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Space and the Processes of Innovation

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Executive Summary

This report starts out by making the case for the recognition of innovation economics as an economic paradigm. Today, innovation is a dynamic term of strategic importance in industrial policy and management. The introductory chapter of the report explores the major concepts and authors in the academic literature surrounding innovation and innovation economics. Schumpeter's concept of creative destruction shows that, by its very nature, innovation should not be touted as a universal benefit but as a complex, disruptive force creating opportunities and challenges to actors in the economic system. In the short term, innovation creates winners and losers. In the long run it is the engine of economic growth, upgrading quality of life and technological progress. Drucker emphasises the need of being mindful of human psychology and the individuals behind the inventions when spurring innovation, indicating that – despite its complex character – innovation is something that can be stimulated and fostered when managed well.

Analysis and Findings

Typology by In- and Outflow

The first aim of this report is to analyse the flow of information between different players in the innovation process, and to underscore the criticality of such flows for the optimisation of innovation. As an approach, different examples of innovation management are categorised based on whether an innovator invites outside active participation or not, and whether innovation is commercialised as proprietary or is made openly available. This methodology makes way for four different configurations of innovation to be discussed:

Innovation projects classified in the *"Closed In, Closed Out"* category are characterised by their non-participatory, often secluded nature throughout the development process and the restricted or commercialised use of resulting intellectual property rights:

- On an inter-organisational basis this can assume one of many forms of industrial partnering, in which external collaboration should bring synergy in terms of market access, costs & skills. Based on their needs and strategic planning, organisations choose to develop either explorative or exploitative types of collaboration.
- This type of innovation can take the form of skunk works: highly focused, geographically separated and hierarchically and procedurally liberal working environments, staffed by cross-functional teams of young professionals. The NASA Technology Petting Zoo and Google X Lab are discussed as examples of the skunk works format.
- In both cases, it is clear that these projects made up only a small proportion of the overall innovation activities, showing that this kind of innovation management is typically part of a wider innovation strategy where some of the research performed can even be peripheral to the organisation or company's core business.

"Closed In, Open Out" innovations present a structure consistently displayed at many research institutes, both university and government owned. They are characterised by a fairly inward looking culture combined with a strong drive to disseminate information in academia and to the public. The Institute of Advanced Study near Princeton University, a traditional example of this kind of innovation structure, is taken as an example.

- The report identifies the absence of any ESA or EU-supported European institute dedicated to space technology innovation. Despite the political rationale for this in terms of industrial policy, arguments are made that there are reasons to support creating such an institute, if only to join the forces of countries without strong national space technology research institutions.

"Open In, Closed Out" innovation practices are characterised by their participatory input process and restricted or commercialised use of resulting intellectual property rights. The degree of participation openness throughout the development, however, is very much dependent upon the method of external knowledge gathering.

- Companies use knowledge brokers to find solutions for well defined scientific problems or organisational challenges. These knowledge brokers, acting as intermediaries between solutions-seekers and problem-solvers, often have extended networks with individual scientists, engineers, experts or small research laboratories around the world. By connecting, recombining and transferring knowledge, they enhance corporate capacity to innovate and compete. "Innomediaries" are increasingly supported by different models for community building.
- Companies or organisations can open innovation challenges to the public through crowdsourcing platforms. One such example is the InnoCentive platform, which connects solution seekers with an online community of millions of problem solvers worldwide. Benefits of this approach include lower costs, more diverse solution sets, and in the end the retained ownership over derived intellectual property. To date, NASA is the only institutional actor in the space field that has experience with the InnoCentive platform to crowdsource challenges.

"Open In, Open Out" modalities of innovation build upon open participation and free use. Online platforms of this category deliver promising perspectives in terms of information and knowledge management, dissemination and accessibility.

- Through citizen science, researchers can increase processing capacity at low cost in science-oriented virtual projects such as Galaxy Zoo. Citizen science benefits participating volunteers, the education community, the scientific community, and society as a whole.
- Open source software (OSS) developers and communities present a novel and successful alternative to conventional innovation models. They also offer opportunities for an unprecedentedly clear look into their detailed inner workings. For the space sector, OSS can be particularly useful because it is stable and incurs low development costs.
- Wikis, operated through Wiki software, are flexible tools to exchange information and amplify understanding within a community. In terms of knowledge management efficiency, they might be useful to streamline innovation processes throughout their development. NASA is already operating a wiki site to push its capability by sharing knowledge, data, and ideas across the organisation. ESA is experimenting with one in the field of global navigation satellite systems.

An Extended Analytical Framework

In a second phase, the analytical framework of this report is expanded in order to discuss other methods or approaches towards innovation. The term "ecosystem" is the first concept investigated in this fashion.

- "Innovation ecosystem" is defined as the dynamic system of interconnected institutions and persons necessary to create, store and transfer knowledge, skills and artefacts which define a product domain. Typically, it combines total company control over the ultimate commercialisation of the central product, but allows a wide range of actors – at different levels – to take part in the ecosystem. This allows the core product – or its company as the focal innovator – to benefit from the surrounding ecosystem in terms of market position and future development and the surrounding ecosystem to feed off the innovations in the core product and interlinked applications.
- Enacting an ecosystem business model entails additional strategy and management challenges in terms of supply-chain coordination and implementation by down-stream complementary products or services across the customer/user community. Profitable and innovative ecosystems at Apple and Google, however, provide evidence that this can be done successfully and without companies losing control. The Lego case study proves that even in times of serious crisis, keen reorientation combined with ecosystem building can put a company back on track.
- In the space business ESA has built an ecosystem around itself. But because of ESA's particular industrial policy, in which generated intellectual property rights remain largely with industrialists, questions arise on whether the ecosystem is leveraged in the most optimal way.

Another systems innovation approach is the use of concurrent design facilities, exemplified by ESA's Concurrent Design Facility. Design engineering, manufacturing engineering and other functions are integrated through a parallelisation of tasks that reduces the overall time required to plan and design a new product. These facilities can serve as a tool for both space and non-space innovation.

Open innovation, networked and interactive innovation concepts between universities and industry play a strong role in creating innovation. University-industry relationships are being developed accordingly and can assume various forms. Exchanging knowledge between the 'real world' and institutes and universities can be enhanced by different forms of academic consulting, by the part-time professor coming from the outside and by its opposite, the ordinary professor who works part-time outside university. The kind of legal doctrine dictating where and how intellectual property rights are allocated between academia and industry has a large impact on the profitability and widespread use of a particular innovation. One explicit example of a mutually beneficial such relationship is the Announcement of Opportunity Instruments for space science, where ESA provides the platform for a probe or satellite, but the scientific instrumentation is provided by universities and institutes.

