmes. This sub-section attempts to clarify some of the terminology used in defining and discussing spillovers as an introduction to the issues considered in the remainder of this report.

2.1.1 Market failures and the rationale for government intervention

Spillover effects (sometimes called externalities) are impacts of economic activity that affect economic actors (society, businesses, and government) that are not directly undertaking the activity. In the case of innovation and the development of technology, spillovers occur when actors not directly involved in the activity are affected by the activity such that it is reflected in their behaviour and economic actions (knowledge spillovers). Users of the innovation that benefit more than that reflected in the price paid for use are benefiting from market spillovers.

Assuming that the effects of the innovation activity are positive and that the actor undertaking the activity is not informed of the effects on others (or cannot quantify these effects), then these impacts are unlikely to be accounted for in decision-making and exist as spillovers. By implication, the innovator only considers the private impacts realised from its own activities.

A government seeking to invest in innovation support programmes - and deciding what technology to invest in, what innovation should be prioritised, or what royalties to charge for the intellectual property created on the basis of the collective or welfare benefits - needs to include spillovers. If spillovers are positive but are excluded from any assessment then the returns to investment will be under reported, potentially leading to under-investment and sub-optimal social welfare outcomes.

A more refined definition of a positive spillover is the value of any benefit enjoyed by all other actors (termed secondary beneficiaries) in excess of the cost paid to acquire those benefits from the initial actor (the direct beneficiary of the programme intervention). For example, where a firm invests in a technology (the direct beneficiary), the spillover is represented by the benefit enjoyed by the secondary beneficiary (other firms, society) from accessing the knowledge/technology, less the cost of acquiring the technology or the intellectual property rights from the direct beneficiary.

In not realising that the activity in question may generate technology or knowledge which has value to secondary beneficiaries, the direct beneficiary is most likely to under invest in or under produce the desired product (for example, in a medicine, an energy saving technology, ideas, etc.). This is referred to as a market failure, as the market fails to efficiently allocate resources to its most productive uses. A more optimal allocation of resources therefore exists if the market were better functioning. Economists refer to the most efficient allocation as being Pareto Optimal[2].

The presence of positive innovation spillovers provides a rationale for increased government intervention to correct the under-investment that otherwise occurs. This is in addition to other forms of market failure that justify intervention in innovation programmes.

2.1.2 Innovation and technology related spillovers

The previous section loosely defined positive spillovers as the benefits from innovation in excess of any rent (royalties) or private return received by the direct beneficiary of the innovation. More specific to technology, Grossman and Helpman (1992) use the following definition:

"By technological spillovers, we mean that (1) firms can acquire information created by others without paying for that information in a market transaction, and (2) the creators (or current owners) of the information have no effective recourse, under prevailing laws, if other firms utilize information so acquired ."[3]

Notably, secondary beneficiaries may be located far from the direct beneficiary geographically, technologically or economically. For example, the secondary beneficiary may only be connected to the direct beneficiary through any number of actors who may not even be known to one another. The pathways by which spillovers may pass can consequently be complex and difficult to conceptualise in an evaluation.

It is possible, however, to formalise definitions of spillovers, their characteristics and relevant pathways. The literature defines up to three broad categories of spillover relevant to innovation programmes:

Rent (or market) spillover are benefits received by the secondary beneficiary in excess of price paid to acquire the intellectual property. For example, in acquiring the rights, further innovations or efficiencies in production processes may be generated which neither beneficiary anticipated or could account for in price, resulting in increased total and/or social welfare. Griliches (1979) is a proponent of these spillovers which are embodied within the product exchanged in the transaction, a distinction investigated thoroughly in the literature[4]. Jaffe and others also refer to this type of spillover as market spillovers, in the sense that to some degree they are accounted for in the programme intervention because government recognises the social benefits of the innovation when commercialised, and not just the benefit to the innovator.

Knowledge spillovers refer to the public goods aspects of knowledge, in the sense that a pure public good is non-rivalrious and non-excludable[5]. These spillovers occur when

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[2] Welfare cannot be enhanced further for one actor without another actor losing out.

[3] Grossman and Helpman (1992) in OECD (2000): Knowledge spillovers through R&D cooperation, by Dumont, M. and Meeusen, W. May 2000, available at: http://www.oecd.org/sti/innovationinsciencetechnologyandindustry/2093436.pdf

4 See Terleckyj (1974), Coe and Helpman (1995), Debression and Hu (1999) and OECD (2000)

5 Non-rivalrous means that knowledge held by one actor does not prevent its consumption by another actor. Non-excludable refers to the fact that knowledge cannot be exploited by the initial actor by preventing other actors receiving and benefiting from it.

knowledge transfer is not wholly accounted for in price (e.g. through the sale of intellectual property rights). Los and Verspagen (2009) recognise that knowledge can be transferred from one firm to another without any economic transactions having to take place or the secondary beneficiary having to pay for it. The presence of knowledge spillovers has implications for innovation support; recognising that knowledge can be shared and built upon by actors, interventions can focus on increasing levels of engagement and exchange between actors that lead to the realisation of positive spillovers, and recognising a spillover has no actual value until exploited in the market.

Wakelin (2000) goes further to suggest that some types of knowledge do not have all the characteristics of a public good, but rather some knowledge is purer than others. For example, some knowledge may be private but can be appropriated by other actors. Knowledge transmitted through scientific journals and via the product itself (accessible through, for example, reverse engineering), and the movement of skilled personnel between firms falls into this category. The result is that a firm may use knowledge originating in another firm without paying the full price for its benefits.

A pure knowledge spillover is one which is entirely disembodied in the sense that knowledge is exchanged informally between beneficiaries through geographical or social interaction and cannot be excluded by business actions. The rationale behind interventions such as technology clusters and research networks is partially an attempt to facilitate these pure knowledge spillovers by improving knowledge exchange.

Product/Network spillovers: these occur when new goods and services create demand for complementary goods in other sectors, or are adapted to other markets (NESTA, 2010). For example, in the case where films create demand for merchandise and toys or the case where the availability of online music increases the demand for music players. If the direct beneficiary is aware of the complementary benefits for secondary beneficiaries (for example the use of texting, sales of music, apps and search facilities on mobile devices), investment by the direct beneficiary may well be higher.

Other types of spillover identified in the literature include international knowledge, productivity, human capital, R&D and technology spillovers (BIS, 2012[6]). Rather than being different to the above definitions, they relate to the sub-divisions of them. Product/network spillovers are also referred to in the literature as creative clustering or regional spillovers (NESTA, 2010) as they relate to the locality and proximity of actors in an innovation system. From the reviewed material, no new advances on Jaffe’s (1996) definition of spillovers has been found.

Without a spillover having a value until exploited by the market, it is difficult to value or predict the occurrence of spillovers. The timescale over which they occur may also be highly uncertain. For example, market spillovers might be anticipated at the early stages of programme design as they are embodied in the technology and could reasonably be expected to occur within a short to medium timescale, accounting for the characteristics of

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[6] BIS (2012) The Impact of Investment in Intangible Assets on Productivity Spillovers https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/32323/12-793-investment-intangible-assets-on-productivity-spillovers.pdf

the relevant innovation system. For knowledge spillovers, the timescales are more uncertain, as they are reliant on various transmission mechanisms. It may be impossible to reliably indicate whether a spillover will be generated or its scale. Programmes characterised by knowledge spillovers of this type may therefore only be able to demonstrate value added through approximate attribution of subsequent evidence of the commercialisation of single or multiple innovations, which would not occur without the spillovers.

In the context of designing innovation support programmes, market and network spillovers might be expected to be defined as part of the programme rationale and therefore embedded to some degree in expected programme outcomes. Knowledge spillovers might be formally defined, depending on the innovation system and planned use of knowledge sharing and dissemination outside of the direct programme beneficiaries (i.e. those in direct receipt of funding for innovation activity).

2.2 Systems of innovation

The design of efficient and effective innovation programmes that take account of spillovers requires some understanding of the factors leading to their occurrence and impact.

Spillovers result from the process of innovation, being the consequence of individual or joint activities and interactions that induce innovation and commercialisation. Such activities and interactions are influenced by a range of factors which taken together can define the 'system of innovation' in which spillovers are generated.

Traditionally, the innovation system was essentially thought of as a linear process of R&D which businesses and research institutes / universities undertook and exploited as sole agents. Further work suggested that such linear processes could be 'science push' - from basic science innovation - or 'customer pull', where customers challenge the upstream innovation system to meet their specified needs and, potentially, contribute to the definition of a solution.

Similarly, Lundvall (1992)[7] broadened this concept by stressing the role of non R&D-based innovation which may occur throughout the linear system - and the learning associated with more routine activities throughout the supply chain from production, distribution and marketing to consumption.

Three key advances are, then, that: in this system, innovation is an outcome of the process of learning which is predominantly interactive and, therefore, a socially embedded process which cannot be understood without taking into consideration the prevailing institutional and cultural setting; ii) that setting implies a large variety of actors and interactions throughout the innovation system – it is no longer merely linear; and iii) such learning may result both from internally generated innovation ('learning-by-doing' – Arrow, 1962) as well as externally transmitted knowledge.

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[7] Lundvall, Bengt-Åke (1992), 'National Systems of Innovation. Towards a Theory of Innovation and Interactive Learning', London: Pinter Publishers

2.2.1 Open models of innovation

These types of characteristics can be seen within the concept of open models of innovation. Classical models of innovative performance are based on the premise that "successful innovation requires control" (Herzog, 2008). This infers that only a firm's internal R&D efforts and learning activities can help boost innovation and, thereby, product development. As a result of such 'closed innovation,' firms are confined to using their own resources and expertise in the generation of ideas and the development, production, marketing and distribution of new products or services.

Empirical work by Chesbrough indicated that firms from various industries, particularly high technology industries, had fundamentally changed the way in which they innovated. These firms were increasingly being drawn to 'open innovation' models whereby 'the use of purposive inflows and outflows of knowledge' are encouraged in order 'to accelerate internal innovation, and expand the markets for external use of innovation, respectively' (Chesbrough, 2006).

Table 2.1 Features of closed and open innovation systems

Closed innovation system	Open innovation system
■ A firm should hire the best and smartest people ■ Profiting from innovative efforts requires a firm to discover, develop, and market everything itself ■ Being first to market requires that research discoveries originate from the original developer only ■ Being first to market ensures that the firm will win the competition ■ Leading the industry in R&D investments results in coming up with the best and most ideas and eventually in winning the competition ■ Restrictive IP management must prevent other firms from profiting from the firm's ideas and technologies	■ A firm does not need to employ all the smart people, but rather gathers expertise both from inside and outside the firm ■ Internal innovation activities are needed to claim some of the significant value which can be created by external innovation efforts, i.e. firms should have some absorptive capacity ■ In order to win the competition, it is more important to have the better business model than getting to market first ■ Winning the competition does not require coming up with the best and most ideas, but to make the best use of internal and external ideas ■ Proactive intellectual property (IP) management allows other firms to use the ('developer') firm's IP

In open innovation models, spillovers may be treated as an opportunity to expand a company's business model. Not many empirical studies report on the scale of these spillovers but there seems to be a general consensus that R&D projects are more likely to be successful when developers have: (1) a high degree of internal cohesion which leads to mutual trust and reciprocity; and (2) a moderate level of relationships with developers outside the project.

There is also evidence from the literature that firms that are too internally focused may miss opportunities, as many knowledge sources necessary to achieve innovation can only be found outside the firm (for example, Chesbrough et al. 2006). The lack of openness of firms to their external environment may reflect an organisational myopia, indicating that managers may over-emphasise internal sources and under emphasise external sources.

Openness to external know-how and technology allows firms to benefit from knowledge that is likely to spill over from other firms' R&D activities, given that this technical know-how is freely available to those willing to invest in searching for it. Nonetheless, knowledge that spills over is mainly 'tacit' in nature (i.e. it is highly contextual and therefore difficult to communicate). Tacit refers to knowledge which cannot be communicated (i.e. it has to be physically learnt by the recipient rather than exchanged). Consequently, unless the knowledge is embodied in staff who move between firms this knowledge can be difficult to communicate and spillover.

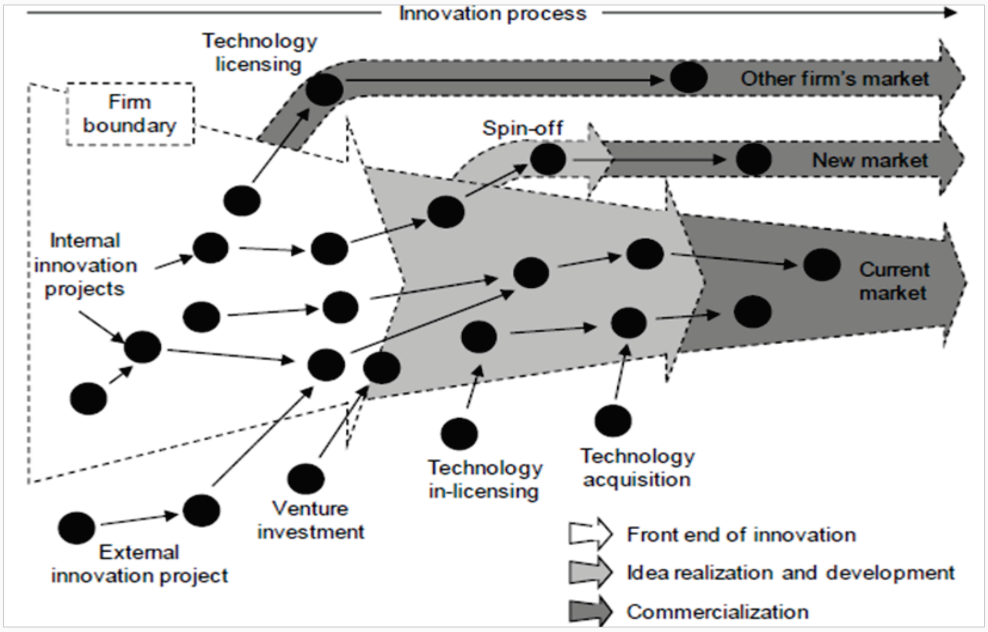
The benefits of openness are not limitless. In their research paper, Roper et al. (2011) find an inverted 'U' shape relationship between the extent of openness, in terms of the variety of knowledge sources used, and a firm's innovation outputs. This suggested that greater openness may not always be advantageous for the generation of potential spillovers. They also find evidence of 'learning effects' as openness in one period enables firms to generate more innovation outputs in the next.

The literature also emphasises the importance of the absorptive capacity of firms in conditioning their ability to benefit from openness, whereby the failure to undertake R&D on their own account limits their ability to make use of knowledge obtained externally.

In practice, all systems of innovation sit somewhere along a broad continuum of open and closed innovation models - with useful knowledge being more or less openly and widely distributed. This knowledge may, in turn, spill over to other firms that may not have been initially involved in the innovation activity. As such, innovative ideas may stem from large companies but also from smaller individual inventors, research facilities of universities as well as from their respective spin-offs[8]. Figure 2.1 illustrates one example of the role of external knowledge and technologies in the innovation process.

[8] A spin-off here refers to 'a company whose business is based on products or technology initially developed in a parent company, university or research institution'. Spin-offs thus act not only as product innovators, but also as a means of transferring knowledge and technology between research facilities and their parent companies (Lejpras and Stephan, 2011)

Figure 2.1 The role of external knowledge and technologies in the innovation process



Source: Chesbrough (2006)

2.2.2 Features of an open innovation system

Building on the evidence from the literature review describing innovation systems, we have identified the main features which shape and define an open innovation system. This forms the basis for the subsequent analysis of factors which increase the propensity for spillovers, especially knowledge spillovers. Seven features have been defined:

- Technology and the nature of innovation: the stage and types of innovation, including its potential for commercialisation or replication, and the type of technology and range of its applications;
- Market and industrial structure: the defining characteristics of the market and industry in which the innovation takes place such as the levels of industrial concentration and competition, and the maturity and capital intensity of the sector; and
- Institutional set-up: the social processes, regulations and other non-market-based institutions that influence the local and external conditions in which knowledge may flow.

Within such an innovation system, the scale and potential for positive spillovers are influenced by a number of further defining features:

- **Actors**: the number and diversity of actors interested in the generation and use of knowledge for the development of a given technology;
- **Relationships**: the nature and strength of relationships, institutional ties and links between actors;

- **Transmission mechanisms**: the mechanisms or pathways through which different types of knowledge are shared and diffused; and

- **Absorptive capacity**: the ability of users to assimilate and make use of knowledge.

The ways in which these features interact defines the innovation system for the development of particular technologies and markets. In so doing, it influences the potential to generate spillovers. The next section seeks to identify those factors, associated with the specified features of the open innovation system, which are identified in the literature as being associated with the capacity to generate spillovers.

2.2.3 The implications of a systems view of innovation

In a systems view of innovation, non-market-based institutions are an important ingredient in innovation outcomes (ter Weel and Verspagen, 2010). The first implication is that the government or policymaking body is part of the system itself – their potency lies in the indirect effects that they have throughout the system. However, their potency is hard to predict precisely.

The second implication of this is that it provides a broader justification for policy instruments compared to policies based only on identified market failures. For example, in a market failure approach, R&D subsidies may aim to overcome a lack of incentives to innovate by lowering private costs to increase investments to socially optimal levels. In a systems approach, such policy instruments are able to serve a more general purpose that includes influencing the knowledge base in firms and to increase firm's absorptive capacity. Similarly, policies aimed at fostering cooperation, in the market failure-based approach, seek to internalise externalities, while in a systems approach these could be aimed at influencing the distribution of knowledge, increase the cognitive capacity of firms/research institutes or achieve greater coordination between actors.

Annex 3 provides a more detailed description of innovation systems.

3 Features of innovation systems and the potential for the generation of spillovers

This section makes a number of propositions regarding the presence of identified factors in open innovation systems and their propensity to generate knowledge spillovers (as identified and described in Section 2). The literature evidence obtained from academics and experts in the field of technological innovation is then used to critically appraise each proposition to reach evidenced conclusions.

Seventy five documents in the academic and grey literature addressing the potential for spillovers were reviewed for this purpose.

3.1 Technology and the nature of innovation

Reflecting the 'generally poor quality of technology indicators' (Los and Verspagen, 2000), limited direct comparative analysis of the role of different technologies and the stage or type of innovation has been carried out in the literature. Difficulties in making a clear distinction between different types of technology and innovation for the purposes of empirical analysis contribute at least in part to this lack of evidence. A need therefore exists for greater operationalisation of theoretical distinctions.

What little evidence is available suggests that such features may be better captured or explained through the way in which they interact with and influence the other underlying features of an innovation system, particularly the association with different relationships between actors, and the flows of different types of knowledge.