Generally speaking, sustaining innovation has been the strength of large companies while disruptive technologies have remained corralled within upstarts. Because of this, upstart companies are often forced to be more risk tolerant and are more inclined to focus on a select group of products and their success in the marketplace. Disruptive innovation is always unpredictable; this is one reason it is important to establish ecosystems around emerging technologies in order to exploit all possible routes to the market. The challenge for large companies, both within the space sector and outside, is to leverage their portfolios of possibly disruptive innovation in a nimble fashion, allowing the relentless focus of upstarts to be deployed even in a larger corporate setting.

Looking then at the development cycle in space projects, it is clear that innovation is ideally integrated in conceptual studies. Innovations are often not welcome in later stages of projects, since they tend to add to risk and cost. For space it is of critical importance to be able to reconcile upstream revolutionary or disruptive innovation with the risk-averseness required in later phases of projects.

Finally, the report looks at the seemingly contradictory process of globalisation and reinforcement of regional economies. In fact, the process only appears to be contradictory. In reality, regional concentration is a response to globalisation since regional concentration normally leads to higher competitiveness in the global marketplace. The two parallel tendencies are, in any event, altering the way firms and organisations can tap into knowledge networks and exploit development and market opportunities. From a geographical perspective, Europe is characterised by decentralised agglomeration. This model, which can be found in both aviation industry and space, seems to serve innovation because of the diversity it brings. However, it is important to note that critical mass is nevertheless necessary to create innovation clusters on the regional level, and hence decentralisation can not take precedence over agglomeration. The two must go hand-in-hand.

Recommendations and Open Points

This report acknowledges that the space industry operates in a highly vertically integrated environment, meaning that innovation often gets stuck within a corporate stovepipe. Space businesses must be aware that innovation and technology development are happening much more rapidly and with a more profound impact outside its own backyard. The report offers the following conclusions regarding European space industry and policy:

- Skunk works is a demonstrated excellent way to structure industrial innovation and can be set up to make leeway for an environment flexible enough to allow for integration of unplanned discoveries. In light of skunk works successes from other leading aerospace and industry actors, sustained support for endeavours like the ESA StarTiger initiative would be beneficial.
- Current industrial partnering structures and practices tend to limit innovation potential, truncating cross-fertilisation benefits and joint innovation. For these reasons, powerful customers should be encouraged to modify contractual supply frameworks to include clauses on innovation-friendly initiatives such as joint ventures for innovation management, technology petting zoos for large contractors and the obligation to share higher amounts of substantive technological information. ESA in particular has, by means of its 'Best Practices', a suitable instrument for project segmentation into custom-made separate work packages. This instrument should be used to push innovation-facilitating larger work packages, combining disciplines that in strict project logic could be kept apart, but which should be kept together if the objective is also to encourage cross-disciplinary innovation.
- Establishing a "European Space Technology Innovation Institute" should be considered. Such an institute could be en-

trusted with basic research and sustaining technology innovation as in-house activities. To lever diversity, it should draw on different disciplines, backgrounds and national approaches. This is especially relevant with the prospect of ESA enlargement, as future Member-States might want to familiarise their industry with space technology development.

- Considering NASA's positive experience with InnoCentive and crowdsourcing, ESA, the EU and industry should develop similar capabilities. ESA could also insist on such platforms being used by contractors, both for break-through and sustaining innovation.
- The use of physical innovation or knowledge brokers can be further optimised. This could be done by making information accessible in a logically ordered way, and by proactively looking for links between innovation in one field and new product opportunities in other fields. Innovation outreach functions are likely indispensable for both the innovation environment within a company and to identify external licensing opportunities. Considering that by far most technology development is taking place outside the space domain, special attention should be given to spin-in opportunities and technology observatories.
- Wikis are powerful tools for improving knowledge and information exchanges; European space actors could set up internal wiki platforms to gather and disseminate specialised data and pre-existing material to staff. In a wider context they can be used as a tool for collective discovery, and are therefore highly relevant where individual projects might want to overcome corporate barriers in the consortia and even create a more interactive dialogue with customers or the public.
- Given numerous examples of positive experiences with citizen science in space related fields, it is worth considering whether ESA –as a central entity– could foster more citizen science through an online interface. Given its public mandate, ESA could also use the crowd sourcing capabilities to foster technical innovation with public participation, and even leave the ensuing innovations in the public domain.
- Development speed and participant diversity are the major advantages of Open Source Software (OSS) for space community use. For software that is not mission critical, an OSS approach would be a good way to decrease costs, maximise innovation and create spin-out opportunities to benefit non-space society. For mission critical software, OSS can also be deployed; source code copies might be made freely available, yet introduction of change into the actual operation or flight software would only take place after the usual excruciating centrally controlled review and authorisation processes, and proper production of documentation.
- ESA should seriously question whether it serves community interests best to leave most intellectual property generated under ESA-financed industrial contracts with the individual industrialists. The alternative, more closely aligned with publicly funded research policy, would be to build a key technologies platform open to all European industry, and therefore a tool for broadly participatory development and innovation. Access to the platform could be controlled and limited to recognised European entities, thus forming a genuine European space technology ecosystem.
- The Announcement of Opportunity Instruments is discussed as an example of university involvement in actual space science projects. The winning instruments, however, are delivered to ESA as a 'box' that must comply with extensive interface requirements, and although ESA may have good visibility of the innards of the box, the innovation remains stove-piped. Whether such restrictive practices are always in the best interest of stakeholders as a whole, or even in the best interest of the providing university or institute is debatable. For this reason, a comparative analysis of the innovation effectiveness of industrial versus Announcement of Opportunity approaches could be considered.
- Linking academics and space practitioners through long-term continuous professional involvement of academics within ESA or industry seems unexplored. The reason for this might be cultural; there is a certain danger when the interaction-bridge is unidirectional, only from practitioner to academia. The opposite direction, where industry taps into the education and research knowledge pools, is the most auspicious innovation option and should therefore be actively developed.
- It is essential to establish ecosystems around emerging technologies in order to

reap all innovation benefits related to their disruptive character. This has not really been done in the small satellite field such as for cansat and cubesat technology. There might be a need to set up a true technology information platform where enthusiasts and professionals can find masses of open information and exchange ideas on how to further develop such promising technology far beyond the domain of universities and amateurs. Space agencies could play a pro-active role in this respect.