3.1.1 Type of technology

Proposition: Multiple applications of general purpose technologies provide greater scope for spillovers, but specialist applications may be easier to spot.

Multi-use or platform technologies with potential for multiple applications across a range of sectors may seem an obvious candidate for bearing spillover potential, since subsequent technical developments require expertise in applications technology which proponents lack, and therefore are unable to appropriate rents. However, there is no empirical evidence available in the literature to bear this out.

It remains possible therefore that while more specialist technologies may have less scope for further applications, such applications may be easier to spot. However on this point too, there is limited evidence and, indeed, Jaffe et al. (1993) find no evidence that more 'basic' inventions diffuse more rapidly than others based on an empirical analysis of patents and patent citations in the US. Instead, the authors find that the extent to which spillovers are localised depends fundamentally on the mechanisms through which information flows, mechanisms which may well vary across technical fields.

The relationship between different technologies and spillovers may be just a matter of timing. In recent analysis by Rincon et al. (2012), the findings suggest that the benefits of intra-industry spillovers between upstream and downstream firms in the ICT sector and inter-industry spillovers between firms sharing the same ICT are characterised by a time lag. The spillovers from ICT here are seen as a source of so-called 'pecuniary spillovers' - inducing a combination of competition and innovation in the ICT sector that can allow other industries using computers to benefit from lower costs.

Such a lag in generating spillovers may reflect the greater difficulty for firms to effectively assimilate knowledge of general purpose technologies, and the associated learning costs as well as the time required for new infrastructure to develop to support a new technology.

Key finding: Positive spillovers from multi-application or general purpose technologies are identified but are associated with lags.

3.1.2 Type of innovation

Proposition: Incremental innovation is easier to replicate BUT the disruption from radical innovation may generate additional innovation.

The relationship between the nature of innovation and the capacity for spillovers has received relatively little attention in the literature. Theoretical discussions suggest that any such relationship is more aptly captured by the underpinning features associated with different types of innovation – with particular emphasis placed on absorptive capacity, and the types of knowledge and the potential openness of knowledge dissemination that may be associated with different types of innovation.

Incremental innovation, for example, is cumulative in nature - consisting principally of small steps that result from the constant learning and knowledge searching by firms. An important dimension of this process is also the feedback between different actors in the system, since each incremental innovation is at least partly a reaction to previous innovation by others.

Leahy and Neary (2007) associate such incremental R&D with industries in which the ability to assimilate external knowledge and learn from other actors is high – from automobiles to microelectronics to pharmaceuticals (Leahy and Neary, 2007).

Jaffe (1996) provides a further distinction between the potential for process and product innovations to generate spillovers, since the former are identified as more conducive to being kept secret and knowledge thereby retained within the firm. As well as limiting knowledge spillovers, process innovation may also be associated with lower market spillovers since it is considered likely that the project proponents will have sufficient technical expertise to appropriate rents from developing follow-up technologies. In contrast, product innovations that are difficult to patent or copyright make interacting knowledge and market spillovers more likely.

Key finding: No available evidence to suggest that the type of innovation, in and of itself, is a determining factor of the potential for spillovers. There appears to be some ambiguity in the literature regarding whether general purpose / multiple application technology programmes give rise to disruption.

Stage of innovation

Proposition: Demonstrators have a greater chance of generating spillovers than pre-commercial innovative activities as third party actors seek to commercialise the knowledge generated.

Evidence in the literature regarding the stage of innovation is limited to an evaluation of the US programme for Small Business Innovation Research (SBIR). Here, evidence suggests that a significant number of firms were established as a result of the demonstration effect arising from the efforts of beneficiary firms to commercialise knowledge as part of their innovation programme (see 3.1.2.1 below).

That the potential for spillovers may be greater at the demonstration phase, where market visibility is greater, reflects their intended purpose to disseminate knowledge. In the absence of evidence to the contrary, however, the possibility remains that the potential role of spin-offs or joint ventures that may arise only at the pre-commercial stage, may also have the potential to generate significant spillovers. The lack of available evidence may reflect a lack of data to aptly operationalise the distinction between different phases in the innovation process at an empirical level. Also, it may be the case that more subtle, underlying factors are driving the nature of the flows of knowledge between firms and industries rather than the stage of innovation itself.

Key finding: No available evidence to suggest that the type of innovation, in and of itself, is a determining factor of the potential for spillovers.

3.1.2.1 The role of demonstrators in generating spillovers[9]

Objectives of the SBIR Programme

The Small Business Innovation Research (SBIR) Programme began in 1977 in the US. The goal of the programme was to encourage small businesses, considered by many to be the engine of innovation in the US economy, to participate in the National Science Foundation – sponsored research programme. In total, there were 44 SBIR-sponsored projects. The objectives of the SBIR programme were:

- to stimulate technological innovation;
- to use small business to meet Federal research and development needs;
- to foster and encourage participation by minority and disadvantaged persons in technological innovation; and
- to increase private sector commercialisation of innovations derived from federal research and development.

Evidence on the resulting outcome of the SBIR Programme

There was wide consensus across evaluators that the SIBR Programme was successful at stimulating R&D as well as efforts to commercialise that would not otherwise have taken

[9] Audretsch et. al (2001): Public/Private Technology Partnerships: Evaluating SBIR-Supported Research http://www.dartmouth.edu/~jtscott/Papers/01-01.pdf

place. Further evidence also shows that the SBIR-derived R&D did lead to commercialisation, and the net social benefits associated with the programme's sponsored research were substantial. Audretsch *et al* (2001) estimated an average private return rate of 76 per cent across the 44 projects. Additionally, the expected social rate of return associated with SBIR funding of these projects was estimated at nearly 84 per cent, further suggesting that the projects were socially valuable.

Main channels via which spillovers were created

The SBIR Programme changed the behaviour of knowledge workers and thereby helped to create a science-based entrepreneurial economy. Due to the demonstration effect by the efforts of scientists to commercialise knowledge:

- a number of the firms that would not have been started in the absence of the SBIR Programme were set up;
- a number of the scientists and engineers that would not have become involved in the commercialisation process in the absence of the SBIR Programme were recruited; and
- as a result of the demonstration effect of SBIR funded commercialisation, a number of other scientists altered their careers to include commercialisation efforts.

3.2 Market and industrial structure

Propositions: Internationally-oriented, high value added sectors characterised by high levels of competition are associated with a greater ability, need or willingness to invest in innovation creating greater scope for potential spillovers.

3.2.1 Industry sector

Within each innovation system, the industry sector has a leading influence on the willingness of actors to accept risk and therefore invest in innovation. The industry sector also contributes to determining the mechanisms of knowledge capture, firm characteristics, the ability to invest in follow-up innovations and therefore the capacity to generate spillovers. For example, Los and Verspagen (2000) find some limited evidence among US manufacturing firms that increasing returns to scale may exist in high-tech industries. For the UK, in identifying the 'net producers' of innovations in 18 manufacturing industries (sectors which produce more innovations than they use), Wakelin (2000) highlights the significant contribution of high value added sectors, including mechanical, electrical and instruments engineering, electronic machinery and chemicals sectors, in generating innovations used in other sectors. Food, drink and tobacco industries, in contrast, produce far less innovations with inter-industry applications.

Insofar as the producers of innovation are unable to fully appropriate rents from the use of their innovations in other sectors, this cross-fertilisation of technology and knowledge will represent inter-industry spillovers. Throughout the literature, the influencing role of the sector on the potential for spillovers is prominent in the following aspects: i) secrecy or degree of openness within the innovation system; ii) networking associated with the technologies and innovation processes of the sectors determining the opportunities for cross fertilisation and exchange; and, iii) the level of human capital and/or entrepreneurial spirit of the sectors which may determine the access to and exploitative potential of external knowledge.

3.2.2 Competitive pressure

The most commonly discussed market and industry factor contributing to within-market/industry spillover effects is the competitive pressure in markets.

The effects of the level of competition or its inverse, the degree of market concentration, are however more ambiguous. While a certain degree of competition is seen as desirable to generate positive externalities as firms have an increased incentive to innovate to stay ahead of the competition, it is also seen as increasing the likelihood that other firms may benefit from others' innovation through imitation, due to the high degree of product substitutability among competitors.

The relationship between innovation and imitation is complex. The greater potential for imitation means that competitors can gain from the knowledge of other firms to a greater extent. However, such pure imitation cannot sustain profitability indefinitely (Jaffe, 1996 and Hanel and St. Pierre, 2002). Indeed, imitation resulting from high competition decreases the benefits of any firm undertaking innovation in the first place, as the appropriable private returns from innovation are reduced. However, imitation can be important in the growth of new markets so that innovations are available at lower cost and much more widely than otherwise would be the case (e.g. Emergence of personal and tablet computer markets). With too much competition, the research effort of any given firm can thereby create a negative externality for other firms.

At the other end of the scale, high market concentration (i.e. having a few large firms in the market), is associated with greater pace of innovative change and thereby greater incentives for firms to find a first mover advantage and extract monopoly rents (at least for a time). Nonetheless, market concentration is also argued to have a dampening effect on innovation since this removes the competitive pressure that provides another important incentive for firms to innovate.

On balance, Aghion et al. (2005) suggests the existence of an inverted U-shape relationship between the level of competition and the propensity for spillovers to be generated from innovation. Here, those markets characterised by medium levels of competition between firms operating on a similar technological field (referred to as 'neck-and-neck' firms), are most associated with generating innovations that may be replicated, applied or absorbed by other actors.

3.2.3 Other market factors

Industry sector structure and competitive pressure can only partially explain the presence of spillovers. Strategic and behavioural considerations can also be significant in this respect. Taking the example of innovation and imitation, empirical analysis by, Slivko and Theilen (2011) find that in nascent (young and small) industries, innovators have less incentive to try to prevent imitation. The lack of pressure to prevent imitation at the early stages of industry development may relate to the relatively low initial value of the innovations in a small market, (i.e. the opportunity costs of what would be lost are lower) as well as the incentive for firms in network industries to cooperate in order to establish a market and overcome the negative spillovers associated with more established industries (due to lock-in effects and need to keep transmission costs as low as possible). Spillovers are more likely to occur in such circumstances. But, as the industry expands, innovative effort is found to decrease because of imitation pressure and higher opportunity costs of losing the generated innovation which may encourage actors to be more insular in focus and less risk taking when making innovation related decisions.

Similarly evidence from a recent analysis of spillovers among manufacturing firms in Sweden, Poldahl (2012), suggests that those firms that act as market leaders are characterised by a comparative advantage in terms of assimilating and learning new outside knowledge stemming from abroad, thus absorptive capacity is higher.

Key findings: The capacity for inter-industry spillovers appears to be greater in high value added sectors (i.e. mechanical, electrical and instruments engineering, electronic machinery and chemicals) than in other sectors. The effect of competitive pressure is ambiguous, with both too much and too little competition likely to limit the capacity for positive spillover effects. Some evidence suggests that spillovers are likely to be greater in nascent industries, irrespective of the industrial structure.

3.3 Institutional set-up

Social norms and conventions, as well as the more formalised institutions of government, arbitrators and regulators, will all have a considerable influence in shaping the way in which agents interact with one another, and the degree to which knowledge is openly exchanged or closely guarded. For example, public infrastructure and local facilities can facilitate the exchange of information and connectedness between actors by reducing travel times or through telecommunication services. Another example is the exchange of knowledge in software development via online ‘cloud’ services. Two of the most prominent characteristics of institutional set-up explicitly addressed in the literature are the roles of intellectual property protection and government funding and support.

3.3.1 Protecting intellectual property

Proposition: limited restrictions and controls on the flow of knowledge between actors in innovation systems open up the possibility for greater spillovers.

Literature evidence suggests that there is a mixture of views among scholars as to whether intellectual property (IP) protection is beneficial to the generation of spillovers. In some cases, strong patent protection is considered to be associated with larger R&D spillovers. Patents are considered by firms as a channel of knowledge disclosure and dissemination, and since the act of patenting entails the codification of knowledge[10], it may make it easier rather than more difficult for a greater number of beneficiaries, across a wider geographic space, to absorb this knowledge (Coe et al. 2008 and Liu, 2012).

[10] Leamer and Storper (2001) define codifiable information as “cheap to transfer because its underlying symbol systems can be widely disseminated through information infrastructure”. However, all information is not completely codifiable. The presence of some specific features makes, in some cases, codification impossible or too expensive. “If the information is not codifiable, merely acquiring the physical infrastructure is not enough for the successful transmission of a message” (Storper and Venables, 2004)

Innovating firms may therefore enjoy the information disclosed in external patents in order to increase the value of their own innovations (Chesbrough, 2006). The impact of other channels through which different types of knowledge are transferred is considered in section 3.5.

While it remains plausible that the act of codifying IP may extend the reach of knowledge spillovers across a wider geographic area, it undoubtedly reduces the level of market spillovers since innovators are enabled to appropriate payment from those seeking to make use of their innovation. IP protection, and other mechanisms of appropriation including secrecy, technical complexity, or the exploitation of first mover advantages, is also seen to serve to limit the potential for imitation and follow-up innovations by other actors, at least in the short term.

In the longer term, scholars tend to broadly agree with the view of Arrow (1962) that: *'no amount of legal protection can make a thoroughly appropriable commodity of something [as] intangible as information. The very use of the information in any productive way is bound to reveal it, at least in part'.*

A study by Feldman (1999) suggests that even codified knowledge (using patent citations) may be localised in the sense that at least initially the knowledge is held with a small number of actors, but that this localisation effect may fade rapidly as the information is disseminated more widely (i.e. after the first year following the patent). For example, knowledge could be held within research groups/networks or within organisations, before codified knowledge is shared with other interested parties. However, even this relatively short period of localisation may be important as, in a number of key sectors (such as electronics and optics), there is such rapid obsolescence that even after this short period of localisation, the realisable value of such knowledge may be negligible.

More recent evidence from Cohen et al. (2011) suggests that the balance between IP as a codifier of knowledge and thereby facilitator of its wider dissemination and the view that IP limits imitation and follow-up innovation in the short-term, is likely to depend on the non-market based institutions or 'rules of the game' surrounding the patents system and social attitudes to knowledge exchange.

In exploring the differences between the Japanese and US systems of patents, Cohen et al. (2011) claim that the ability of firms to appropriate at least some of the value of their innovations is essential for any innovation to occur. In countries such as Japan, where the appropriation of rents arising as a result of innovation and the rewards from arbitration on infringements appear to be relatively small, patenting is more common.

Further, the authors find that 'imitation lags' are much more compressed in Japan than in the US (lags are substantially longer in the US, ranging from 40% longer for unpatented product innovations to about 80% longer for patented process innovations). Where such lags exist, and patents serve to effectively prevent inventions from being copied, innovative firms may obtain significant competitive advantage and spillovers will be low.

However, in the longer term and particularly for firms operating in Japan, the use of patents does not necessarily keep rival firms out, but instead they allow these firms to establish or strengthen a non-exclusive right to be a player in a technological domain. In the Japanese case, by encouraging a greater number of products per patent system, not only does the system encourage spillovers, but it also ‘tends to generate technological interdependence among competitors’ and thereby institutionalises an incentive for firms in the same technological domain to share information.

While patents are quite important in certain industries, such as pharmaceuticals, it is important to stress that in most industries firms rely predominantly on mechanisms other than patents to protect their innovations. Such mechanisms include secrecy, first mover advantages and the exploitation of complementary capabilities (e.g. complementary sales/service or the manufacture of complementary goods).

Key findings: Formal protections are only sufficient to delay imitation, although it remains possible that such delays may limit potential for positive spillover effects. IP systems may promote technological interdependence among competitors which in turn may, paradoxically, actually create incentives for firms to exchange information.

3.3.2 Government funding and support

Proposition: Although government funding may crowd out private investment to some extent, it is to be expected that funding through technology support programmes will be targeted at activities with non-appropriable social and environmental benefits and therefore greater scope for market spillovers

Empirical analysis of the relationship between government funding of innovation in Germany by Boente (2004) has suggested that publicly funded R&D in higher-technology industries induces private R&D investments within these industries, with the potential for spillovers.

In the US, evaluation of public policy interventions in innovation support through the ATP programme by Watkins and Schlie (2006) provides indicative evidence that publicly financed R&D provides cash flow that enables firms to bridge the gap between invention and commercialisation and attract venture capital. There is also some evidence from the Canadian SDTC demonstration funding programme evaluation of this ability to lever in private finance during or after the project has completed due to the derisking that has occurred through the public sector ‘risk capital’ injected. Anecdotally, the award of an SDTC grant was a good benchmark of quality which allowed potential investments to pass an initial “sniff test” with venture capitalists and other investors who invested partly because firms had been SDTC backed.

Haskel and Wallis (2010) regressed total factor productivity (TFP) growth on various measures of direct public sector R&D spend including research councils, block grants to universities for research, civil R&D and defence R&D. Using newly available data on TFP growth, they find quite strong evidence of market sector productivity benefits from public R&D spend on research councils. Similarly, Lejpras and Stephan (2011) find that the innovativeness of research spin-offs with strong local dimensions depends heavily on support from public authorities and institutions. Where innovation is not local, cooperation intensity is found to be a far more important determinant.

Regarding the types of spillover to be generated from government funding, Haskell and Wallis (2010) found no evidence of market spillovers from UK public spending on defence related R&D. The apparent lack of evidence may be due to the secrecy surrounding innovation in defence R&D and associated lags in application to other sectors.

However, there are clear examples of innovation activity undertaken by for example Qinetiq from defence related R&D finding application in other sectors (for example innovations around missile tracking, submarine propulsion technology, radar etc. have translated respectively into technology for sport (such as HawkEye in cricket and goal line technology), new propulsion systems, and the identification of wind turbines by radar.

Feldman and Kelley (2006) analyse the extent to which firms' openness to sharing innovation results with other firms affects the probability they are awarded R&D subsidies by the government. They review data about applicants to the 1998 competition of the U.S. Advanced Technology Program at the National Institute for Standards and Technology (NIST) and find that firms which participated in new research joint ventures and connections to universities and other firms, and which were open in the communication of their results, were more likely to receive the subsidies. In short, projects are selected that are conducive to knowledge spillovers in order to raise the social rate of return on the project. The role of the inter-relationships between actors and the potential scale and scope of spillovers is considered in more detail in section 3.4.2.

Key findings: The effectiveness of public funding in creating scope for greater spillovers depends on the incentives it provides for leveraging additional private investment into innovation (increasing the level of knowledge generated) and for knowledge sharing. There is little evidence that public funding crowds out private investment.

3.4 Actors and the relationships between them

Propositions: Information sharing through formalised relationships and alliances and cooperation between actors in innovation systems can lead to technology transfer, and can increase the potential for positive knowledge spillover effects.

3.4.1 Cooperative agreements and strategic alliances

Businesses may develop new technological capabilities through in-house innovation activities (for example, R&D) and through the use of external strategic technology alliances. A strategic alliance will typically take the form of an agreement between two or more organisations to achieve a shared strategic goal. In the field of innovation management, this shared strategic goal typically involves the co-development of a new technology or product. Various types of cooperative agreements can be arranged between innovative firms, and these are outlined in Table 3.1 below.

Table 3.1 Forms of cooperative agreement

Technology agreement/ partnership	Typical duration	Comments
Licensing	Fixed-term	Licensing refers to the exploitation of other firms' intellectual property within a certain time frame, for which the licensee (i.e. the firm that in-licenses the technology) pays a fee plus a royalty based on sales

Technology agreement/ partnership	Typical duration	Comments
Joint R&D agreements	Medium/long-term	These comprise agreements between firms or organisations to collaborate on the development of specific technologies, products, or processes
Venture capital	Flexible	This will typically involve established firms investing in entrepreneurial and innovative start-up firms
Joint ventures	Long-term	Joint ventures will normally involve the creation of an independent organisation in which two or more firms own equity. This implies a relatively high commitment for the participating firms. In general, each firm will bring specific capabilities to the joint venture that the other firm does not have. For instance, a joint venture could be combining the technological capabilities of one firm with the market capabilities of another.
Acquisitions	Long-term	Acquisitions refer to the full integration of a firm's complete portfolio of technological capabilities. Acquisitions are particularly useful when a firm wishes to: (1) acquire a (specialised) knowledge or technology base or (2) shortcut the R&D process when it is a relatively late entrant in a particular technology area

Evidence from the literature suggests that the establishment of such forms of voluntary and informal interaction may ensure that knowledge is rapidly disseminated amongst innovative firms. Indeed, the empirical evidence in the literature consistently finds a significant relation between external information flows and the decision to cooperate in R&D (Cassiman and Veugelers, 2002 and Lejpras and Stephan, 2011).

In the case of spin-offs, Lejpras and Stephan (2011) confirm that there is a strong positive relationship between the intensity of cooperation between actors and the magnitude of the spillovers generated through business spin-offs.

The research evidence broadly supports the finding that the greater intensity of R&D cooperation is favourable to knowledge diffusion and innovative activities, particularly in knowledge intensive sectors.

3.4.2 Informal relationships

In addition to formal research consortia, firms have other types of less formal relationships with other organisations that involve sharing knowledge, and which may provide pathways for spillovers (Feldman and Kelley, 2006), for example flows of knowledge between actors in an innovation system may be captured through supplier–customer relationships, professional associations and informal networks of research and corporate organisations.

The literature highlights the latter link between firms and research institutes as particularly relevant to the formation of pathways for knowledge spillovers given universities' public role in creating and disseminating knowledge. This is supported by Gittelman and Kogut (2003) who demonstrate that exchanges between university and industry scientists, as measured by joint publications, have a positive impact on firms' innovative output. Similarly Cockburn and Henderson (1998) find that the degree to which pharmaceutical firms are connected to universities and encourage collaboration with academics is important for realising knowledge spillovers.

Spillover benefits from supplier-customer relationships are less well documented, although in theory it is deemed likely that such relationships provide an important feedback mechanism to actors' innovative processes since the detailed knowledge of a product's strengths and weaknesses and areas where improvements would yield big payoffs will tend to reside with those who use the technology i.e. the downstream users. For the creative industries, NESTA (2010) highlights the possibility of users making upstream suppliers more innovative through their sophisticated demands. Here, the example given is the advances in computer chips and servers to cope with the increasing graphic intensity of computer games demanded by games manufacturers and programmers.

The strength of ties and levels of trust among actors in an innovation network is found to have a positive impact on information and knowledge transfer that may generate spillover effects (Fritsch and Kauffield-Monz, 2007), based on the provision of rapid and explicit feedback and the 'enabling character' of networks to foster joint problem-solving arrangements, and induce collective learning. As Uzzi (1996) explains 'social relations [that typically meet with networks] make information credible and interpretable'.

Focussing on international or inter-regional spillovers Coe et al. (2008) identify that countries where the ease of doing business is high (captured in institutional factors) tend to benefit the most from international R&D spillovers, while Rodriguez-Pose and Crescenzi (2006) identify a significant positive relationship between a constructed 'social filter' - which seeks to capture the quality of the institutional set-up - and positive R&D spillovers. Furthermore, it was found that a good 'social filler' can often increase the potential of regions to assimilate knowledge spillovers.

In an empirical analysis of the role of actors fostering spillovers in Italy, Aiello and Cardamone (2008) highlight that asymmetries in the knowledge flows between firms is likely to influence R&D spillovers, with particular reference to the relative size of different firms. Fritsch and Kauffield-Monz (2007) find that the smaller the firm, the more knowledge was transferred to the network partners, possibly reflecting relative bargaining and negotiating power.

The use of networks to exchange information, particularly by smaller firms may be understood in terms of the facilitation role the network plays in bridging gaps between actors, communicating innovations in an easy to understand way and at relatively low cost. Larger firms may already benefit from more established relationships with actors, specifically within supply chains, and therefore benefit less from such networks. In this context, Audretsch and Feldman (1996) contend that the establishment of network ties or geographic clusters may be seen as an alternative for smaller firms to investment in absorptive capacity (explored in section 3.6).

3.4.3 Geographic proximity and clustering

High geographical (and social) clustering or other measures of proximity between innovative firms have been frequently cited in the literature as supporting spillovers. In most cases, these spillover effects take the form of 'localised knowledge spillovers' (e.g. Jaffe, 1996 and Cincera, 2005). The geographical extent of such knowledge spillovers is limited and declines with distance. Limits to geographical clustering have been estimated to be 180 minutes in Europe (Rodriguez-Pose and Crescenzi, 2006) or 75 miles in Germany (Funke and Niebuhr, 2000).

Such a consistent finding is perhaps best explained in terms of the channels through which different types of knowledge flow. Spatial proximity is likely to matter more, the more contextual - and therefore difficult to codify - the information is. The finding in Jaffe (1996) that spatial proximity played an important role for chemicals R&D productivity, but had a much lesser effect on pharmaceutical R&D, may corroborate this view since the patenting or codification of knowledge is much more important and less geographically bound in the pharmaceutical sector (see section 3.3.1 for discussion of the role of IP protection).

Breschi and Lissoni (2001) also attribute the faster diffusion of innovation and greater potential for spillovers among geographically concentrated clusters to the tacit nature of some research. In this case, they argue that some degree of personal contact or oral communication is necessary for knowledge to be effectively transferred (other mechanisms for knowledge transfer are explored separately in section 3.5). It follows that firms located in regions with high flows of both private and public or academic R&D are more likely to be innovative than firms located elsewhere due to the benefits from the knowledge that leaks out from these sources (Brescht and Lissoni, 2001).

A dense cluster of actors can also be characterised by strong ties, meaning that the actors are mutually connected to each other and the beneficial effects of proximity may therefore be explained in terms of the positive network effects explored in section 3.4.2. Indeed, by introducing measures of the collaborative links into a model with geographic measures and other local conditions including local human capital and transport infrastructure, Lejpras and Stephan (2011) find that the relevance of geographic proximity to cooperating partners willing to enhance their firms' innovativeness is minimal. In fact, the authors find that non-local collaboration links are more conducive to innovativeness than are local ones, perhaps reflecting that non-local collaborations are unlikely to be formed in the absence of a strong case for R&D and productivity benefits.

3.4.4 Links with universities

By being near and 'open' to universities (where leading-edge research is normally conducted) as well as to a number of other innovative firms, owners of local firms are more likely to have direct access to important discoveries or the knowledge that is necessary to exploit them commercially, thereby gaining an innovative advantage over distant rivals. In the biotechnology sector, for example, collaboration with universities is a central mechanism by which biotechnology firms acquire knowledge and disseminate research findings (Ruegg and Fuller, 2003).

Almeida and Kogut (1997) find that knowledge spillovers from university research to firms are highly localised. This claim is also supported by Brouwer et.al (1999) who find that firms located in agglomerated Dutch regions tend to produce a higher number of new products than firms located in more peripheral regions. The potential for spillovers therefore relates to a firm's capacity to engage in strategic alliances and/or personal relationships with those innovative firms (this is further discussed in section 3.4).

Potential limits to the use of external linkages and open sources of knowledge highlighted in the literature, which may make external R&D or knowledge links unattractive, include:

- difficulties assigning intellectual property rights;
- a lack of appropriate expertise of potential contractors compared to those within a firm's own R&D department;
- transaction costs of knowledge linkages: search is costly, as is the need to write appropriate contractual agreements for numerous formal linkages;
- the level of prior experience of openness; and
- the prior knowledge of R&D processes and absorptive capacity.

This means that while the returns to additional linkages or information sources may at first be positive, eventually there will be a point at which there may be excessive reliance on different external sources of innovation, so that an additional source actually serves to diminish the returns to external networking at the margin (Roper et al. 2011).

Key findings: More open systems of knowledge dissemination are associated with greater potential to generate spillovers. However, the extent of openness may be constrained by prior levels of experience and knowledge of open innovation and the costs of establishing knowledge linkages.

The generation of spillovers requires cooperation early in the development process and often involves a significant informal knowledge transfer, found in more open innovation systems. In the most open systems, there is some suggestion that transfers can compensate for lack of absorption capacity, for example using spin-offs.

Geographical clustering and the proximity of actors (especially at sub-national levels) is important for the generation of knowledge transfers and related spillovers.

Universities and their research networks and spin-offs can play an important role in ensuring external knowledge flows are taken advantage of.

3.5 Transmission mechanisms of different types of knowledge

Proposition: the presence of channels through which knowledge is more readily identifiable, accessible, and interpretable, and less easily appropriable, will have a greater capacity to generate spillovers.

3.5.1 Different types of knowledge

The literature generally differentiates tacit knowledge from codified knowledge. The former may be less tangible, but is disseminated more rapidly compared to knowledge that is codified in more formal statements.

In the context of examining innovation in a regional context, the European Commission Expert Group (DG Research) identified three knowledge bases (Table 3.2): ‘analytical’, ‘synthetic’, ‘symbolic’.

Table 3.2 Three knowledge bases

Analytical	Synthetic	Symbolic
Innovation by creation of new knowledge	Innovation by application or novel combination of existing knowledge	Innovation by recombination of existing knowledge in new ways
Importance of scientific knowledge often based on deductive processes and formal models	Importance of applied problem related knowledge (engineering) often through inductive processes	Importance of reusing or challenging existing conventions
Research collaborations between firms (R&D department) and research organisations	Interactive learning with clients and suppliers	Learning through interaction in the professional community, learning from youth/street culture or ‘fine’ culture and interaction with ‘border’ professional communities
Dominance of codified knowledge due to documentation in patents and publications	Dominance of tacit knowledge due to more concrete know-how, craft and practical skill	Reliance on tacit knowledge, craft and practical skills and search skills

Source: EC Expert Group (DG Research), 2006: Constructing Regional Advantage, p49

This typology seeks to recognise the different types of knowledge of the competencies required to use the knowledge. An analytical base is critical for activities where knowledge creation is based on formal and codified models. A synthetic knowledge base is critical for activities where innovation takes place through a novel combination of existing knowledge, requiring a common social and institutional context. Activities that draw on a symbolic knowledge base are more directly dependent on informal and interpersonal interaction. In practice, particular technologies/industries/innovation systems make use of different combinations of these knowledge creating activities; the combination reflecting the specific characteristics of the industry and its innovation system.

3.5.2 Different transmission mechanisms

A number of different mechanisms exist through which knowledge may flow and subsequent spillovers may occur. Knowledge may be accessed through individuals or organisations, as well as through the information embodied in traded goods and services and that contained within artefacts, such as patents (which are considered separately in section 3.3.1). The mechanisms for transfer stem from these three access points, and range from labour mobility and turnover, through trade and value chains facilitated by foreign direct investment or internal multinational knowledge transfer, to the web of relationships which can be formed in industrial systems, which may be characterised by geographical proximity. To add further complexity, mechanisms of transfer may be potentially combined within certain more definable pathways related to particular forms of spillover.

While explicit or codified knowledge can be transferred in such formats as a blueprint or operating manual, its interpretation and assimilation still requires some level of interaction – i.e. there is a need to disseminate this knowledge by an intrinsically ‘spatial’ communication technology. Tacit knowledge is mostly acquired via the informal take-up of learned behaviour and procedures, when a researcher or product developer moves from one firm to another.

Previous work by BIS (2012) has identified a number of mechanisms that facilitate knowledge transfer and related spillovers:

- mobility of skilled and experienced labour, as a channel for knowledge spillovers between and (especially) within industries and regions, and between overseas and domestic firms. These spillovers are enhanced through geographical proximity;

- knowledge obtained through international trade in intermediate inputs, where domestic companies importing the input will benefit from the technology developed by foreign companies;

- knowledge obtained as the result of foreign direct investment (FDI), between parent and subsidiary company; and

- acquisition of foreign technologies by domestic companies, through the exchange of blueprints at prices which are lower than the costs originally incurred by the innovator.

These spillovers mechanisms can be either active or passive:

- *Active* spillovers – are the resulting outcome of direct learning about external technological knowledge. Spillovers occur if an external design becomes available to firms at less than the original cost incurred by the inventor or developer. If the creation of a new product or process is consequently easier, spillovers are capable of raising the productivity of the beneficiaries research and as external knowledge gradually becomes part of the internal knowledge base, further innovation is likely; and

- *Passive* spillovers – are the result of trade and external investment including FDI (see box overleaf). The use of specialised and advanced intermediate products that have been invented by other actors, allows knowledge of their technological content to diffuse. If the intermediate good costs less than its opportunity cost (i.e. the cost of producing the good internally, including the cost related to learning and R&D activities), there is a gain for beneficiary firms associated with having access to other firm’s intermediate goods.

3.5.3 Labour mobility

Human capital spillovers are a particular type of knowledge externalities that are accessed by learning from the knowledge and information held by individuals or evidenced by their skills. A previous literature review commissioned by BIS (2012), highlighted that these are believed to depend crucially on the geographical proximity of the workers concerned, thereby facilitating spillovers between workers within the same region, city, or firm (so-called 'agglomeration effects'), since the mobility of skilled workers is localised, where social norms and infrastructure networks facilitate direct communication.

Localised mobility of individual workers, in particular, skilled ones, is also seen as an important knowledge diffusion mechanism, to the extent that labour mobility is capable of spreading knowledge rather than merely shifting it from one place to the other (Brescht and Lissoni, 2001). This spread as opposed to shift of knowledge through labour mobility will be supported where working with more skilled and productive co-workers results in more productive efforts due to imitation, social pressure, leading-by-example or learning-by-doing.

Rather than full-on labour flows characterised by a researcher or developed moving job, NESTA (2010) highlights that knowledge held by individuals may also be shared openly between creative professionals, researchers and their companies and research institutes either through informal relationships (see discussion on the role of informal relationships in section 3.4.2) or due to the openness of the innovation system.

3.5.4 Trade and foreign direct investment

One of the most commonly explored mechanisms for spillover generation in the literature has traditionally been the openness to international trade. Traded goods are seen to embody knowledge, which can be obtained by the importer of the good, be it through reverse engineering or simply the knowledge from its use or the very existence of a market for the good.

The literature however points to evidence of limited spillover benefits from international trade. This is considered particularly likely if domestic firms are not themselves engaged in R&D activities. Engagement in R&D activities is also seen as a necessary condition for domestic firms to help promote diffusion of knowledge from multinational enterprises (MNEs). As such, FDI without domestic R&D is found to have no significant effect on improving productivity (Todo and Miyamoto, 2002). The lack of R&D activity can also be associated with a lack of absorptive capacity, as through the undertaking of innovation, a firm is able to generate further capacity to innovate and better understand and mimic the innovations from others. The role of absorptive capacity is explored in section 3.6.

'FDI' as a channel for spillovers from technological innovation[11]

Three ways in which FDI can act as a channel for technology spillovers between foreign affiliates of multinational enterprises and host-country firms can be identified:

- *labour mobility and (labour) turnover*: multinational affiliates in host countries will normally hire local labour and teach those workers about their technology

[11] NBER (2009) and Keller (2009)

through formal or on-the-job training. When these employees leave the affiliate to work for domestic firms, the knowledge they have acquired will thus be transmitted to the latter, resulting in technology spillovers;

- *business operations*: technological learning spillovers are likely to be generated as domestic competing firms start ‘copying’ foreign enterprises. These within-industry effects are often referred to as horizontal FDI spillovers; and

- *market transactions with local firms*: these are often referred to as vertical spillovers that can occur if the affiliate buys inputs from local suppliers or sells them to local downstream companies at a price below these inputs’ market value, in which case the company buying the input benefits from the R&D associated with the input without incurring the cost of these efforts.

Key findings: The benefits of knowledge flows embodied in trade and FDI are likely to be limited by the capacity for firms to absorb this information. The interaction with, or direct hiring of, skilled labour can provide a way for firms to access external knowledge.

3.6 Absorptive capacity

Proposition: the greater the level of human capital within an innovation system, the greater a firm’s capacity to identify relevant technologies outside its boundaries and to use external knowledge and techniques in the internal innovation process.

As identified above, making information freely available does not guarantee that it can be readily absorbed. As emphasised by Cohen and Levinthal (1989), using the results of external R&D requires effort by the recipient firm. Rather than thinking of R&D spillovers as exogenous, they argued that a firm needs to invest in its "absorptive capacity" if it is to realise R&D spillovers from other firms. Even if information can be appropriated, it need not be a free good to other firms.

Jaffe (1986) highlights that a significant fraction of the total "flow" of spillovers affecting firms' own research productivity comes from firms outside of the receiving firm's immediate technological neighbourhood. In that respect, Griffith et al. (2003) highlight that higher absorption capacity will enable recipient firms to:

- scan for the best available external knowledge;

- absorb and use external know-how in the most efficient way; and

- increase their appropriation of the returns from new innovations.

Enhancing absorptive capacity through investment in human capital[12]

Investments in human capital influence the extent to which innovating firms can benefit:

- directly from increased productivity gains;

[12] Rincon A., Vecchi M. and Venturini F. (2012)

- indirectly through productivity spillovers between workers; and
- (indirectly) by the extent to which external knowledge can be absorbed within the firm and utilised in the firm's on-going business activities

A general consensus exists in the literature that absorptive capacity is associated with greater spillovers. At the level of the firm, Aiello and Cardamone (2008) find evidence that the capacity to absorb technology, proxied by internal levels of human capital, leads to greater spillovers. At the level of the inter-industry spillovers and through spillovers at international level (embodied in goods), Poldahl (2012) finds evidence of an incremental absorptive capacity effect accruing to high-productivity firms. Observing the quality of tertiary education systems, Coe et al. (2008) also demonstrate that countries with higher levels of human capital tend to benefit more both from their own R&D efforts and those from other countries.