- Space agencies can open new markets for disruptive technologies by predicting and specifying needs without identifying a concrete way to meet these needs. This is arguably what is happening in space science, which has a history of setting out very demanding goals and accepting a very high degree of innovation as necessary within the projects in order to get there. No matter how one might imagine space science's role in innovation, one can ask if space agencies should not go one step further and put up miniaturisation needs which will demand disruptive innovation, and hence give birth to it.
- Large companies with an extensive technology inventory can look for tell-tale signs of disruptive innovation and create spin-off entities without subjecting them to a continuous battle for resources against other company units promoting established products. Large companies need to be able to create small firms as homes of disruptive innovation, and transform them into independent companies as soon as at all possible.
- Companies and other actors in the European space sector should go beyond technology mapping to generate innovation strategies and dynamics which encourage unplanned innovation. Serendipity management is a key for successfully harvesting of innovation benefits, and this is true also in the space domain.
- Space agencies can encourage the likelihood of serendipitous discoveries by having regular innovation conferences to encourage innovators to look beyond traditional market and scientific barriers, by having internal and external technology observatories, and by themselves using the internet as a technology management and innovation tool. Doing so will benefit both the agencies and the market place.
- Customers should include innovation requirements in early phases of their engagements with industry. Though not always easy, it is a timing that needs to be appreciated, instead of allowing the logical innovation shyness of later phases to permeate the early phases in which innovation should be explicitly pursued.

1. Introduction

1.1 The Significance and Types of Innovation

Innovation refers to a process that begins with a novel idea and concludes with market introduction. Invention by itself is therefore not an innovation. Innovation sometimes leads into a blind alley, sometimes to danger, but for highly developed economies innovation is essential for maintaining affluence and a high quality of life. This is so not only because innovation is necessary to solve issues such as energy and food shortages and climate change, but because highly developed economies are no longer competitive in standard manufacturing. Innovation and intellectual capital, though, remain a stronghold for these economies; leading to groundbreaking design work, state-of-the-art manufacturing, software development, and related management and capital allocation activities.

Two basic types of innovation exist: sustaining and disruptive. Sustaining innovation can either represent evolution or revolution and its distinguishing feature is its operation within existing markets. In contrast, disruptive innovation establishes new markets yet will often, over time, displace other, older technologies in existing markets. Sustaining innovation is often cutting-edge while disruptive innovation is usually not. Instead, disruptive innovation opens up new markets with technology that is often less sophisticated than sustaining innovation technologies.

Space is often described as a hotbed of innovation. Space innovation is almost always planned and therefore is almost always sustaining. Development projects with a long duration would normally involve complex and clear road-mapping to identify which innovation areas would be required in order to achieve objectives. Bread-boarding and initial technology development therefore has to take place in the early phases of a spacecraft project. After the early phases, spacecraft projects become innovation averse, since a need for innovation in order to fulfil specifications will entail significant economic and schedule risks, and in some instances might jeopardise the viability of the whole project. The Obama administration's emphasis on developing 'game-changing technologies' before making any concrete exploration should be understood in this light yet the innovation record casts doubt on the idea that revolutionary innovation, even if sustaining, can be ordered in this fashion. Disruptive and revolutionary innovation is often the result of serendipity within a larger initiative marked by a clear sense of purpose or destination. For example, the Apollo programme resulted in significant revolutionary innovation, all of which took place in the context of tremendous external pressure to reach the Moon within a decade.

One concern about space innovation is that it tends to be rather insular. In the late 1980s and early 1990s Edzard Reuter of Daimler gambled billions on creating an 'integrated technology company', joining consumer electronics, aerospace and car and truck manufacturing under one hat.[1] One reason for the failure of this gamble was the remarkable stove-piping of innovation processes. One of the biggest challenges of industries with significant innovation and intellectual property is exactly to be able to leverage these assets across the full range of company activities, and to identify licensing potential within other industries.

A stock-in-trade response to the question of how to leverage and stimulate innovation effectively is the 'open innovation' approach. The concept was popularised about 10 years ago by Henry Chesbrough, who believed 'open innovation' is the antithesis of the traditional vertical integration model where internal research and development activities lead to internally developed product that are then distributed by the firm. In this view, open innovation implies the use of purposive inflows and outflows of knowledge to accelerate internal innovation, and expand the markets for external use of innovation, respectively.[2]

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[1] "Company History in Brief" Daimler AG 7 Dec. 2011 <http://www.daimler.com/dccom/0-5-1324890-1-1324909-1-0-0-1345593-0-0-135-0-0-0-0-0-0-0-0.html>.

[2] Chesbrough, Henry, Wim Vanhaverbeke, and Joel West, eds. Open Innovation: A New Paradigm for Understanding Industrial Innovation. Oxford: Oxford University Press, 2006.

Since its introduction, many researchers have elaborated on the nature and the extent of this concept. Open innovation contains many elements that do not always fit under one label. The phrase 'open innovation' itself can be misleading since innovation managers must precisely calibrate the way they deploy each tool contained within the umbrella concept of 'open innovation'. Open source software, for instance, is a far-reaching open innovation tool where both inputs and outputs flow with little if any restriction, yet 'open innovation' might contain significant 'closed' elements, as can be seen from the example of crowd sourcing, where the inflow of ideas is extremely open, but where the utilisation of the results might be completely closed.

1.2 Innovation Economics

For decades traditional economic theory has been dominated by two prevailing schools of thought: neo-classical and neo-Keynesian economics. Though both models differ fundamentally in their axioms and implications, they both disregard the modifiable facets of productivity and innovation in the creation of wealth and growth. Only within the last 15 years a theory and narrative of economic growth focused on innovation has emerged: innovation economics. Unlike other economic doctrines, innovation economics does not treat knowledge and technology as something that happens outside economic activity. Instead, it makes an explicit effort to understand and model how innovation occurs by seeing advances as a result of intentional and unintentional activities by economic actors, including governments.[3]

The societal investment in space is an important part of innovation economics for two reasons: the investment itself is innovation inducing, and the investment provides an innovation infrastructure. Space activities as innovation generators were addressed earlier, yet, space infrastructure as an innovation infrastructure, as an innovation enabler, requires separate consideration.