Firms with greater absorptive capacity (measured by a firm's R&D spending intensity) are associated with an increased likelihood of engaging in production and technology cooperation with other actors (Liu, 2012). It may also be conjectured that firms with a highly skilled workforce or a higher internal technological capacity might be better both at absorbing incoming spillovers and at protecting their knowledge through secrecy, technical complexity, or lead times (Cassiman and Veugulers, 2002).

Key findings: A wide body of literature indicates that the absorptive capacity of firms (usually measured in terms of the scale of human capital) and innovation systems as a whole is directly related to greater potential for spillovers.

3.7 Conclusions

3.7.1 Suggested criteria for establishing the capacity for significant spillovers

In summary the literature is not exhaustive or consistent on the range of factors that influence the capacity of an innovation system to generate spillovers. There are, however, a number of factors that appear to be recognised, and which could form the basis of an evaluation of programmes in terms of their potential to generate spillovers. These are summarised in Table 3.3.

Table 3.3 Factors influencing the scope for innovation systems to generate spillovers

Features of innovation system	Factors increasing the tendency for innovation systems to generate spillovers	Factors with ambiguous impacts on the potential for spillovers
1. Technology and innovation	Multi and general-purpose technologies (in the long run)	
2. Market and industrial structure	High value added industries, with multi-purpose applications Nascent industries	Level of competition High capital/factor intensity High market concentration
3. Institutional set-up		IP protection Government funding

Features of innovation system	Factors increasing the tendency for innovation systems to generate spillovers	Factors with ambiguous impacts on the potential for spillovers
4. Actors	Active role of universities and research institutes	
5. Relationships between actors	Network ties and cooperative agreements among actors	Geographic clustering of program beneficiaries
6. Transmission mechanisms	Low costs of transmission	Interaction with international trade / FDI IP protection
7. Absorptive capacity	High levels of absorptive capacity	IP protection

3.7.2 The measurement of spillovers

Going beyond the identification of factors that might increase the propensity of a system to generate spillovers is the task of specifying and measuring the impacts of spillovers.

Due to the variety of ways in which spillovers may arise, measuring spillovers is not an easy task. While market spillovers may largely be quantifiable based on the value of new products generated, knowledge spillovers are much more difficult to capture. A variety of approaches to measure spillovers have been developed.

Academic interest in the scale of spillovers has been strong historically but approaches have tended to focus more on the inter-industry level or, in the context of R&D spillovers facilitated by international trade, at the macroeconomic level.

Two main approaches have been identified to directly establish the users and the consequences. The first seeks to use input-output (I-O) tables to approximate the technical linkages between the investors in R&D and other potential (non-paying) users. This assumes these linkages can be approximated by the supply chain, and the technology matrix can be used to estimate the effects of R&D on productivity (the 'technical flow' approach).

The second approach seeks to estimate the effects of 'other party R&D' on the costs and structure of production of other (non-paying) users, and controlling for their own levels of R&D (the 'cost function' approach), by using econometric models.

In both approaches, the effects on users are normally defined in economic terms, but may also be defined using social or environmental indicators. While the literature usually defines users as businesses, they can also include other social organisations including public bodies. Similar approaches have been developed at least conceptually to define national and sub-national technology clusters and the extent of related spillovers.

While many of these studies summarised in Hall (2009) have attempted to quantify the spillovers, each fails to distinguish between the impacts of knowledge from the other types of spillover, or in other cases distinguish between private return and the wider social return from the initial investment. Nevertheless, Hall (2009) provides an overview of the scale of impacts to be anticipated depending on the method of quantification (production function versus cost function approaches) and the data used (firm, plant, industry or regional level data). In general, the majority of empirical studies summarised indicate a rate return from R&D investment of 25-75%, with a few outlying studies indicated a return as high as 100%. Nadiri (1993) explicitly estimates the indirect and social rates of return from R&D investment at industry level (the spillover). He estimates the social rate of return ranges from 20% to over 100% with an average close to 50%. With net private rates of return estimated in the region of 20-30%, spillovers are significant in many industries often with a value greater than the private rate of return.

While the literature suggests a broad order of magnitude of the benefit from spillovers, it does little to establish the linkages between the presence of factors in the innovation system and the scale of impacts to be expected. Neither does it relate the value of spillovers to the particular influences of technology innovation support programmes. It also indicates that there is a wide variation between the direct benefit and the indirect benefit of R&D.

3.7.3 The identification of proxies

As an alternative, a number of indirect proxy measures to capture spillovers have also been employed in the literature, including information from R&D expenditure (e.g. Wakelin, 2000), patent applications (e.g. Jaffe, 1996), and innovation surveys (e.g. Slivko and Theilin, 2011).

While an individual firm in a given sector may not benefit from R&D conducted by other firms in the same sector, it is suggested that the level of R&D activity in a sector may give an indication of the level of technological opportunity and the size of the available pool of technological knowledge.

As well as the number of patents and patent citations, more subtle measures of spillover have been taken from patents, by making use of the fields of additional information and secondary uses supplied (e.g. Los and Verspagen, 2000). This approach exploits the knowledge on secondary application areas classified in supplementary patent classes and the systematic distinction between claimed 'invention information' and non-claimed 'additional information', which does not form part of the invention as such but “might constitute useful information to the searcher" (WIPO, 1989, p. 26). Use of these measures of R&D activity and patents, however, tend to overlook alternative channels of knowledge flow, and over-emphasise the relative importance of IP outputs in the wider innovation process.

As an alternative source, innovation surveys provide a wider range of proxies from which estimates of knowledge spillovers may be implied, including information on the breadth and depth of a firms' sources of external knowledge or innovations (e.g. Roper et al. 2011), as well as information on the ways and extent to which they seek to limit knowledge from flowing outside of the firm, through secrecy (e.g. Cohen et al. 2001).

Finally, various estimates of the technological complementarity and the geographical distance of firms from each other, and of sectors, have also been used as proxies to estimate the extent of spillovers (e.g. Jaffe, 1986 and Cincera, 2005). Rather than measuring spillovers directly, such approaches assume that clustering alone is sufficient to explain the presence and potential range of spillovers.

Given the lack of strong evidence in the literature linking the influence of technology support programmes on the generation of spillovers, the remainder of the study seeks to develop a framework that links the normal programme logic associated with a support programme (and which defines the purpose and direct programme outputs, outcomes and impacts) with the factors associated with an open innovation system. This is intended to provide the basis for a programme level evaluation describing the potential for spillovers of a given programme.

4 Implications for the development of an M&E framework

4.1 Applying the findings and lessons from the literature review

The second objective of the study was to use the criteria associated with the likelihood of spillovers in the context of a monitoring and evaluation (M & E) framework. This framework should:

- Inform programme development (i.e. what should be established in any business case) in order to identify potential features of a given innovation programme that may be conducive to spillovers;
- establish the case for government intervention in the relevant technology areas;
- provide quantitative and qualitative methods for measuring the potential for spillover impacts; and
- provide an ex post methodology for measuring spillover impacts that can be applied as part of future programme evaluations.

4.2 Open innovation systems as the starting point for spillover definition

The starting point for the M & E framework for spillovers presented here is that future innovation support programmes would be constructed on the principles of an open innovation system. In other words that innovation support programmes move from funding discrete beneficiaries in isolation and where beneficiaries retain, to themselves, all knowledge generated (closed system), to one where beneficiaries are required / encouraged to share knowledge generated, and to interact in the pursuit of knowledge generation; and in which producers of knowledge should also be interacting with at least some users of knowledge. This begs the question of whether an 'open' programme can operate in a 'closed' innovation system – but one can imagine programmes targeted at closed systems with the object of increasing their level of openness.

This is not to say closed programmes do not produce spillovers – the social benefits / costs of innovations are still unlikely to be fully reflected in market prices. However, open programmes in open systems, by definition, provide the context in which knowledge has opportunity to find the greatest numbers of contributors that can enhance knowledge and to make use of it.

This in turn placed the primary focus on knowledge and network spillovers, since these are the effects associated with the wider dispersal and take-up of knowledge beyond the boundaries of the support programme. Market spillovers associated with the direct programme beneficiaries would be identified through standard programme evaluation frameworks.

4.3 The features of an open innovation system can be used as evaluation criteria to establish the likelihood of spillovers

The experience of the team supported by the literature review suggests seven dimensions to the open system which can be applied, as evaluation criteria; to innovation programmes ex ante or ex post to assess the potential for the generation of spillovers (see Table 4.1). These criteria need to be translated into usable indicators for monitoring and assessment.

Table 4.1 Features of open innovation systems as evaluation criteria and the basis of indicators

Features of innovation system	Factors increasing the tendency for innovation systems to generate spillovers [Ambiguous factors in square brackets]	Possible Indicators
Technology and innovation	■ Multi and general-purpose technologies (in the long run)	■ Scope for multiple application (number/value) ■ Scope to be disruptive
Market and industrial structure	■ High value added industries, with multi-purpose applications ■ Nascent industries ■ [High capital/factor intensity] ■ [Competition] ■ [High market concentration]	■ Value added of sector(s) ■ Nature of supply chains ■ Market trends / future opportunities / market pull ■ Nascent industries ■ Capital intensity
Institutional set-up	■ [IP protection] ■ [Government funding]	■ IP provisions / practice ■ Role / operation of standards bodies ■ Govt. funding of users – market influence
Actors	■ Active role of universities and research institutes	■ Levels of public / semi-public research activity
Relationships between actors	■ Network ties and cooperative agreements among actors including with research institutes ■ [Geographic clustering of programme beneficiaries]	■ Active networking arrangements
Transmission mechanisms	■ Low costs of transmission: ■ Higher costs of Codified knowledge – written / published / standards ■ Potential lower costs of Tacit knowledge – workers changing employment, which can be high (i.e. poaching staff from rivals)	■ Type and cost of mechanisms based on the type of information and role of labour mobility

Features of innovation system	Factors increasing the tendency for innovation systems to generate spillovers [Ambiguous factors in square brackets]	Possible Indicators
	■ [Interaction with international trade / FDI] ■ [IP protection]	
Absorptive capacity	■ High levels of absorptive capacity ■ [IP protection]	■ Levels of R&D activity amongst competitors / users

These factors are reflective of fairly broad concepts. For use in an evaluation framework, these concepts need to be translated into more tightly defined evaluation criteria and related indicators. The relevance and feasibility of these factors as evaluation criteria can be tested in discussion and review of selected TSB programmes. An illustration of the potential for this approach is provided in Table 4.2.

Table 4.2 Application of open innovation system features to selected TSB programmes – potential for knowledge spillovers (High Medium Low)

Features of innovation system	Factors increasing the tendency for innovation systems to generate spillovers	Possible Indicators	Low Carbon Building Programme	Offshore Renewable Energy Catapult	Connected Digital Economy Catapult
Technology and innovation	Multi and general-purpose technologies (in the long run) with specific applications	Scope for multiple application (number/value) Scope to be disruptive	Specific technologies with scope for some replication in sector - incremental, not disruptive	Specific technologies with scope for some replication, in and out of sector – incremental (to onshore wind) Standardisation will increase future replication opportunity Longer-term looking to enable market disruption to conventional electricity markets – (e.g. links to storage systems to affect supply-demand relations)	Generic technologies with scope for extensive application across sector – pursuit of disruptive technologies
Market and industrial structure	High value added industries, with growth in multi-purpose applications	Value added of sector(s)	Low value added buildings sector. Possibly emerging niche products	High value added energy sector – potential applications in other high value sectors	High value added ICT sector – take-up across high and low value sectors.
		Role of supply chains	Limited influence of supply chain on innovative behaviour	Innovations in supply chain significant – new business models	Multiple supply chains
		Market trends / future opportunities / market pull	Policy driven – limited scope. Principal/agent problem	Mix of technology push and market pull – move to reduce 'bespoke' applications	Strong market pull
	Nascent industries	Nascent industries	Some nascent niches	Emerging sector	Emerging sectors
	[High capital intensity]	Capital intensity	Medium capital intensity (e.g. Green Deal & ECO)	High capital intensity	High and low capital intensity opportunities
	[Competition]				
	[High market concentration]				

Features of innovation system	Factors increasing the tendency for innovation systems to generate spillovers	Possible Indicators	Low Carbon Building Programme	Offshore Renewable Energy Catapult	Connected Digital Economy Catapult
Institutional set-up	[IP protection] [Government funding]	IP provisions / practice Operation of standards and verification bodies – provision of warranties to de-risk Govt. funding of users – control of market	Some IP issues Role of building standards – limits pace of innovation but underpins developments over time Public buildings – limited market / impact	Some IP issues Role of technology standards Direct and in-direct costs of testing (in-situ validation very costly) Subsidies for users / strong impact	IP issues relate to reducing transaction costs of securing copyright Non-regulated standards – but seeking industry defined standards to de-risk investment and increase inter-operability of applications Public sector use of IT – considerable market impact
Actors	Active role of universities and research institutes	Levels of public / semi-public research activity	Low levels – industry driven and in discrete areas although active research around building energy modelling and climate resilience	Active role of HEIs/RTOs across a number of fronts, including gearboxes, blade materials, foundation design, array design, transmission, etc. Materials research	Active university role (e.g. machine/human interface) Development of high performance computing (HPC)
Relationships between actors	Network ties and cooperative agreements among actors including with research institutes [Geographic clustering of programme beneficiaries]	Active networking arrangements (number/diversity) Geographic cluster	Limited links between researchers users Limited clustering	Active engagement between beneficiaries – and influence on sector relationships Some clustering around OEMs (Scotland central belt) and installations (i.e. at port facilities) e.g. Barrow, Mostyn Docks, Kings Lynn, Felixstowe, etc.)	Active engagement between beneficiaries and with potential users Significant cross-sector working Clustering important based on labour movements
Transmission mechanisms	Low costs of transmission: Relatively higher costs of codified knowledge (i.e. published and industry standards)Lower costs of	Type and cost of mechanisms	Emphasis on codified knowledge – slow and costly	Mix of codified and tacit knowledge Reliance on codified knowledge (especially standards from oil & gas	Emphasis on tacit knowledge / movements of labour Investment in de-skilling use of knowledge and

Features of innovation system	Factors increasing the tendency for innovation systems to generate spillovers	Possible Indicators	Low Carbon Building Programme	Offshore Renewable Energy Catapult	Connected Digital Economy Catapult
	Tacit knowledge (i.e.contextual and implicit) [Diversity of mechanisms] [Speed of transmission] [Interaction with international trade / FDI] [IP protection]			sector) - need to increase tacit knowledge (through learning by doing)	making it easier to use (e.g. use of large data sets)
Absorptive capacity	High levels of absorptive capacity	Levels of R&D activity amongst competitors / users (scanning/foresight?)	Limited R&D activity	Considerable levels of R&D activity – but greater in other RE sectors (wave/tidal)	High levels of R&D activity – designed to reduce barriers to usage

Note: [Ambiguous factors in brackets]

4.4 Establishing the presence of spillovers and their impact

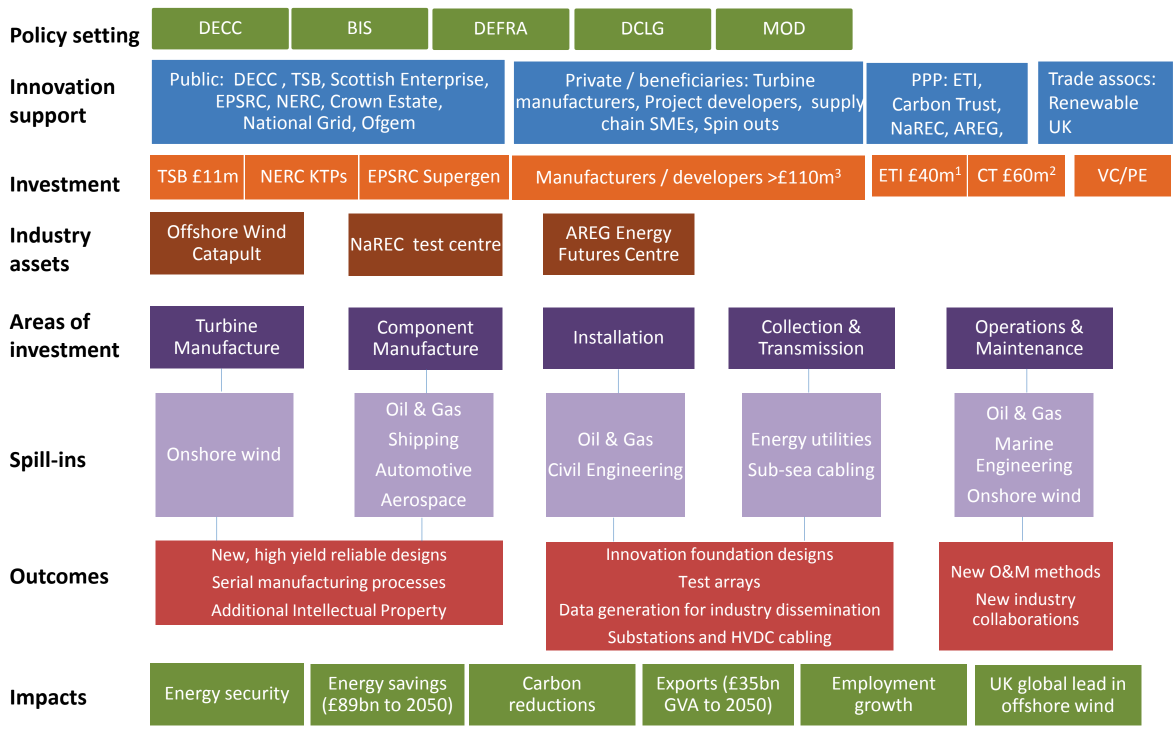
The development of criteria and indicators to establish the potential for spillovers is helpful in comparing potential programmes and for providing further justification (or not) for past investments made without reference to spillovers.

The next step is to consider ways in which spillovers might be specified and assessed in the context of given innovation systems. This, in turn, places the focus on the nature of the actors and their relationships, and the knowledge transmission mechanisms. Since knowledge is a specified output from support programmes, a starting point is the intervention logic for any support programme. This will help not only in specifying knowledge spillovers, but also market and network spillovers.

4.4.1 Initial intervention logic

An initial intervention logic has been constructed to capture the range of actors across the value chain, taking the offshore wind renewable energy Catapult as an example (Figure 4.1).

Figure 4.1 An initial intervention logic for offshore wind renewable energy Catapult



Sources: (1) www.eti.co.uk/technology_programmes/offshore_wind/ (2) www.carbontrust.com/our-clients/o/offshore-wind-accelerator (3) Based on 50% match funding intervention rate.

Figure 4.1 identifies the intended inputs, activities (in very broad terms) and intended outcomes and impacts. It identifies the main actors and it recognises the use it can make from the knowledge gained from other innovation programmes ('spill-ins').

It does not, however, separate out the spillover effects, nor does it yet provide a full description of the innovation system in which the programme sits.

4.5 Defining knowledge spillovers as the basis of ex ante assessment

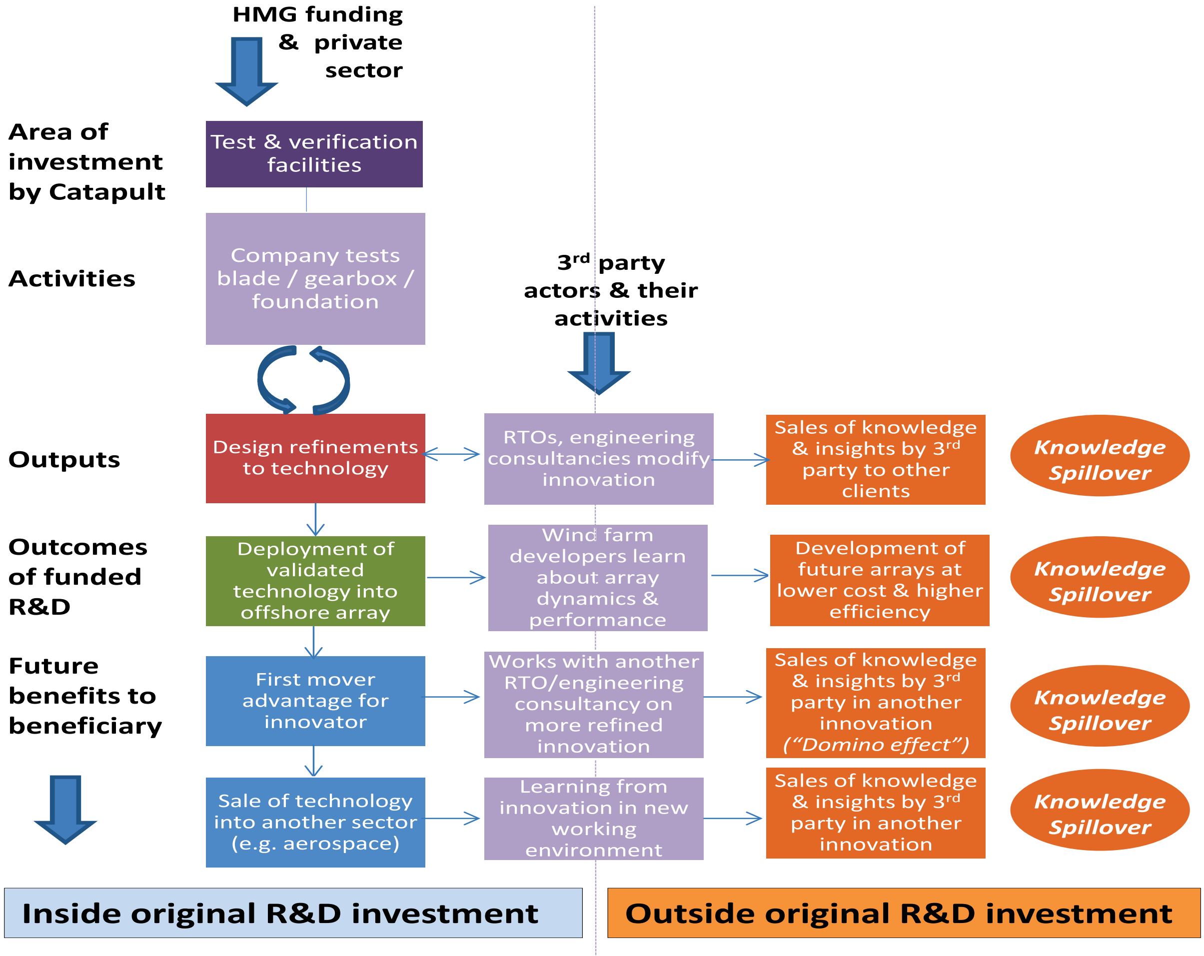
The intervention logic provides a starting point. From this two steps are required:

- first, to use it to define the wider innovation system in terms of the general range of actors and the innovation system in terms of the intended flows (and types) of knowledge; and

- second, to use it to define the specific activities and outputs that have the potential for spillover effects.

The scope for spillovers can then be defined in terms of the commercialisation potential, for example with reference to intermediate outcomes of dissemination and engagement, and final outcomes such as spin-outs and licensing, as the basis of monitoring and evaluation.

Figure 4.2 Initial breakout of spillover potential based on the offshore wind renewable energy Catapult



4.6 A general framework for assessing spillover potential

The general framework combines the idea of programme outputs, outcomes and the flow of future benefits (within and across sectors), with underlying concepts of an open innovation system. It does this both in terms of the nature of the technology and markets and, especially, the management of the system as measured by the type of knowledge and its transmission, with reference to network actors their relationships and absorptive capacity.

This leads to a framework of indicators for assessing the potential for knowledge spillovers, ex ante, (or to review ex post), through the range of outputs, outcomes and impacts, as described in Figure 4.3. Given a benchmark (which will need to be established), the indicator framework will allow an assessment of whether a proposed support programme will have a higher or lower level of spillover than the benchmark.

Figure 4.3 A suggested framework for assessing ex ante the scope for knowledge spillovers

Core programme supported by govt. funds (Usual indicators)	**Outputs**	**Outcomes**	**Sector Impact**	**X-sector impact**	**Assessment of spillovers (relative to benchmark)**
Examples	Technical progress / testing / validation Increases in new partnerships / networks	Market testing and commercialisation	Market take-up and expansion Market spillovers	Application of new innovation in other markets / sectors	↓
SPILLOVER POTENTIAL					**HIGHER SPILLOVER IF:**
Sector level analysis:					
Technology and innovation	Multi and general purpose technologies: ■ Scope for multiple applications ■ Risk of technology being disruptive				Indicator: ■ High ■ High
Market and industrial structure	Size and value added of sector: ■ Potential market size (UK/global) ■ Scope for market pull ■ Capital intensity (Investment as share of sales) ■ Immaturity of sector (nascent / emergent / mature) ■ High / low GVA per worker				Indicator: ■ Large ■ High ■ High ■ High ■ High
Institutional set-up	Rules of the game vis-à-vis IP protection: ■ *Levels of IP protection and scope for imitation / learning* ■ Government funding and support ■ Impact on perceived risk to investors				Indicator: ■ *Context* ■ Positive ■ Positive
Actor level analysis:					
Actors	Number and type of actors: ■ Presence of research/technology organisations (RTOs)				Indicator: ■ High
Relationships between actors	Levels of networking: ■ Collaborations between industry and RTOs				Indicator: ■ High

	■ Co-operation agreements between competitors ■ Scope for knock-on effects through supply chain ■ Scope for new industrial alliances	■ High ■ High ■ High
Transmission mechanisms	Types of knowledge (tacit / codified); (analytical, synthetic, symbolic): ■ *Dominant type* ■ Extent of distributed systems ■ Labour mobility with/across sectors ■ Exports/imports of sales/purchases as % of totals ■ FDI as % of sector investment	Indicator: ■ *Context* ■ High ■ High ■ High ■ High
Absorptive capacity	Characteristics of potential users of knowledge: ■ Levels of R&D amongst competitors and 'adjacent' sectors ■ Levels of human capital (share of workforce with given level of qualification)	Indicator: ■ High ■ High

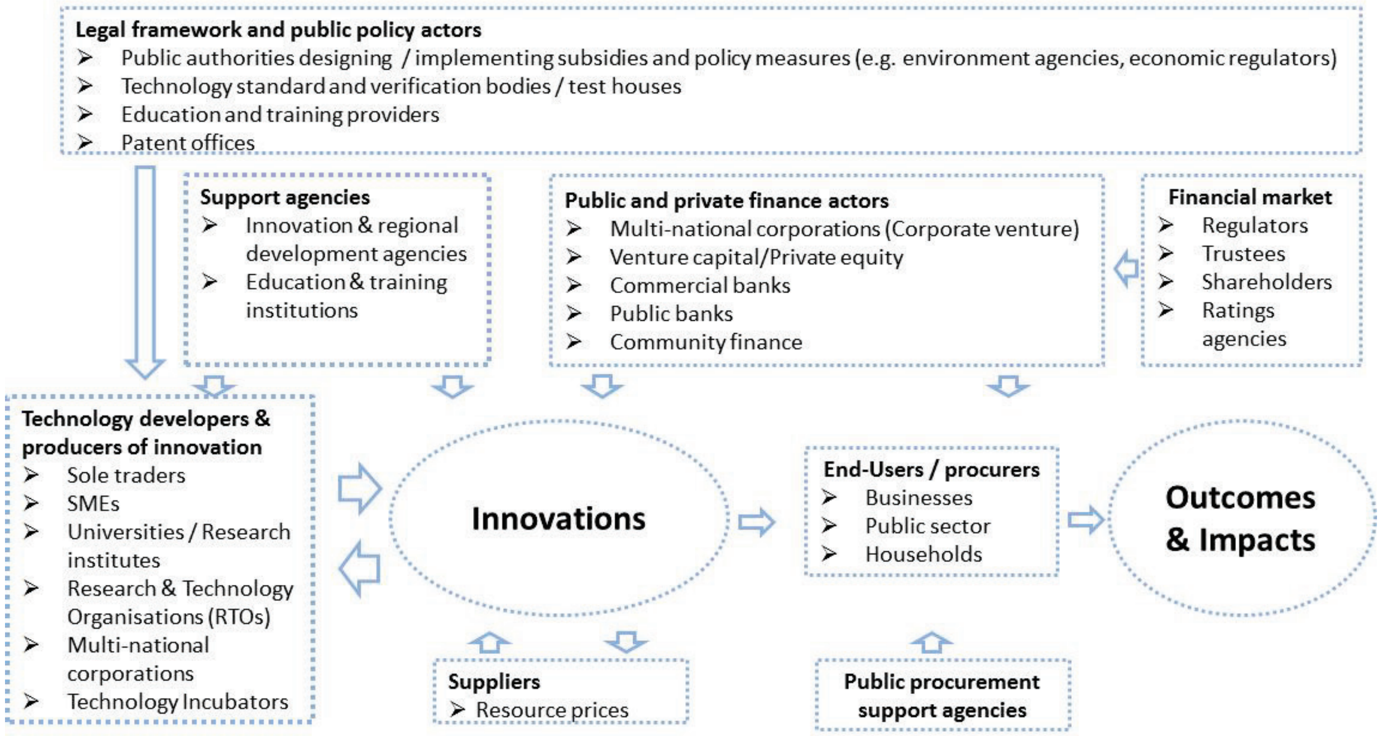
Note: Context indicators – significant but ambiguous implications for levels of spillover – but should be examined on a case by case as to whether the levels are 'optimum'

4.6.1 Scope for populating indicators

The indicators described in Figure 4.3 have been examined in relation to the possibilities of populating them from primary or secondary data.

Table 4.3 indicates that only a small number of indicators can be populated from secondary data, and even then the data needs careful interpretation. The remainder of the indicators can only be populated on the basis of a qualitative assessment, using detailed information of actors that define and operate the innovation system. These actors (Figure 4.4) include the innovators, the potential users of the innovation, the market and technology regulators, research and technology organisations including universities, and investors.

Figure 4.4 Actors in an Open Innovation System



Source: ICF GHK

Table 4.3 Indicators for assessing the scope for knowledge spillovers

Theme	Indicator	Source	Description
Technology and Innovation	Scope for multiple applications	Qualitative assessment	
	Risk of technology being disruptive	Qualitative assessment	
Market and industrial structure	Potential market size (UK/global)	ONS/IDBR[13,14] BIS/UKTI/TSB Trade associations Industry research	UK GVA by sector; employment by sector
	Scope for market pull	Qualitative assessment	
	Capital intensity (investment as share of sales)	ONS - input-output tables[15]	Capital formation / final demand (by 110 production categories)
	Immaturity of sector	Qualitative assessment BIS/ UKTI - Supply chain market intelligence Trade associations	Mapping of technology supply chains and RD&D assets can help categorisation by industrial technology (e.g. see previous work by ICF GHK for Regional RDA Network under New Industries, New Jobs (NINJ) policy)
	High/low GVA per worker	ONS/IDBR[16,17]	GVA per worker – categorisation on the basis of above/below average 'productivity'
Institutional set-up	Levels of IP protection and scope for imitation/learning	Intellectual Property Office (IPO)[18]	Patents by sector/total number of patents
	Impact of the perceived risk to investors	Qualitative assessment BIS, GIB, BVCA	
Actors	Presence of research/technology organisations	Qualitative assessment Knowledge Transfer Networks	
Relationship with	Collaborations between industry and RTOs	Qualitative assessment	

13 http://www.ons.gov.uk/ons/search/index.html?newquery=GVA+industry
14 http://www.ons.gov.uk/ons/search/index.html?pageSize=50&sortBy=none&sortDirection=none&newquery=employment+industry
15 http://www.ons.gov.uk/ons/publications/re-reference-tables.html?edition=tcm%3A77-256175
16 http://www.ons.gov.uk/ons/search/index.html?newquery=GVA+industry
17 http://www.ons.gov.uk/ons/search/index.html?pageSize=50&sortBy=none&sortDirection=none&newquery=employment+industry
18 http://www.ipo.gov.uk/ipreview-doc-ff.pdf

Theme	Indicator	Source	Description
actors	Cooperation agreements between competitors	Qualitative assessment	
	Scope for knock-on effects through supply chain	Qualitative assessment	
	Scope for new industrial alliances	Qualitative assessment	
Transmission mechanisms	Types of knowledge	Qualitative assessment	
	Labour mobility with/across sectors	Qualitative assessment	
	Export/imports of sales/purchases as % of totals	ONS - input-output tables[19]	Exports/final demand; imports/total supply of products (by 110 production categories)
	FDI as % of sector investment	UKTI[20]	FDI by sector, LEP and region
Absorptive capacity	Level of R&D amongst competitors and 'adjacent sectors'	ONS[21] BIS R&D Scoreboard TSB/UKTI	Gives a breakdown of 11 sectors within manufacturing, services and agriculture
	Level of human capital (share of workforce with given level of qualification)	ONS/NOMIS (Annual Population Survey/Labour Force Survey – workplace analysis)	Employment by sector and occupation. Sectors can be categorised on the basis of their occupational structure (i.e. sectors where graduates make up at least 40% of the workforce – K1 sector; sectors where graduates make up 25-40% of the workforce – K2 sectors; etc)

[19] http://www.ons.gov.uk/ons/publications/re-reference-tables.html?edition=tcm%3A77-256175

[20] https://www.google.co.uk/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&cad=rja&ved=0CDYQFjAA&url=http%3A%2F%2Fwww.ukti.gov.uk%2Fdownload%2Ffile%2F344820.html&ei=CvQtUaeXHYXitQbL0oHYAQ&usg=AFQjCNE6JIUsuF-yDdLI7f75mwocX-h6sA&bvm=bv.42965579,d.Yms

[21] http://www.ons.gov.uk/ons/rel/rdit1/bus-ent-res-and-dev/2010/stb-berd-2010.html

4.6.2 A scenario based approach to the estimation of knowledge spillovers

The work has shown that it is possible to assess the relative propensity to produce spillovers. In an ex ante setting, this would require an investigation of the knowledge flows and implications for innovation activity for a given selection of technology and market domains.

The qualitative assessment will need to consider whether factors that increase the likelihood of knowledge spillovers are present and to what extent. The analysis will need to develop an essential narrative explaining the technological and market context, the presence of different actors, the interactions within the specific innovation system, and the capacity for transmission and absorption.

This research approach is akin to scenario development, and the approach could make use of related techniques such as workbooks and workshops. Since these techniques are used in producing technology ‘roadmaps’, the approach should be familiar to many of the actors, and would provide the basis for the necessary judgments about the relative spillover potential of investment options.

4.6.3 Possible use of multi-criteria analysis to establish the relative potential of an intervention to generate spillovers

The requirement to establish the relative significance of spillover potential of a proposed support programme / intervention, in the absence of quantitative data and using a scenario based research approach, suggests the possibility of developing and applying a multi-criteria analysis. This would be based on the seven factors and indicators already defined. For a given programme the presence of each factor would be scored, with a higher score the greater the presence. Each criterion would be weighted according to the relative importance accorded to individual criterion.

The sum of the weighted scores would provide the basis for comparison with previously scored interventions or between a range of planned interventions. This would allow a ranking of the different Catapults and (in the context of other interventions) of different sectors or topic areas.

Scoring of significance: The scoring of significance could either be against one intervention (e.g. a particular catapult) explored in depth and against which all other interventions are measured; or the score could be assessed against the absence of the factor (e.g. the lack of networks between universities and industry).

In either case the scoring would be subjective based on the research method. The scoring method, if used repeatedly in different contexts and programmes would require strong guidance to ensure consistency regarding how judgements were informed and made.

Weighting of factors: The significance of factors in a given innovation system may vary, according to the particular technological, market and cultural context. For example, the absence of networks between universities and industry may be less important because university based research is of less importance for the particular technology.

4.7 The scope for quantification of spillovers

The examination of spillovers indicates that quantifying the value of spillovers at a given point in time, when the focus is on knowledge spillovers, is problematic – the best that might be attempted is an ordinal ranking of support programmes with reference to established benchmarks or counterfactuals, using the indicator set and research methodology described.

There are studies that have sought to quantify spillovers from the perspective of supply chain and market impacts. These studies tend to assume that the business users of the knowledge are close substitutes to the producers of the innovation (i.e. in terms of sector, firm size and relationship with other actors) and/or that existing inter-industry linkages are stable and provide a reasonable proxy. Using these assumptions, these studies have used econometric methods to quantify the value of spillovers for particular industrial sectors.

As summarised earlier in Section 3.7.2 Nadiri (1993) estimates that spillovers are significant in many industries with the social rate of return on R&D expenditure ranging from 20% to over 100% with an average close to 50%comapred to net private rates of return in the region of 20-30%.