The efficiency of knowledge sharing and hence of research have experienced a paradigm shift as a result of the revolution in information technology; a revolution which could not have succeeded so fully without the space based telecoms infrastructure. The information technology infrastructure is, however, itself a hotbed of innovation, and stimulates further innovation also in space based telecoms infrastructure in what can be considered to be a virtuous circle of innovation. This virtuous circle interacts with connected virtuous innovation circles that were enabled by new information technology. Thus the virtual workplace, so critical for many creative industries for interregional and intercontinental collaboration, would not function without the step-functions of increased functionality coming from information technology innovation, and without the virtual workplace innovations in animated movies or architecture, for example, would be slowed down or become impossible.

Space based navigation systems have brought substantial innovation in themselves, with atomic clocks being a good illustration, but are, importantly, enabler of suite upon suite of terrestrial innovation. Traffic and fleet management has an obvious new face as a result of GNSS systems, less obvious were originally the innovations leading to precision farming, where navigation systems also interface with Earth observation data gained from space. The next sustaining innovation step that can be expected in this field is the completely automated farming.[4]

The overall point in terms of innovation economics and space is that it is very difficult to capture all the interacting factors leading to innovation and new efficiencies in a simple, quantitative way. What is clear, however, is that space infrastructure is often a key element of ecosystems breeding innovation. In ESPI Report P39 two methodologies for capturing the socio-economic benefit of GMES are examined. The study describes benefits though analysis of value-chains, both one by one and when interacting. What is not captured, and possibly impossible to capture in any truly substantiated fashion, is the benefit of GMES as an innovation enabler. One may extrapolate from the value curves of existing benefits how future innovation should bring further benefits but, in the absence of a wealth of historical data and in view of the complexity of determining interacting virtuous innovation circles, all results in this respect are highly approximate. Per definition serendipity can not be predicted, but what can be said is that space-based assets often play a key role as innovation enablers, sometimes obvious, but often in the shadows. The hunt for dark matter and dark energy through, for instance, Herschel and Planck Space Observatories might not appear to be

[3] Atkinson, Robert D., and David B. Audretsch, "Economic Doctrines and Policy Differences: Has the Washington Policy Debate Been Asking the Wrong Questions?" The Information Technology & Innovation Foundation, September 2008.

[4] Dorfman, Jason "Agricultural Robots: Fields of Automation." The Economist 10 Dec. 2009 <http://www.economist.com/node/15048711>.

a path to commercial riches, yet experience shows that increased understanding of our universe often leads to commercially relevant innovation as well. Discovery of dark matter and dark energy might occasion types of innovation we can not yet imagine. Exploitation of nuclear energy was predicated on basic science, and the creation of a one atom transistor only arose as a consequence of effective information flow between basic and applied science. Investment in basic science, such as space science, is a key enabler of fundamental serendipitous innovation.

1.2.1 Creative Destruction

Inherent in progress is the obsolescence of old technologies and their replacement by newer ones; it is a challenge in innovation economics and in practical management to understand and optimise results of the creative destruction cycle.

Austrian-American economist Joseph Schumpeter, inspired by Marxist theory, elaborated on this central idea in the first half of the 20th century. In his book "*Capitalism, Socialism and Democracy*" he states:

> » The essential point to grasp is that in dealing with capitalism we are dealing with an evolutionary process ... the fundamental impulse that sets and keeps the capitalist engine in motion comes from the new consumers' goods, the new methods of production or transportation, the new markets, the new forms of industrial organisation that capitalist enterprise creates.[5]

Schumpeter calls this process "*creative destruction*", characterised by dynamic innovation competition between actors. The main source of economic growth and improvements in quality of life is technological advance by means of innovation.[6] Translated into theoretical economics, it implies that stationary capitalism or even capitalism with growth rates of all activities at a uniform rate is a contradiction in terms.[7] Innovation by entrepreneurs is the disruptive force that sustains, even as it destroys the value of established companies or technologies that might have enjoyed some degree of monopoly power derived from a previous technological, organisational, regulatory, and economic status.[8]

In the world of space technology development, creative destruction does not play out as rigorously as in completely commercial markets because its publicly funded structure protects incumbents more than the market does. The reason for this increased protection, particularly on the prime-contractor level, is the need for continuity, the inherently high entry barriers, and the political pressure to protect incumbents and retain existing jobs, even at the expense of creating fewer new ones with more viable features. A central challenge in managing the part of the innovation economy depending on public financial support is figuring out how to calibrate the level of creative destruction that might be allowable, keeping in mind that every time creative destruction is impeded the possible downside is less industrial efficiency. The bail-out of General Motors (GM) in the United States has been criticised exactly along these lines, yet that criticism would be more understandable if the creative destruction cycle would be self-contained within the United States where in reality the disappearance of GM would have led to destruction within the United States, but to creation in other regions of the world. Hardly something America Firsters would relish a lot, even if it might have made sense from the perspective of global economics.

1.2.2 Planned Abandonment

Peter Drucker, protagonist of the Austrian social ecology school, was influenced by Schumpeter's economic vision. Although both subscribed to the importance of change and innovation, Schumpeter was concerned with the overall dynamics characterising the economic system; Drucker considered the role of people's behaviour in spurring innovation and emphasised the discipline of "planned abandonment" within companies, organisations and governments.

Drucker explains that businesses and governments have a natural human tendency to cling to "yesterday's successes" rather than seeking to evaluate when the usefulness of those successes has faded.[9] To ensure a long-term growth perspective and continuity, economic actors should make efforts to over-

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[5] Chartrand, Harry H., eds. The Competitiveness of Nations in a Global Knowledge-Based Economy. New York: Harper Torchbooks, 1962.
[6] Diamond, Arthur M. "Schumpeter's Creative Destruction: a Review of the Evidence" Journal of Private Enterprise, 12.1 (2006): 120-146.
[7] Metcalfe, Stanley J., eds. Evolutionary Economics and Creative Destruction. New York: Routledge, 1998.
[8] Silvia, John E. ed. Dynamic Economic Decision Making, Strategies for Financial Risks, Capital Markets, and Monetary Policy. Hoboken: John Wiley & Sons Inc., 2011.
[9] Hounshell, David, ed. From the American System to Mass Production, 1800-1932: The Development of Manufacturing Technology in the United States (Studies in Industry and Society). Baltimore: The Johns Hopkins University Press, 1985.

come this kind of inertia. According to Drucker, decentralisation, simplification and concentration on the core business are ways to achieve this. Many aspects of innovative firm behaviour presented in this report are in line with this premise. Yet, although concentration on the core business is conventional wisdom in commercial management, successful conglomerates such as General Electric (GE) in the United States serve as strong counterpoints, suggesting that many core businesses under a single banner can sustain high profits. Conglomerates like GE have been successful although their company portfolios are as diverse as those held by private equity firms. The secret of success is surely the high degree of autonomy granted to the companies in the portfolio, each of which might well be focused on a core business.