The literature does not however:

- establish the linkages between the presence of factors in the innovation system and the scale of impacts estimated; and
- relate the value of spillovers to the particular influences of technology innovation support programmes

The relative scale of potential spillover to direct impacts of R&D investment however makes it difficult to suggest using the direct benefit as a proxy.

This argument is supported given that knowledge spillovers are likely to be at their greatest when innovation leads to market disruption and the realignment of demand and supply relationships. Since the econometric approaches assume these relationships are stable, it seems unlikely that the results of such models would provide even a rough approximation to the social value of knowledge spillovers.

However the literature does tend to support a conservative position that spillovers add a minimum of 20 percentage points to the direct benefit. However, this is likely to significantly underestimate the true value of spillovers.

4.7.1 Moving towards monetisation of knowledge spillovers generated by support programmes

As a basis for decision-making, and determining investment priorities, especially across competing policy areas, establishing the monetary value of spillovers is clearly desirable.

To estimate the gross value of the spillover attributable to the support programme based on the intervention logic of the programme, the following variables would need to be considered:

- the number of knowledge spillovers – where knowledge generated and attributed to the support programme leads to commercialisation of a product or process, or to the achievement of direct cost savings from application of the knowledge (recognising the difficulty of attribution of the knowledge obtained to the support programme;
- the average market value of the commercialisation / cost saving transaction based on the knowledge generated;
- the consumer surplus attached to the value of the product or process (the amount over and above the price paid, that users are willing to pay); and
- the elapsed time period between the activities of the support programme and the timing of commercialisation as the basis of discounting future benefits

To estimate the net additional economic impact, the following variables would need to be considered:

- the sales of the old product / process replaced by sales of new products / processes - the market displacement effect;
- the productivity of new compared to replaced products / processes; and
- supply-side multiplier effects

4.7.2 Use of overall market share estimates as an upper limit to spillover impacts

An alternative or complementary approach is to scope out the future trends in the potential total global market value of the markets in which the knowledge produced by the support programme would find potential application. This has been attempted for each of the Catapult programmes; and builds on the wider approach of TSB to establishing investment priorities based on the four questions (see 4.7.2.1 below). The assessment would then seek to establish the potential market shares that the activities of the support programme might secure.

In general, market estimates as a starting point for estimating projected impacts tend to provide very high values; partly because there is usually a requirement for a generalised rather than highly specific market perspective, partly because of inclusion of export markets, and partly because they tend to factor in annual growth rates. However, market estimates are possible with due consideration of other factors as the basis of appropriately conservative estimates.

Using the market values, it is possible to take a view on the probability (often in the form of scenario descriptions) that the actors influenced by a support programme, will generate knowledge capable of being commercialised and to take a given share of the market. These scenarios and the underlying narratives represent a logical extension to that required for the application of the ex-ante assessment framework.

In the context of programmes (such as Catapults in the UK) where impacts are largely in the form of spillovers rather than direct programme beneficiaries, it could be argued that these market estimates provide a first estimate of the spillover value. The extent to which the estimates might be justified as a spillover estimate will depend on the scenarios used and the credibility of the underlying intervention logic.

4.7.2.1 TSB assessment of investment options

Prioritisation within TSB starts with four questions which TSB uses to assess all its activities.

1. How big is the market? This involves understanding the current size and likely growth of the market, the requirements for successful products or services and the competition both at home and overseas.

2. What is the UK capability? This involves examining the underpinning capability in UK universities and research organisations (and in terms of both ideas and people), UK business capability, both existing and potential, and the possibility of re-aligning capability currently aimed at another market to address more valuable needs.

3. Is the timing right? This involves looking at the growth of the market needs and the rise of the capability to meet them and the likely intersection of those trajectories.

4. Can a TSB programme make a real difference? This involves examining the degrees of risk associated with the area, the potential impact of government activity and likelihood of it proceeding without support because of the risk-reward balance.

These questions are applied to both individual programmes and the overall portfolio.

4.8 The scope to use the framework across TSB programmes

The relevance and utility of the framework is at its greatest when seeking to inform investment choices between different sectors and technologies, where there is some expectation of significant knowledge based spillovers.

Where technology support programmes are highly focused on individual beneficiary outcomes, supported by investment in knowledge protection, AND the sector/technology area would be classed as having an effectively ‘closed’ innovation system, then the nature of and context of the intervention militates against spillover generation.

Review of the range of TSB programmes (Table 4.4), suggests that the framework has the greatest utility in monitoring and supporting investment choices in the Catapult programme. It would also have relevance in the context of Knowledge Transfer Networks (KTNs) which are explicitly directed to facilitating an open innovation system.

The framework is not designed for use at project compared to programme level – and therefore would not be used in the context of individual project appraisals. However, it could be used to assess the relative potential for spillovers of the various sectors, topic areas and technologies which frame these project level interventions. This potential would in turn provide an additional criterion for the selection of projects.

Table 4.4 The range of TSB programmes and their propensity to generate spillovers

Programme	Programme description	Scope to apply the framework	Potential for spillovers
Catapult	Catapult centres focus on a specific technology where there is a potentially large global market and a significant UK capability. Centres will allow businesses to access equipment and expertise that would otherwise be out of reach, as well as conducting their own in-house R&D. They will also help businesses access new funding streams and point them towards the potential of emerging technologies. The Centres bridge the gap between universities and businesses, helping to commercialise the outputs. The Catapults will also complement and link with the other programmes which the TSB already manages to promote collaboration between universities and business, and to drive innovation and find commercial opportunities for new technology and ideas.	Tested and applicable	As a programme targeted at large global markets, through development of multi-application and disruptive technologies, based on an understanding of open innovation – Catapults would be expected to have the greatest potential for spillovers of all the programmes.
SMART	SMART is a grant scheme which offers funding to small and medium-sized enterprises (SMEs) to engage in R&D projects in the strategically important areas of science, engineering and technology, from which successful new products, processes and services could emerge Smart is available to single companies. Three types of grant are available: - Proof of market grant - Proof of concept grant - Development of prototype grant	Most appropriate at sector rather than individual company level, where it would be difficult to establish the basis for spillovers. The utility of the framework would also depend on the level of knowledge protection provided under the grant.	Depends on the sector, and the model of innovation which tends to dominate.
Small Business Research Initiative (SBRI)	The SBRI programme enables government procurement to drive innovation. It provides opportunities for innovative companies to engage with the public sector to solve specific problems. Competitions for new technologies and ideas are run on specific topics and aim to engage a broad range of organisations. SBRI enables the public sector to	The framework would be most appropriate when applied to the particular topics used to frame the competitions.	Depends on the particular topics and the models of innovation which tend to dominate.

Programme	Programme description	Scope to apply the framework	Potential for spillovers
	engage with industry during the early stages of development, supporting projects through the stages of feasibility and prototyping.		
Knowledge Transfer Partnerships (KTPs)	KTPs support UK businesses wanting to improve their competitiveness, productivity and performance by accessing the knowledge and expertise available within UK Universities and Colleges. A KTP is a relationship formed between a company and an academic institution ('Knowledge Base' partner), which facilitates the transfer of knowledge, technology and skills to which the company partner currently has no access. Each partnership employs one or more recently qualified people (known as an Associate) to work in a company on a project of strategic importance to the business, whilst also being supervised by the Knowledge Base Partner.	The framework would be most appropriate to groups of projects defined in the context of a particular market and technology. As with SMART, the utility of the framework depends on the level of knowledge protection and scope for transfer.	Depends on the particular sectors in which projects occur and the models of innovation which tend to dominate. It also depends on the scope for individual projects to produce novel and non-incremental innovations.
Knowledge Transfer Networks (KTNs)	KTNs facilitate connection and collaboration with the UK's innovation communities to unlock new opportunities in key research and technology sectors. A KTN provides an online networking platform to enable free access to online tools in a secure and confidential setting to explore challenging issues and to provide access to different collaborations. As a single overarching national network in a specific field of technology or business application, a KTN brings people together to stimulate innovation – from businesses of any size, research organisations, universities, and technology organisations, to government, finance and policy. There are 15 KTNs and all 15 KTNs collaborate to form a 'network of networks'.	The framework would be most appropriate to groups of projects defined in the context of the particular market and technology framing each of the KTNs. The utility of the framework depends on the level of knowledge protection and scope for transfer – as an 'open innovation' method, the framework is of particular use.	Depends on the particular sectors in which projects occur and the models of innovation which tend to dominate. The increased level of networking and collaboration means a greater likelihood of spillovers. It also depends on the scope for individual projects to produce novel and non-incremental innovation.

Source: TSB website and commentary from ICF GHK

4.9 Using the evaluation framework to inform investment decisions

The evaluation framework described above provides the potential to indicate the relative propensity of different programmes to generate knowledge spillovers, ex ante and ex post.

Whilst the propensity of spillover generation might inform some investment decisions between programmes, it does not follow that the programmes with the greatest propensity for spillovers should necessarily provide the greatest return. It may be that closed programmes operating in a closed system with a very specific objective and innovation context offer higher returns (if not the overall scale of benefits) than an open programme.

The investment decision can then perhaps be separated into two choices: the first between innovation programmes that are essentially closed, and those which are essentially open; and secondly between competing open programmes.

4.9.1 Deciding between closed and open innovation programmes

The choice for a closed programme might depend upon, inter alia:

- the nature of the technology (is it well defined and discrete?);
- the desired nature of innovation (is it largely incremental?);
- the clarity as to the innovators and methods of research (are these readily identifiable?);
- the planned use of results (is it the intention that innovators are the primary users of the results of innovation?); and
- the required levels of certainty and timing of benefits (is the benefit stream to be applied in the nearer term?)

Situations that meet the above criteria and where spillovers are of limited interest would be funded on the basis of standard rates of return; and would not be subject to the spillover assessment framework.

To the extent that there is a choice between a closed and an open programme, then the current approach of requiring the demonstration of a minimum level of return of any programme reduces the risk that the open programme may be ineffective or inefficient compared to the closed programme.

On the other hand, concerns over deadweight loss that might be significant in a closed programme would be less of an issue.

4.9.2 Deciding between different open programmes

The evaluation framework is essentially focused on this choice. It enables some degree of the relative ranking of different programmes. Ex ante it can establish (relative to a specified benchmark or counterfactual) whether a proposed support programme has the potential to generate relatively high spillover activity. Ex post, the framework is useful for defending investment programmes of innovation support which were not justified on the basis of spillovers.

The framework could also be used to help design the support programme in such a way as to maximise the opportunity for spillovers, by identifying strengths and weaknesses as the basis of adjusting the design and operation of the support programme.

4.9.3 Deciding between innovation support and other policy choices

In a more strategic scenario where the choice for the policy maker is between defending current, or pursuing increased future investment allocations between innovation support programmes and other policy choices, some quantification of the impacts from spillovers is required. Acknowledging the difficulties in quantifying spillovers, it is still helpful to identify where they are likely to occur to inform decision making.

To more fully account for spillovers in decision making, one approach might involve extending the ex-ante assessment to include a more detailed assessment of the market opportunities and possibilities for spillovers. This can be achieved by looking at the market size and shares of existing technology and on that basis scale the potential value of new innovations based on projected uptake and market share. In the case of disruptive innovations, this is notoriously difficult as a new market can often be created or it can capture market share multiple other sectors.

5 Conclusions

5.1 The feasibility of establishing knowledge, network and market spillovers

The research has examined the feasibility of establishing a methodology for assessing the potential of technological support programmes to generate spillovers; in particular knowledge, network and market spillovers.

5.1.1 Establishing the innovation system

The first part of the study examined a number of TSB support programmes to better understand the possibilities for spillovers and the programme features that might be expected to give rise to spillovers. The inception work concluded that, as a starting point for the research, a distinction should be made between support programmes commissioned in the context of closed and open innovation systems; since the latter would by definition be more likely to produce spillovers. The work in the Report has considered this distinction and has used a description of an open innovation system as the basis for structuring the findings of the literature review, and as the basis for the subsequent evaluation framework.

5.1.2 Findings from the literature review

The literature review broadly confirms the view that support programmes characterised as 'open' within innovation systems that are 'open' are more likely to produce spillovers, because of their intended interest in building a community of interest around a particular technology and its development. It is within this community of interest that research and development is undertaken and in which findings are disseminated.

The open innovation system is defined by the technology and related market applications and by the actors in the system with an interest in the technology and its take-up (including their relationships). As knowledge is shared, knowledge spillovers occur, and form the basis for subsequent market and network spillovers.

Certain factors in an open innovation system can be identified that increase the tendency for knowledge spillovers

There are a number of factors (seven have been defined specifically) that can be identified from the literature that suggest the possibility of greater knowledge spillover effects from a technology innovation programme (given the type of innovation system within which it sits). There are also a number of factors which are understood to influence spillover generation, but where the evidence is ambiguous. Overall, the literature is generally diverse and fragmented and has not examined in a systematic way the range and relative importance of different factors - and does not provide definitive evidence.

5.1.3 These specified factors have been partially tested, using TSB 'Catapult' programmes, as a basis for an evaluation framework

These factors are reflective of fairly broad concepts. For use in an evaluation framework, these concepts need to be translated into more tightly defined evaluation criteria and related indicators. The relevance and feasibility of these factors as providing a basis for assessing spillover potential has been tested in discussion with managers of the offshore wind and the connected digital economy Catapult programmes.

Feedback suggests that the factors do provide a credible basis for knowledge spillover assessment and are, in many cases, formally considered in current programme design. An attempt at a qualitative assessment of three programmes was considered to be a fair representation. The assessment does not, however, formally include assessment of market spillovers, whilst network spillovers are to some extent implicit in the understanding of knowledge spillovers.

5.2 Establishing ex ante the presence of knowledge spillovers and their impact - Expanding the programme intervention logic to better define the innovation system

The development of criteria and indicators to establish the potential for spillovers are considered helpful in comparing programmes and for providing further justification (or not) for investments made in support programmes without reference to spillovers.

Examination of standard approaches to programme assessment revealed that there is a need to include knowledge as a specific output from most support programmes, reflecting spillovers in the outcomes and impacts of such programmes. Modified programme intervention logics were considered the best approach to illustrating this.

Using the offshore wind renewable energy Catapult as an example, a programme intervention logic was designed to capture the range of actors across the value chain, and to better reflect the innovation system in which the Catapult sits. Whilst this logic is recognised as a (still) somewhat abbreviated analysis of the innovation system, it illustrates how broadening the analysis illustrates the breadth of interest and engagement in programme activity.

The programme logic identifies the intended inputs, activities (in very broad terms) and intended outcomes and impacts. It identifies the main actors and it recognises the use it can make from the knowledge gained from other innovation programmes (‘spill-ins’).

It does not, however, separate out the spillover effects, nor does it yet provide a full description of the innovation system in which the programme sits.

This intervention logic, then, provides a starting point; and from which at least two further analytical steps are required:

- first, to use the expanded logic model to further define the wider range of actors and the possible flows (and types) of knowledge within the intervention / innovation system; and

- second, to use the model to define the specific activities, outputs and outcomes that have the potential to generate knowledge spillover effects

Given these steps, the scope for spillovers can then be defined in terms of the commercialisation potential – for example, with reference to intermediate outcomes such as dissemination / engagement and to final outcomes such as spin-outs and licensing – as the basis of monitoring and evaluation.

5.3 A general framework for assessing spillover potential

To assess the knowledge spillover potential of a technology support programme deemed to be operating in an open innovation system requires an expansion to the standard programme logic of the support programme. The programme logic describes the outputs, outcomes and the flow of future benefits of identifiable programme beneficiaries (within and across sectors) as appropriate to the programme (visualised in the usual horizontal flow from left to right).

At each step in the flow of research and its commercialisation from outputs through to impacts, there is the potential for knowledge spillover, depending on the technology and the characteristics of the system (visualised as a vertical flow of spillovers from each step in the programme logic. The flow of spillovers is then a function of the seven factors identified. The potential scale of these spillovers can be assessed at each step by reference to indicators that seek to measure the presence of each of the seven factors in the relevant innovation system and hence the scope for spillover generation. Generally, high and positive values against each indicator would suggest the presence of spillovers from the support programme.

This framework of indicators is used for assessing the potential for knowledge spillovers – either ex ante or to review ex post - through the range of outputs, outcomes and impacts. Given a benchmark (which will need to be established – using a reference programme), the indicator framework will allow an assessment of whether or not a proposed support programme will have a higher or lower level of spillover than the benchmark.

5.3.1 Scope for populating indicators

The indicators described in Figure 5.1 have been examined in relation to the possibilities of populating them from primary or secondary data. Only a small number of indicators can be populated from secondary data, and even then the data needs careful interpretation. The remainder of the indicators can only be populated on the basis of a qualitative assessment, using detailed information of actors that define and operate the innovation system.

The qualitative assessment will need to consider whether factors that increase the likelihood of knowledge spillovers are present and to what extent. In doing so, the analysis will need to develop the essential narrative, explaining the interactions within the specific innovation system and the spillover potential.

This approach is akin to scenario development, and the approach could make use of related techniques such as workbooks and workshops. Since these techniques are used in producing technology ‘roadmaps’, the approach should be familiar to many of the actors.

5.3.2 Possible use of multi-criteria analysis to establish the relative potential of an intervention to generate spillovers

The requirement to establish the relative significance of spillover potential of a proposed support programme / intervention, in the absence of quantitative data and using a scenario based research approach, suggests the possibility of developing and applying a multi-criteria analysis. This would be based on the seven factors and indicators already defined. For a given programme the presence of each factor would be scored, with a higher score the greater the presence. Each criterion would be weighted according to the relative importance accorded individual criterion.

The sum of the weighted scores would provide the basis for comparison with previously scored interventions or between a range of planned interventions. This would allow a ranking of the different Catapults and (in the context of other interventions) of different sectors or topic areas.

5.4 The scope for quantification of spillovers

The examination of spillovers indicates that quantifying the value of spillovers at a given point in time, when the focus is on knowledge spillovers, is problematic – the best that might be attempted is an ordinal ranking of support programmes with reference to established benchmarks or counterfactuals, using the indicator set and research methodology described.

There are studies that have sought to quantify spillovers from the perspective of supply chain and market impacts (which tend to assume that the business users of the knowledge are close to identical to the producers of the innovation and/or that existing inter-industry linkages are stable and provide a reasonable proxy). Using these assumptions, these studies have used econometric methods to quantify the value of spillovers for particular industrial sectors.

Reviews of the economic literature (Nadiri (1993)) have attempted to estimate the indirect impacts of R&D on direct impacts to businesses, capturing the social value of spillovers involved. On this basis, the net rate of return on R&D investment is estimated to be in the region of 20-30% with the social rates of return estimated to be in the range of 20-100% of R&D investment, with an average close to 50%.

The literature does not, however:

- establish the linkages between the presence of factors in the innovation system and the scale of impacts estimated; and
- relate the value of spillovers to the particular influences of technology innovation support programmes

Based on a range of 20% to 100% in the relative scale of spillover to direct impacts of R&D investment there is a wide variation between the direct benefit and the indirect benefit of R&D, which makes it difficult to suggest using the direct benefit as a proxy.

This argument is supported given that knowledge spillovers are likely to be at their greatest when innovation leads to market disruption and the realignment of demand and supply relationships. Since the econometric approaches assume these relationships are stable, it seems unlikely that the results of such models would provide even a rough approximation to the social value of knowledge spillovers. The literature would tend to support a conservative position that spillovers add a minimum of 20% to the direct benefit. However, this is likely to significantly underestimate the true value of spillovers.

5.4.1 Moving towards monetisation of knowledge spillovers generated by support programmes

As a basis for decision-making, and determining investment priorities, especially across competing policy areas, establishing the monetary value of spillovers is clearly desirable.

A bottom-up approach would seek to estimate the number and value of individual spillovers in the form of a conventional impact assessment methodology – with due reference to the risks and benefits of deadweight / crowding out and market displacement effects.

An alternative or complementary approach is to scope out the future trends in the potential total global market value of the markets in which the knowledge produced by the support programme would find potential application. The assessment would then seek to establish the potential market shares that the activities of the support programme might secure through the development of market scenarios.

In the context of programmes (such as Catapults) where impacts are largely in the form of spillovers rather than direct programme beneficiaries, it could be argued that these market estimates provide a first estimate of the spillover value. The extent to which the estimates might be justified as a spillover estimate will depend on the scenarios used and the credibility of the underlying intervention logic.

5.5 The scope to use the framework across TSB programmes

The relevance and utility of the framework is at its greatest when seeking to inform investment choices between different sectors and technologies, where there is some expectation of significant knowledge based spillovers.

Where technology support programmes are highly focused on individual beneficiary outcomes, supported by investment in knowledge protection, AND the sector/technology area would be classed as having an effectively ‘closed’ innovation system, then the nature of and context of the intervention militates against spillover generation.

Review of the range of TSB programmes suggests that the framework has the greatest utility in monitoring and supporting investment choices in the Catapult programme. It would also have relevance in the context of Knowledge Transfer Networks (KTNs) which are explicitly directed to facilitating an open innovation system.

The framework is not designed for use at project compared to programme level – and therefore would not be used in the context of individual project appraisals under for example SMART . However, it could be used to assess the relative potential for spillovers of the various sectors, topic areas and technologies which frame these project level interventions. This potential would, in turn, provide an additional criterion for the selection of projects.

5.6 Using the evaluation framework to inform investment decisions

The evaluation framework described above provides the potential to indicate the relative propensity of different programmes to generate knowledge spillovers, ex ante and ex post.

Whilst the propensity of spillover generation might inform some investment decisions regarding choice of programmes, it does not follow that the programmes with the greatest propensity for spillovers should necessarily provide the greatest return. It may be that closed programmes operating in a closed system with a very specific objective and innovation context offer higher returns (if not the overall scale of benefits) than an open programme.

The investment decision can then perhaps be separated into two choices: the first between innovation programmes that are essentially closed, and those which are essentially open; and secondly between competing open programmes.

5.6.1 Deciding between closed and open innovation programmes

The choice for a closed programme might depend upon, inter alia:

- the nature of the technology (is it well defined and discrete?);
- the desired nature of innovation (is it largely incremental?);
- the clarity as to the innovators and methods of research (are these readily identifiable?);
- the planned use of results (is it the intention that innovators are the primary users of the results of innovation?); and
- the required levels of certainty and timing of benefits (is the benefit stream to be applied in the nearer term?)

Situations that meet the above criteria and where spillovers are of limited interest would be funded on the basis of standard rates of return; and would not be subject to the spillover assessment framework.

To the extent that there is a choice between a closed and an open programme, then the current approach of requiring the demonstration of a minimum level of return of any programme reduces the risk that the open programme may be ineffective or inefficient compared to the closed programme.

In marginal cases, however, it may still be the case that spillover generation and impact has to be demonstrated; although concerns over deadweight loss that might be significant in a closed programme would be less of an issue.

5.6.2 Deciding between different open programmes

The evaluation framework is essentially focused on this choice. It enables some degree of the relative ranking of different programmes. Ex ante it can establish (relative to a specified benchmark or counterfactual) whether a proposed support programme has the potential to generate relatively high spillover activity. Ex post, the framework is useful for defending investment programmes of innovation support which were not justified on the basis of spillovers.

The framework could also be used to help design the support programme in such a way as to maximise the opportunity for spillovers, by identifying strengths and weaknesses as the basis of adjusting the design and operation of the support programme.

5.6.3 Deciding between innovation support and other policy choices

In the more strategic case where there is a choice between defending current, or pursuing increased future, investment allocations between innovation support programmes and other policy choices, some quantification of the impacts of spillovers is likely to be required. Nevertheless that spillovers may still be identifiable but not quantified may still help to inform decisions.

The scope for quantification could be explored on the basis of extending the ex ante assessment into a more detailed assessment of market opportunities and possibilities for given market shares.

ANNEXES

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Annex 2 Literature review protocol

A2.1 Search strategy

A2.1.1 Specific review questions

The aim of the review is to establish the underlying evidence base for the relevance and significance of the factors associated with spillovers from technological innovation. In order to ensure that all relevant aspects are covered and that there is sufficient focus to the analysis to make sure that the specific research objectives are met, the study team has developed a series of research propositions, in consultation with the BIS steering group.

These research propositions are summarised below, and cover factors falling under four categories:

- industry / market characteristics;
- programme characteristics;
- beneficiary characteristics; and
- approach to dissemination and diffusion

This range of factors includes consideration of the content of R&D activity, market and industry context, as well as the [internal and external] transmission mechanisms of knowledge, and the characteristics of the type and nature of secondary beneficiaries.

The relevance and significance of these factors and the extent to which these generate spillovers represents a substantial area of debate and contention which needs to be examined. The literature review will also seek to draw out further evidence of the size, range and likelihood of spillovers emanating from public support for technological innovation, and particularly how these are measured and evaluated.

This work seeks to provide evidence to support a practical, indicator based approach to assessing the merits (and drawbacks) of government interventions to support technological innovations and the generation of positive spillovers.

A2.1.2Search strategy and inclusion parameters

The literature is likely to be fragmented across the wide range of research propositions identified, with different types of study (academic, programme evaluation) and approaches, likely to provide evidence on only a limited number of the identified factors. More specific defining parameters (e.g. paper selection criteria in terms of conceptual, empirical or methodological criteria) will therefore not be established.

Instead, the research propositions will be pragmatically interrogated by focusing keywords on the specific factors or characteristics of interest. The defining parameters set out in Table A2.1 have been established to ensure inclusion of a wide range of sources and perspectives in the literature in order for the reviewers to examine the full range of factors associated with increasing spillover impacts.

As the review and literature search progresses, the emerging evidence will be mapped against the identified research propositions, in order to identify gaps. In order to uncover articles to fill evidence gaps that might otherwise not be found, reviewers will also employ the 'snowballing' technique, in which the reviewer is pointed in the direction of potentially informative work from the references section of work under review.

Further, we choose not to employ strict quality criteria in the initial selection process. Typically, these might include assessments of theory robustness, methodology, generalisability, contribution etc. Instead, we are keen not to exclude a priori contributory work from practitioner and policy communities whose 'quality' might be determined by different criteria, and which may provide more practical insights. It is therefore considered important to review the outputs of relevant government research and commissioned projects.

Table A2.1 Search strategy and inclusion parameters for identifying literature sources

Historical antecedents

The study will not be specifically constrained by any particular dates. It was noted, however, that the more recent literature will likely reflect findings of earlier studies and so should be predominant in the review. Seminal papers will also be included, since their findings should still be robust.

Language and geographic scope

English-language articles only. International experiences to inform the review.

Firm and intra/inter-industry levels

Of particular interest are firm, intra-industry and, to a lesser extent, inter-industry external effects (as opposed to cross-country analyses), as UK programmes of innovation support target these levels.

Populations

Coverage of all sectors and the full population of firms (large companies and SMEs)

Specified key words

Combinations of "spillover" OR "external effects"; "externality" OR "social return" AND:

- "technology", "innovation", "R&D"; AND
- "knowledge", "absorptive capacity", "learning effects"; OR
- "market", "intra-industry", "inter-industry", "firm*", "supply chain"; OR
- "network*", "proximity", "cluster*", "agglomeration" "joint venture", "critical mass"; AND
- "open innovation", "knowledge transfer", "diffusion", "dissemination"; OR
- "general purpose technology"; "incremental innovation", "radical innovation" OR
- "intellectual property", "appropriation"; OR
- "public investment"; "public procurement"; "programme evaluation"; "project evaluation"

Literature sources

- Desk searches of EBSCO Host databases, including *EconLit with full text*, and RePEc, to identify peer-reviewed journal articles, book chapters and non-peer reviewed academic research
- Consultation with key research centres and institutes including: Nesta, the National Bureau of Economic Research (NBER), the OECD, the Institute of Fiscal Studies (IFS), Warwick Business School, Aston Business School and Oxford Intellectual Property Research
- Evaluative material from desk searches of online publications from UK and EU innovation support programmes and their sponsoring departments e.g. BIS, TSB, DG Research, DG REGIO, European Agency for Competitiveness and Innovation (EACI)
- Other grey literature from follow-up research to Jaffe (1996), including evaluative material from the Advanced Technology Programme (ATP) and Technology Innovation Program (TIP)

Reference management software (Zotero) will be employed to efficiently manage and record the database searches. This will help to ensure the review is comprehensive, enhance the internal workflow and facilitate a transparent quality assurance process. Notes will be recorded detailing the reasons why material has been discounted.

From this systematic review, a large volume of 80-100 studies in the academic and grey literature that addresses the research propositions will be examined. It should be noted that such a review will not reflect exhaustive coverage of the literature. Instead, the systematic review will be undertaken with pragmatic considerations to the fore, and decisions made with regard to what should and should not be included, in order to inform the development of a robust, credible and evidenced-based M&E framework in stage 3.

A2.1.3 Data Extraction Template

For the recording of content from the literature, the research team will make use of a 'data extraction' template common to each study, which sets a number of categories derived from the specific review questions. This approach guides readers to focus content on the review questions and issues of relevance for appraisal of the evidence, while the use of a common template reduces inconsistencies and improves validity and reliability.

The data extraction template has been piloted and subsequently revised to ensure that it works effectively – to facilitate analysis of both academic and grey literature sources, and the early identification of evidence gaps. An Excel database has been created that summarises each study according to the criteria shown in Table A2.2.

Bibliographic information, as well as notes on the purpose and focus of the study under review will be extracted based on an initial scan of study abstracts and executive summaries. A more detailed reading of the identified sources will then seek to identify the evidence associating the identified factors with spillover generation and indicate whether the study provides corroboratory (Y), contradictory (N), neutral (n/a) or no evidence (blank), using the designated shorthand provided in brackets.

To inform the comparative assessment of the available evidence, the reviewer will also extract information on the methodology used, the main results of the study in terms of the economic and social impacts of spillovers, and any policy recommendations.

Table A2.2 Data extraction template

Reference	Reference No. Study Title Author Year Journal Peer Reviewed	**Study purpose**	Purpose Commissioning organisation Geographic Scope Link to source
Focus of the study	Level of spillover Type of spillover Technology / sector	**Review of Methodology**	Methodology (Empirical, Case Studies, Literature Review, etc.) Measurement of spillover Measurement of impact
Research propositions for increasing spillovers (corroborate, contradict, neutral, no evidence)			

Industry / Market factors - International markets - High levels of competition - Leaders in business - Nascent sector - High capital intensity - High industry value added		Beneficiaries - Upstream beneficiaries - Strong clustering - High levels of absorptive capacity - Public procurement as market driver - High social benefits from applications	
Programme - General purpose technologies - Incremental innovation - Demonstration stage		Dissemination / Diffusion - Open methods of knowledge transfer - Low levels of IP protection / secrecy - High levels of coordination/ networking	
Study results	'Economic' spillover impacts 'Social' spillover impacts Recommendations for policy design / M&E	**Quality assessment**	Appropriate methodology? Statistical robustness? Bias in results? Use in synthesis (Y/N) Reason for non-inclusion

A2.2 Detailed results

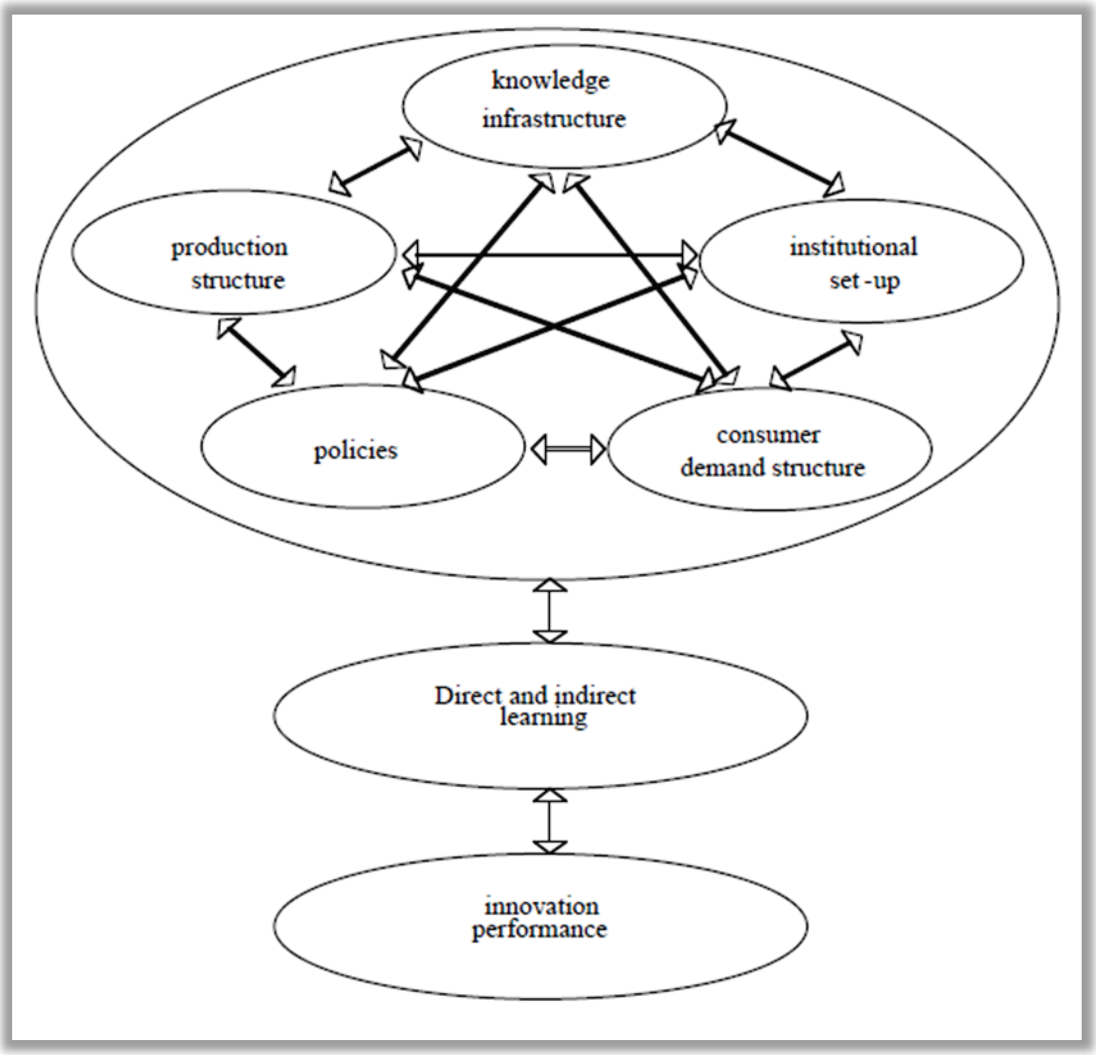
M:\KI Innovation\
Shared\K&I Analysis\:

Annex 3 An Overview of 'Innovative Systems'

A3.1 The 'Innovative Systems' Approach

The 'innovative system'[22] (IS) literature points out that innovative performance is a matter of systemic interactions between many different activities and interactions between actors of different kinds (see Figure A3.1). This implies that innovation and technology development are the result of a complex set of relationships amongst different actors, which includes enterprises, their customers and suppliers, universities, interest organisations and government research institutes[23].

Figure A3.1 The Innovative Performance of an Innovation System



[22] Innovative and innovation will be used interchangeably. In any case, the same abbreviation 'IS' is used

[23] OECD (1997): http://www.oecd.org/science/innovationinsciencetechnologyandindustry/2101733.pdf

Informal and formal knowledge production is the central, general activity in innovation systems. Formal knowledge production refers to knowledge acquired at universities and research institutions while informal knowledge production comprises of knowledge gained through practical work, experiments, prototyping (referred to as ‘learning-by-doing’) and knowledge gained in interaction with markets and users (referred to as ‘learning-in-interaction’ acquired through ‘use-driven innovation’, ‘learning-by-using’, lead users, lead markets, etc.).

A3.2 National Innovation Systems

The national innovation system (NIS) approach stresses that the flows of technology and information among people, enterprises and institutions are key to the innovative process.

A3.2.1 Channels through which knowledge can flow in NISs

There are four basic knowledge flows among actors in a national innovation system:

- interactions among enterprises - primarily joint research activities and other technical collaborations;
- interactions among enterprises, universities and public research laboratories - including joint research, co-patenting, co-publications and more informal linkages;
- diffusion of knowledge and technology to enterprises - including industry adoption rates for new technologies and diffusion through machinery and equipment; and
- personnel mobility - this focuses on the movement of technical personnel within and between the public and private sectors

Table A3.1 outlines important knowledge flows in a national innovation system and suggested ways to measure them.