In the European space industry there is a similar tendency of conglomeration, which in terms of innovation poses two questions, the first being whether each company within the portfolio is granted autonomy similar to that granted by General Electric or by private equity firms, and the second being how innovation is leveraged across the portfolio. As to the latter question, we know from the Edzard Reuter example that integration of the firms is not the solution. However, as explained later a degree of central innovation management is necessary in order to ensure that the diverse parts of the conglomerate are aware of innovation of relevance generated elsewhere in the group of firms. In economic terms, creating disparate but powerful company components within a conglomerate can be rendered efficient by making sure innovations made in one component are shared amongst all components. It appears, however, that centralised innovation leveraging functions are missing both in commercial and institutional settings, although such management would be highly facilitated by the new information technologies available.

A more fundamental issue in the top-down European space marketplace is whether customers can truly benefit from vertical integration from prime-contractor down. The automobile manufacturing industry is characterised by a huge independent parts manufacturing sector which is not limited to production for only one car manufacturer. This means that innovation spreads far more easily than in stove-piped, closed vertical integration systems. As an example, in the 1970s the lambda sensor of parts manufacturer Bosch was adopted by two different car brands. Use of the lambda sensor quickly spread to other brands, and within four years that particular type of sensor was used globally. The space industry is more highly vertically integrated, with the consequence that innovation more often stays in the stovepipe. From the perspective purely of innovation it might be wondered if a heavily innovation dependent field of activity like space would not benefit from an insistence that system integrators would be only that, and, as a consequence, that vertical integration would be discouraged.

The ‘best practices’ system of ESA seeks to ensure a degree of technology neutrality by obliging prime-contractors to put a certain percentage of subcontract work up for open competition, and by monitoring the competition process where a bidder for such subcontracted work belongs to the industrial grouping of the prime-contractor. However, even with such measures it is difficult to avoid a certain amount of drag in favour of the ‘family member’, even if he might not be the possessor of the most suitable or most innovative solution.

1.3 Avenues of Innovation

It is easy to think about innovation only in the context of the needs of a specific enterprise or a specific customer. Yet, innovation is rarely an ivory tower undertaking. Innovation can be fostered, and many local, regional, national and European programmes seek to do so – to such an extent that one of the current European buzzwords is EU as the ‘Innovation Union’. The emphasis of the current report is, however, mainly on the analysis of the flows of information between different players in the innovation process, thereby underscoring the criticality of such flows for the optimisation of innovation. It is a commonplace that legendary innovators such as Thomas Edison were more collectors and combiners of ideas, who created new marketable products by virtue exactly of ingenious combination, and that the genius of Steve Jobs was to take rather unspectacular technologies and package and market them in such a fashion that huge new markets opened up. All this points to the importance of cross-fertilisation for the sake of innovation, and explains the current popularity of functions such as technology brokers.

When considering how valuable information and knowledge can and should flow, the first task of an enterprise is to make sure internal company added value is reaped and all licensing opportunities are exploited. This is, as mentioned before, particularly critical and difficult for large companies or conglomerates. Internal technology brokering is, in fact, an underdeveloped discipline.

Moving beyond the borders of the single firm the challenge of an innovation society is to find a balance between free flowing information and the stimulus to create new technical knowledge by allowing inventive firms to benefit from their inventiveness. The patent institution is an attempt in this direction since a patent gives exploitation exclusivity against the sharing of the data on the invention. But one shoe does not fit all, and there is nowadays a very extensive tool box from which to choose, thereby giving the possibility of tailor-making information flows for the great variety of cases.

If one analyses first how different technology domains interface in terms of innovation, the first observation is that the non-space field provides far more innovation than space and far more innovation relevant for space innovation, than the other way round. This might sound provocative but is not; it is a simple reflection of the fact that non-space high-tech business is magnitudes bigger than the space business, and therefore evidently more innovation is made outside the space business than inside. Whether the same is true on a "dollar-for-dollar" basis is questionable, but the important point is that the space business must be keenly aware of the innovations and technology development outside of its own stovepipe simply because there are rich pickings to be had. Technology observatories aiming at identifying non-space innovations relevant for space are a must – although the opposite is also true, space merits technology observation by other disciplines, and it is not so clear that this really happens on a systematic basis. That ESA has a technology transfer office is laudable, but it would be equally laudable if other industries would be looking proactively at space, rather than expecting to be spoon-fed. That spoon-feeding is the order of the day is a good illustration of why the Edzard Reuter model failed.

The relationship between civil and military space innovation deserves special mention. During the Cold War era general military innovation enriched the civilian domain a lot, where now the military might have become more of a recipient. In the space domain most dual use technology, like Galileo, is coming from the civilian side, and particularly in Europe, where the civilian space budgets are much larger than the military ones, innovation is centred on civil space to such an extent that one can say that civil space could survive without military space, but military space could not survive without civil space – and never could.

2. Typology and its Meaning for Space

The introductory chapter briefly characterised the dynamic nature of innovation in society and space in particular. The goal of this report is to present a holistic analysis of different factors that influence the optimisation of innovation processes, with a special focus on the criticality of information flows, industrial management, and – to a limited extent – policy. In what follows, the different types of innovation model are categorised based on whether an innovator invites outside active participation or not, and whether innovation is commercialised as proprietary or is made openly available. Four configurations are thus possible. The open innovation concept of Chesbrough represents only one of these types; the one where information from the outside flows freely in, but the ultimate innovation is commercialised as proprietary, and hence, in the terminology of this report, moves out in a closed fashion.

The starting point for the analysis of the four different innovation models is concrete, general examples and the endpoint of the typology analysis is a first assessment of the relevance for the specificities of space.

The last part of the report hones in very specifically on the innovation situation of space and looks at practical methodologies that transcend the mere open/closed innovation perspective.

2.1 Closed In, Closed Out

2.1.1 Skunk Works

The term "skunk works" originated within Lockheed Martin's Advanced Development Programs during World War II. A dedicated Lockheed team was able to design and build the XP-80 Shooting Star jet fighter in only 143 days. The distinguishing feature of skunk works is that a group of experts, chosen within a company, is set up in order to develop some experimental technology or new application in secrecy and at speed, free from bureaucracy constraints or strict application of regulations. Skunk works are highly focused, geographically separated from other parts of the company and hierarchically and procedurally liberal. The skunk works model is designed to counteract environments that stifle innovation, mainly large organisations where there is heavy bureaucracy and rigid processes and where borders that hamper the flow of information and innovation are not only those that isolate the organisations from the "outside world" but particularly those that isolate different areas of expertise within.

It has been said that skunk works are useful when a company is confronted with very specific business issues.[10] Skunk works can have a positive impact on morale and engagement of employees, and because of their informal and less hierarchical structures, they may provide managers with an advantageous tool to keep them meaningful engaged during lean times.[11]

Many technology executives foresee an even greater recourse to skunk works and similar activities in the future due to the rapid pace of technology change and the break down of information barriers.[12] In this latter respect, it should be noted that although skunk works per definition exclude active participation in innovation from the outside, they are obviously highly extrovert in terms of seeking freely available information in the global information society. The closed aspect of the information inflow is only that such inflow is non-participatory.

The skunk works technique was recommended by the U.S. National Academy of Engineering in a report issued in 1991, which recognised the "superiority of cross-functional teams for speed".[13] Many companies decided to dedicate 'cross-functional' innovation teams to the reaching of specific goals, thus exploiting synergies among different fields of expertise.

According to Speidel and Bonner, however, this approach "is more like sticking a needle through the wall of a silo, rather than actually

[10] King, Julia. "When IT Gets to Play: Skunk Works Projects Deliver Value." Computerworld 5 Dec. 2011 <http://www.computerworld.com/s/article/359534/When_IT_Gets_to_Play?taxonomyId=14&pageNumber=1>.
[11] Ibid.
[12] Ibid.
[13] U.S. National Academy of Engineering, ed. People and Technology in the Workplace. Washington D.C.: National Academy Press, 1991.

making it sustainably permeable".[14] They argue that the mission-oriented feature of a skunk works team may hamper the emergence of topics based on observation and interactions among the members of the team. Furthermore, the closed environment does not make contributions from external sources possible, nor does it help finding solutions that may come from unexpected sources.

2.1.2 "Technology Petting Zoo" at NASA's Jet Propulsion Laboratory

The 'Technology Petting Zoo' is the NASA Jet Propulsion Laboratory's (JPL) own version of a skunk works. It is a place where JPL engineers, and other IT users, can test new consumer technologies and imagine their potential business value. A social networking site, which everybody within JPL can join, is used to rate the results of their work. An open-door policy prevails, since the Technology Petting Zoo is an expansion of the skunk works concept in the sense that no geographical separation is sought from other parts of the company, yet it is company internal and a central location for inspiration and innovation for staff members.[15] The JPL petting zoo was one of the first organisations to work on Apple's iPhone and to understand that a diversity of applications is the key of the new product's success.

Many of JPL's mechanical engineers have become experts in IT as a result of their enthusiasm for the petting zoo.[16] They have developed, for example, a 3D model of NASA's Mars Curiosity Rover, which users can control with a 3D mouse.

2.1.3 The Concept of "Successful Failure"

At the 2008 Wharton Aerospace Conference, Frank J. Cappuccio said that the historic productivity of Lockheed Martin's skunk works was fuelled by people unafraid to take risks and a "can-do" culture that generates ideas quickly.[17] A key element in skunk works is to embrace the concept of "successful failure"[18]. This goes hand-in-hand with the informality and an interdisciplinary approach that there must be a high tolerance of failure when creativity is demanded and the limits of the possible explored. Selecting the right people for a skunk works is critical for success. A high degree of security in the job must be provided in order to stimulate border crossing thinking, but in order to avoid abuse of the security people must be highly and intrinsically self-motivated.

Many companies regard the focused nature of skunk works and the associated risk tolerance as the best way to attract young talented engineers who have little patience for bureaucratic red tape and slow decision making.

2.1.4 Google X

The existence of the Google X Laboratory was revealed in November 2011 in The New York Times.[19] According to the article, Google is tackling a list of 100 challenges from two different top secret sites.

The premise of entirely closed innovation, as presented in the theoretical framework in chapter one, implies that innovation projects are developed using only internal resources and competencies, and can only exit the process by commercialisation via the firm's own distribution channels.[20] In this sense, the Google X lab seems to be a renewed exemplification of the closed innovation paradigm. There are, however, several contextual factors that challenge the classification of this project.

First, the scope and type of innovation research at the Google X lab is peculiar, bordering on the fanciful. The topic list, as far as it is public, mentions concepts such as the space elevator, advanced robotics, artificial intelligence applications and integrated online-connected house automation devices.[21] Despite the limited amount of information available, two trends can be distin-

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[14] Speidel, Klaus-Peter and Michael R.J. Bonner refer to the concept of 'knowledge silos'; someone who gathers all the know-how of a position or department and does not like to share it with other colleagues, whether because of a lack of trust or a way to build security and value within an organisation. This concept was described in Blanchard, Ken, and Gerry Ridge, eds. Helping People Win at Work: A Business Philosophy Called "Don't Mark My Paper, Help Me Get an A". Upper Saddle River: FT Press, 2009.
[15] King, Julia. "When IT Gets to Play: Skunk Works Projects Deliver Value." Computerworld 5 Dec. 2011 <http://www.computerworld.com/s/article/359534/When_IT_Gets_to_Play?taxonomyId=14&pageNumber=1>.
[16] Ibid.
[17] The Wharton School, ed. Innovation in Aerospace and Defense: From 'Skunk Works' to Convoy Trainers, Innovative Minds Tend to Think Alike. Philadelphia: U.S. University of Pennsylvania, 2008.
[18] Ibid.
[19] Cain Miller, Clair and Nick Bilton "Google's Lab of Wildest Dreams" 13 Nov. 2011 The New York Times 26 Jan. 2012 <http://www.nytimes.com/2011/11/14/technology/at-google-x-a-top-secret-lab-dreaming-up-the-future.html?pagewanted=1&_r=1>.
[20] Herzog, Philipp, ed. Open and Closed Innovation, Different Cultures for Different Strategies. Wiesbaden: Gabler, 2011.
[21] Cain Miller, Clair and Nick Bilton "Google's Lab of Wildest Dreams" 13 Nov. 2011 The New York Times 26 Jan. 2012 <http://www.nytimes.com/2011/11/14/technology/at-google-x-a-top-secret-lab-dreaming-up-the-future.html?pagewanted=1&_r=1>.

guished: (1) most projects are in their early conceptual design phase, (2) the research is focusing on ground-breaking and potentially disruptive innovation. In other words, the research performed at Google X lab is not directly concerned with the core competences of Google as an overall company wanting to make profit in the shorter term. Rather, it can be regarded as a result of a technological diversification strategy to increase long term viability and sustainability.