Table A3.1 Knowledge flows in NISs

Source of Knowledge Flows	Benefits of Knowledge Flows/Evidence	Effective measurement
A. Joint industry activities		
1. Technical collaboration among enterprises 2. Informal interactions (e.g. strategic technical alliances)	Joint industry activities are especially evident in new fields such as biotechnology and information technologies, where development costs are particularly high. Firms collaborate to pool technical resources, achieve **economies of scale** and **gain synergies from complementary human and technical assets** Innovation system studies in Norway and Finland indicate that the share of new products in overall sales is **higher** among firms involved in **co-operative ventures**, [although other factors may have also contributed to this finding]	Technical collaborations within industry can be mapped using **firm surveys** as well as **literature-based surveys**, where the latter requires information on industry alliances through reviews of newspaper and journal articles, specialised books and journals as well as corporate annual reports and industry directories These linkages can also be fully captured through **cluster analyses** and other techniques
B. Public/private interactions		
On one side, the public component consists primarily of public research institutes and universities. On the other side are private enterprises	Government-supported research institutes and universities are main performers of generic research and produce not only a body of basic knowledge for industry, but are also sources of **new methods, instrumentation and valuable skills**. Public-sector research also serves as an overall repository of scientific and technical knowledge in specific fields Studies of national innovation systems to date reveal that the public research sector **may be more important as an indirect source of knowledge than as a direct source of scientific or technical discovery**. This tends to vary by **sector** and is **less** true for science-based industries and sectors such as **construction** and **energy**, where there may be **direct flows** from scientific discovery to technological development **Indirect spillovers** from public research to the private sector – through general access to the knowledge base and technical networks – are **considerable** for **many sectors**. There is also a **significant localisation effect**,	1. **Joint research activities** – Using the most accessible measure, the number of joint research and technical activities between firms and universities/research institutes can be counted using data published by government funding agencies, universities and other sources 2. **Co-patents and co publications** where the number of co-patents or co-publications developed by enterprises in collaboration with a university or research institute can be compiled by analysing patent records and publication indices 3. **Citation analysis.** Since it is the practice of users of technical knowledge and ideas to cite their sources, citation analysis can be used to assess the degree to which enterprises draw

	whereby the knowledge flows from the public sector to industry may be most important in a specific locale or region	upon the information contained in either the patents or publications of universities and research institutes 4. **Firm surveys** where surveys of firms reveal the extent to which they consider universities and public research institutes as sources of knowledge useful in their innovative activities. These surveys also capture more informal networking between industry and the public research sector
C. Technology diffusion		
Dissemination of technology as new equipment and machinery	Technology diffusion is particularly important for **traditional manufacturing sectors** and **service industries** who may not be R&D performers or innovators themselves. Also, the **most innovative** firms are those with the ability to **access outside knowledge** and to link into knowledge **networks**, including **informal contacts**, user-supplier relations and technical co-operation Most studies show that technology diffusion at a broad level has **positive impacts on productivity** in **industry**. For instance, the intense use of advanced machinery and equipment in production contributed even more to the improvement of the technology intensity of Japan's economy than did research spending (OECD, 1996)	**Firm surveys** have traditionally been used to track the use of different types of technology in industry. Questionnaires ask manufacturing firms about their use of advanced manufacturing technologies or service firms about their use of information technologies Technology diffusion can also be measured **by tracing inter-industry flows of R&D** through purchases of machinery and equipment. Such embodied technology diffusion is assessed through input-output matrices which track the exchange of goods among industrial sectors having different R&D intensities
D. Personnel mobility		
Personal interactions, skills and networking capabilities of personnel, largely determined by qualifications, overall tacit knowledge and mobility of the labour force	Nordic studies have shown that a high level of mobility of qualified personnel contributes to the overall skill level of the labour force as well as to the innovative performance of the economy	**Labour market statistics** can be used to track the movement of personnel categorised by skill level between industrial sectors and between industry and universities/research institutes

Enhancing knowledge flows in a developing country - Korea's Innovation Success[24]

Developing countries can acquire technology in three ways: (1) imitation of foreign capital goods; (2) foreign direct investment; and (3) foreign licensing. The government can in turn influence these avenues of acquisition in a variety of ways including: (1) FDI policies, (2) foreign licensing regulations, (3) intellectual property rights regimes, and (4) the purchase of technologies for public enterprises.

Nonetheless, in order for developing nations to take full advantage of acquired technologies, governments will need to enact policies that aid domestic firms in using and diffusing these technologies throughout the country. This goal is most readily achieved by establishing institutions and networks that dissipate the tacit and codified knowledge underlying novel technological systems. Furthermore, as technology is changing at an increasingly rapid pace, incremental improvements in processes, inputs, or equipment are required to adapt products and processes to the local environment as well as enhance productivity and lower costs. For any of the strategies discussed, research has demonstrated that an economy's absorptive capacity depends heavily upon the level of education and training. This implies that the NIS will be more effective, conferring wider and longer-term benefits, if a key input is a technical human capital base able to assess and decide on technology matters.

Korea's active learning and NIS:

- Korea's first goal was to promote the flow of technology into the country. Notably, Korea did not follow the traditional route of promoting foreign direct investment (FDI) and foreign licensing, but rather concentrated on turnkey factories (defined as factories providing a complete product or service that is ready for immediate use). The steel, paper, chemical, and cement industries were all founded on imported turnkey plants, and then expanded by locals. Korea also imported capital goods from advanced countries which were deemed the most productive method of technology transfer.

- To promote R&D, the government adopted a series of incentives including tax breaks and exemption from military services for key personnel. These incentives combined with the success of publicly-funded R&D centres motivated firms to establish centres of their own.

- Korea's success was also largely brought about by the nation's strong absorptive capacity from a high level of general education. Korea's investment in education allowed engineers and scientists to have a level of understanding of the local plants and imported technology great enough to not only maintain them, but to improve and reproduce them.

[24] Source: National Innovation Systems Overview and Country Cases: http://www.cspo.org/products/rocky/Rock-Vol1-1.PDF

A3.3 Regional Innovation Systems

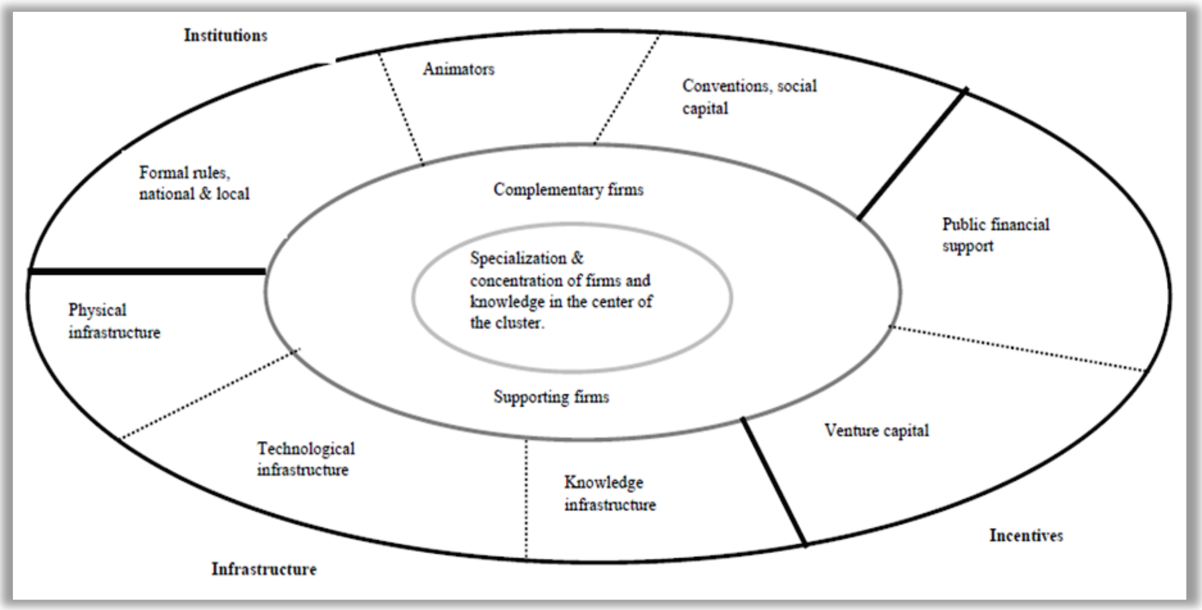
A3.3.1 The 'Triple Helix'

The basics of a regional innovation system (RIS) are in principle the same as for a NIS. However, RISs are defined differently in that they are seen as "regional clusters that are supported by surrounding firms." A RIS therefore has two key features:

- firms in the regional core cluster; and
- an institutional infrastructure

Figure A3.2 illustrates a "complete" RIS whereby the core is constituted by the firms in the regional cluster and is surrounded by supporting as well as complementary firms. Other institutions are also present which facilitate cooperation and knowledge spillovers and transfers. The institutional structure facilitates innovation and includes several elements: (1) industry specialisation and structure; (2) governance structure and its autonomy (including public and private administrative set-up and intermediating structures); (3) the financial system and its autonomy (including finance of activities of firms, R&D and infrastructure); (4) structure of the research and development functions as a part of knowledge generation; (5) training and competence building system, (6) non-organisational institutions (such as contracts, laws and norms) and (7) operational cultural factors.

Figure A3.2 Components of a complete RIS (commonly referred to as the Triple Helix)[25]



[25] Adapted from Eriksson, 2000; taken from CESIS Working Paper No.10: http://www.kth.se/dokument/itm/cesis/CESISWP10.pdf

A3.4 Sectoral Innovative Systems

The ‘innovation system’ approach can also be applied to different sectors. IThe agricultural and energy sectors are considered below.

A3.4.1 Innovation in agribusiness[26]

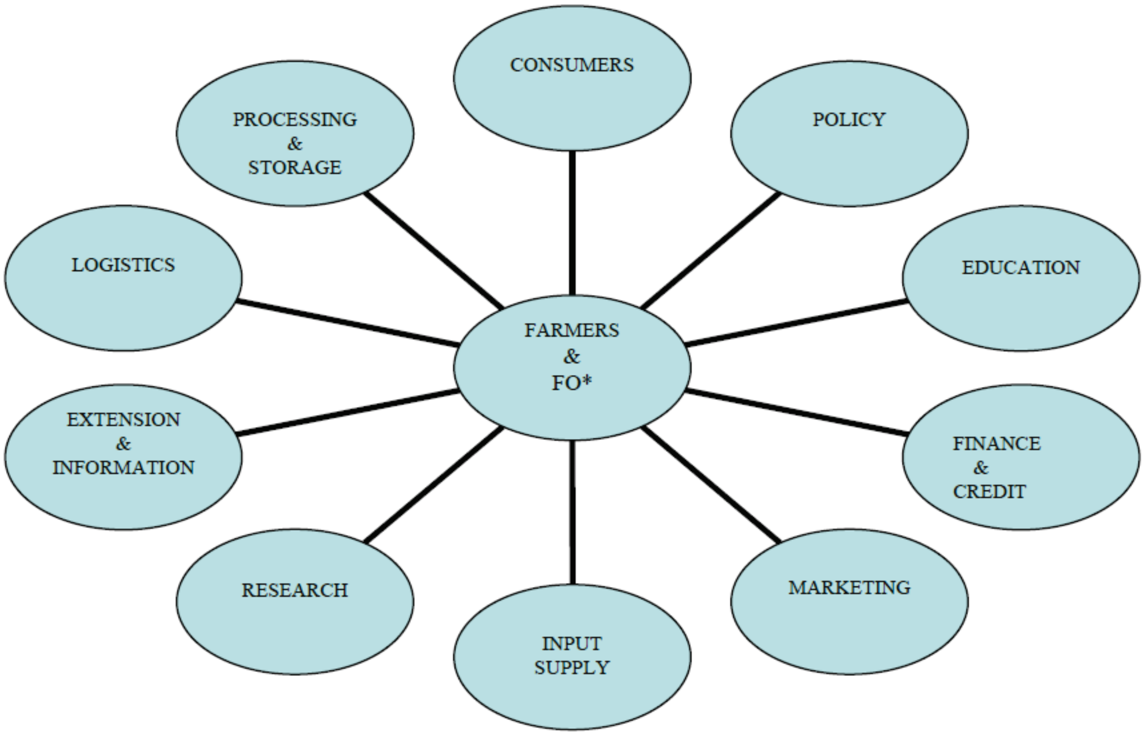
Relevance of the innovation system approach in agriculture

Agricultural innovation involves a diverse set of agents and consequently, it requires different sets of functions, the most important ones being technological innovation, communication and the adaptation of new ideas. Each function is equally important and actors need to collaborate in order to achieve innovation. As such, the innovation system approach provides a useful framework to explore the linkages amongst stakeholders in agricultural innovation diffusion.

Case example: Australia’s Agricultural Innovation System (AIS)

Australia’s AIS consists of various actors who perform specific roles in the innovation-dissemination process. Figure A3.3 gives an essence of who they are.

Figure A3.3 Major actors in Australia’s AIS (FO*: Farmer Organisations)



Types and goals of innovation-related activities

A survey carried out by Australia’s Victoria University indicates that 93% of agricultural organisations surveyed are involved in technology development, 67% in technology diffusion, 60% in training and 53% in demonstration. These are essential contributors to the successful operation of the AIS. Other types of technology innovation undertaken are:

[26] Agricultural Innovation System in Australia, Victoria University: http://www.jbsge.vu.edu.au/issues/vol01no4/Sudath.pdf

evaluation; integration; use; policy; introduction/selling; acquisition (local/international); and financing.

This increased innovation is likely to have a positive influence on the whole of the country's agricultural sector. According to organisations surveyed, these gains will be mainly driven by:

- the provision of knowledge and information;
- the introduction of new products and processes;
- increased commodity quality;
- increased commodity production;
- reduced environmental damage;
- increased market opportunities;
- improved production flexibility;
- reduced labour costs;
- reduced material costs; and
- reduced energy consumption

A3.4.2 Innovation in the energy sector[27]

Energy technology development is to a large extent influenced and shaped by the conditions in the energy sector in general. Often development of new technologies however, also to some extent, transcends the limits and borders of the existing energy sector and integrates knowledge and perspectives from other fields. This therefore means that the networks of the technology developers reach outside the sector.

Case example: Danish wind energy innovation system

The successful development of wind power technology in Denmark in the latest decades is now relatively well-known. The wind power innovation system encompasses a very broad range of actors, stretching from engaged citizens and small investors, over industrial sub-suppliers, consultants, public authorities and NGOs, to large international companies, policy makers, and industry associations (this is depicted in Figure A3.4).

Another important group of actors are the private owners of windmills, locally, primarily in rural areas. The owners are usually either individual farmers or groups of citizens that organize in local co-operatives in order to establish windmills locally.

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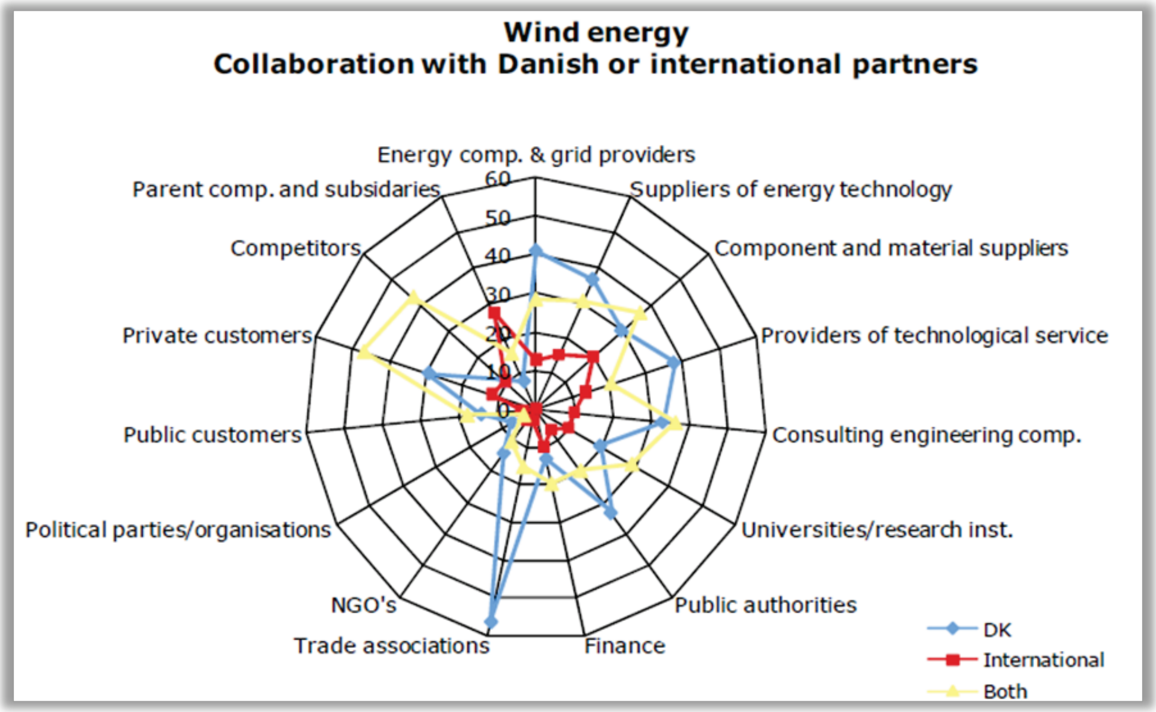
[27] Nordic energy innovation systems - Patterns of need integration and cooperation, Nordic Energy Research (Nov, 2008): http://www.nordicenergy.org/wp-content/uploads/2012/02/Nordic-energy-innovation-systems-Patterns-of-need-integration-and-cooperation.pdf

Figure A3.4 Wind energy: Collaboration with Danish or International Partners



The following were found to be the main drivers of innovation:

- **Innovative learning**: this is the main contributing factor to Denmark's success in the wind energy sector. Innovative learning in the wind area, to a large degree, occurs through practical application of windmills. Experience is then gathered in dialogue with owners and operators of windmills and wind parks. This allows products to be gradually improved. In Denmark, the well-developed supply chains between the manufacturers of windmills and the multitude of sub-suppliers enabled large-scale experimentation to be carried out, enabling numerous technological opportunities and advances.

- **Expanding knowledge-base**: many of the sub-suppliers are small and medium sized companies from the machine and metal industries in Denmark. These types of companies have had a strong importance for wind energy innovation since the 1970s and continue to grow in the current era. In addition to these specialised suppliers, the wind energy industry also now comprises of other business actors who bring important technical know-how. These include: consultancy companies, service providers, providers of simulation and control systems, investors and developers of wind farms

- **Internationalisation**: the Danish wind industry has also been largely exposed to internationalisation. Large multinational conglomerates have invested heavily in the industry, enabling Danish manufacturers to establish production subsidiaries in a number of countries around the world

- **A greater role played by research institutions:** research institutions have helped create an arena for better and greater information exchange through their on-going research. For instance, they have been active in establishing test and certification systems for windmills in collaboration with the energy authorities

- **Considerable national funding for research and development in wind energy over the years:** the Danish wind energy industry has received significant financial support from the state. A substantial share of the funding devoted to national R&D programmes has been channelled to the wind energy sector for long mainly to enable collaborative projects between research institutions and private companies.

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