Support for such an approach is strong. Research points out that technologically diversified firms may invest more in R&D because the diversification in their research portfolio tends to reduce the risk inherent to R&D projects. In other words, the company can risk more experimental research because their successful, established products will provide enough financial support to reduce overall risk. Especially for large companies, such an approach can reduce the variance associated with the returns of these investments and prevent a negative lock-in effect in one particular technology, thus sustaining the evolution and business renovation of the firm.[22] In the NYT article revealing the Google X lab, Google spokeswoman, Jill Hazelbaker, declined to comment on the lab, but said that investing in speculative projects was “an important part of Google’s DNA”. She added: “While the possibilities are incredibly exciting, please do keep in mind that the sums involved are very small by comparison to the investments we make in our core businesses”.[23]

In this case the “closed in, closed out” form of innovation is part of a wider innovation strategy in which different forms can co-exist. Large companies with higher budget margins can more easily set up a distinct innovation project with only a relative small proportion of their budget. Potential advantages of this investment are paramount: (1) over time, it could change or widen the scope of the company’s core competences, hence facilitating reorientation within the market or ecosystem, (2) lead to cross-fertilisation between different technologies, (3) spur gains from unrelated technologies and, (4) can result in unexpected inventions of strategic or commercial use (i.e. serendipity). Either way, it creates a vast competitive advantage for the firm or organisation involved.[24]

Some of the Google X projects listed, like the space elevator concept, are directly relevant for space sector. Others, when developed successfully, can lead to spin-ins into space industry, like the research on advanced robotics and artificial intelligence. As Google holds the Intellectual Property Rights (IPR), it is up to the company to determine a commercial strategy on the distribution and selling of these technologies to other actors in the market and space ecosystem.

2.1.5 Industrial Partnering

In recent decades there has been unprecedented growth in industrial partnering and reliance on various forms of external collaboration.[25] Historically, firms organised research and development (R&D) internally and relied on outside contract research only for relatively simple functions or products. Today, companies in a wide range of industries are executing nearly every step in the production process, from discovery to distribution, through some form of external collaboration. By relying on ‘outside’ expertise, a company breaks an element of the closed in/closed out paradigm, yet innovation in an industrial partnering situation is still entirely closed since the innovation process is closed to all but the partners, and the ultimate commercialisation is done only through the partners, relying on proprietary means.

The reasons why inter-organisational collaboration can contribute to a company’s innovation strategy are numerous:

- Access to new markets and technologies: Inter-organisational collaboration might imply access to complementary assets needed to turn innovation projects into a commercial success.[26]
- Pooling complementary skills: Working together with other organisations might encourage the transfer of codified and

[22] Garcia-Vega, Maria. “Does Technological Diversification Promote Innovation? An Empirical Analysis for European Firms” 13 Feb. 2012 <http://dspace.cigilibrary.org/jspui/bitstream/123456789/18590/1/Does%20Technological%20Diversification%20Promote%20Innovation%20An%20Empirical%20Analysis%20for%20European%20Firms.pdf?1>.

[23] Cain Miller, Clair and Nick Bilton “Google’s Lab of Wildest Dreams” 13 Nov. 2011 The New York Times 26 Jan. 2012 <http://www.nytimes.com/2011/11/14/technology/at-google-x-a-top-secret-lab-dreaming-up-the-future.html?pagewanted=1&_r=1>.

[24] Garcia-Vega, Maria. “Does Technological Diversification Promote Innovation? An Empirical Analysis for European Firms” 13 Feb. 2012 <http://dspace.cigilibrary.org/jspui/bitstream/123456789/18590/1/Does%20Technological%20Diversification%20Promote%20Innovation%20An%20Empirical%20Analysis%20for%20European%20Firms.pdf?1>.

[25] Hagedoorn, John. “Inter-Firm Partnerships and Co-Operative Strategies in Core Technologies.” New Explorations in the Economics of Technical Change. Eds. Chris Freeman, and Luc Soete. London: Pinter Publishers, 1990. 3-37.

[26] Teece, David J. “Profiting From Technological Innovation: Implications for Integration, Collaboration, Licensing and Public Policy.” Research Policy 15 (1986): 785-805.

tacit knowledge.[27] This might result in the creation and development of resources that would otherwise be difficult to mobilise and to develop.

- Cost sharing: Inter-organisational collaboration might help to spread the costs of research and development among different parties.
- Risk sharing: Reducing the inherent uncertainties associated with novel products or markets. Collaboration results in a considerable reduction of the risks associated with R&D-intensive innovation projects, such as costs, time to market, and threat from market forces.[28]
- Enhancing organisational learning: Learning occurs within the context of membership in a community and different kinds of organisations and organisational practices may be required to access that community.[29]

Obviously, reliance on external partners involves hazards.[30] A lack of trust between the parties, difficulties in relinquishing control, the complexity of a joint project, and different skill-learning capabilities are all barriers to effective collaboration. In firms with a variety of collaboration agreements in different domains there can be confusion about who is a strategic ally and who is not. Partnering decisions should thus depend on each partner's size and position in the value-chain, the level of technological sophistication, resource constraints, and prior experiences with alliances.

There is a degree of tension between explorative and exploitative collaborations. The intent behind an exploration alliance is a desire to discover new opportunities, whereas an exploitation alliance involves the joint maximisation of complementary assets and possibly a more limited need of innovation. Explorative and exploitative collaborations have different effects on a firm's innovation strategies. In exploitative collaborations, the main purpose relates to the enhancement of existing organisational competencies and best use of existing skills. These collaborations focus on complementarities between technologies and products already present.

[27] Kogut, Bruce. "The Stability of Joint Ventures." Journal of Industrial Economics 38 (1989): 1-16.
[28] Porter, Michael, ed. Competitive Strategy. New York: Free Press, 1980.
[29] Hamel, Gary. "Competition for Competence and Inter-Partner Learning within International Strategic Alliances." Strategic Management Journal 12 (1991): 83-103.
[30] Powell, Walter W. "Neither Market nor Hierarchy: Network Forms of Organization." Research in Organizational Behavior 12 (1990): 295-336.

Explorative collaboration is instrumental in creating new competencies; learning processes and joint experimentation figure prominently in this type of collaboration.[31] To achieve the learning objectives, partners rely more on personal and informal modes of coordination and control.[32,33] Structures in which job responsibilities are less explicit and flexible working procedures have been introduced seem to suit innovation projects that focus on novelty rather than efficiency.[34,35]

The observation that inter-organisational collaboration has considerable potential to contribute to the innovation strategies of organisations does not mean that all collaborations are successful. On the contrary, estimates suggest that as many as 60 percent of all alliances fail.[36] Unintended knowledge spill-overs[37], learning races between the partners[38], diverging opinions on intended benefits[39], and lack of flexibility and adaptability[40] are frequently cited reasons for alliance failure.

2.1.6 And Space?

The closed nature of skunk works and their typical geographical separation make them particularly suitable for space security and defence initiatives. For organisations or industrial entities with a considerable civil portfolio there is a challenge to convince militarily dominated customers that sensitive information can remain confidential. A skunk works dedicated to security related work is one way to gain credibility in this respect. Clearly the downside is that cross-cutting access to information within the organisation becomes

[31] Koza, Mitchell P., and Arie Y: Lewin. "The Co-Evolution of Strategic Alliances." Organization Science 9.3 (1998): 255–264.
[32] Ibid.
[33] Ring, Peter S. and Andrew H. Van de Ven "Developmental Processes of Cooperative Interorganizational Relationships." Academy of Management Review 19.1 (1994): 90–118.
[34] O'Reilly, Charles A. III, and Michael L. Tushman. "The Ambidextrous Organization." Harvard Business Review 82.4 (2004):74–82.
[35] Christensen, Clayton M., and Michael Overdorf. "Meeting the Challenge of Disruptive Change." Harvard Business Review 78.2 (2000): 66–76.
[36] Bleeke, Joel, and David Ernst, eds. Collaborating to Compete: Using Strategic Alliances and Acquisitions in the Global Marketplace. New York: John Wiley, 1993.
[37] Teece, David J., ed. Managing Intellectual Capital. Oxford: Oxford University Press, 2002.
[38] Hamel, Gary. "Competition for Competence and Inter-Partner Learning within International Strategic Alliances." Strategic Management Journal 12.4 (1991): 83–103.
[39] Lorange, Peter, and Johan Roos, eds. Strategic Alliances: Formation, Implementation, and Evolution. Oxford: Blackwell, 1992.
[40] Doz, Yves L. "The Evolution of Cooperation in Strategic Alliances: Initial Conditions or Learning Processes?" Strategic Management Journal 17.7 (1996): 55–83.

very difficult if it has to be gained through interaction with non-skunk works staff. As a result, skunk works will inevitably lead to a higher degree of competence duplication within the organisation, and hence to higher cost. Still, such parallel innovation universes create innovation opportunities, particularly if innovations from the security domain can be safely introduced into the civilian domain. Parallel innovation chains can be very fruitful if they to some extent 'compete', and if a consolidation of the competition will be possible for the end products, sub-systems or individual technologies. Such consolidation processes require considerable management attention in order to avoid loss of security work credibility, and might therefore often not be done – to the detriment of overall societal innovation. The results of the civilian innovation process might be accessed within the skunk works environment, but the opposite will hardly take place as a matter of course.

The Google X approach is, to some extent, driven by the same considerations of secrecy as normal skunk works and a desire for the same 'innovation hothouse' atmosphere. In contrast to skunk works, the innovation topics pursued in Google X are decidedly peripheral to Google's mainstream business. Since many of lab employees involved work only part time, including the founders of Google, there might be also a creativity boost because time is reserved for being creative in fields entirely different from those where the innovators are normally involved. Industrial diversification might be discouraged in conventional management theory, but innovation diversity would seem to have a lot of merit, simply because the involvement in entirely different innovation projects strengthens the collaborative perspectives that are often fundamental for disruptive innovation.

In space, staff members are often extremely specialised and the scarcity of good system engineers is frequently lamented. System engineers are not per se innovators but they bring a broader technical view than specialists, and this broader view is required for effective innovation. Open innovation stratagems might be part of the answer in terms of making the space sector more innovative, but not necessarily the only one. Google X or Technology Petting Zoo-esque approaches might be another, and there are good arguments for having non-space innovation localities embedded in space technology campuses and to invite aerospace technology specialists to work on non-space projects on a part time or limited basis. This is obviously an investment, but often a better one in terms of continuing education than the best suite of courses. That is true even if most of the non-space innovation projects will fail. Keeping technical expertise sharp even with the specialists is a management challenge, and one might suspect that the Google founders spend part of their time with Google X to avoid the complacency of multi-billionaires.

Ten years ago ESA started experimenting with one-off skunk-works concepts through the StarTiger programme, which stands for "Space Technology Advancements by Resourceful, Targeted and Innovative Groups of Experts and Researchers".[41] StarTiger was a new type of research and development initiative in ESA's innovation portfolio aimed at dramatically reducing the turn-around time for key technological developments.[42] Since its inception, the programme has been proven successful in two pilot projects. In 2002, StarTiger developed a terahertz imager useful for both astronomical research and environmental monitoring. Since then, the technology was adapted and used in airport security scanning. The second StarTiger project was completed in 2010 and produced a prototype 'external coronagraph'; a double-satellite system able to block out sun continuously in an artificial eclipse to allow uninterrupted observation of the corona.[43] So far the programme has been successful; demonstrating that ESA too can bring about major progress in a chosen area of technology in a skunk works-style environment. In parallel, the programme was determining the basic ground rules on how such schemes will be prepared, undertaken and judged in the future. Thus StarTiger also wanted to determine the pitfalls associated with its particular approach, in order to identify and address these challenges for future programmes. Considering these positive first experiences, it would appear relevant to continue and broaden this initiative in the future.

Industrial partnering is a traditional method of cooperation in the space business. This is true for individual projects –where top-down prime-, subcontractor relationships are created– and for industrial groupings clustered around the two largest system integrators, Astrium and Thales Alenia Space, as well for the smaller cluster around newcomer, OHB

[41] "StarTiger secures way to eclipse Sun in space" 27 Apr. 2012. European Space Agency 27 Feb. 2012 <http://www.esa.int/esaCP/SEMYGYF098G_index_0.html>.

[42] "About StarTiger" 9 Mar. 2009. European Space Agency 28 Feb. 2012 <http://www.esa.int/esaMI/Technology/1166701003697_0.html>.

[43] "StarTiger secures way to eclipse Sun in space" 27 Apr. 2012. European Space Agency 27 Feb. 2012 <http://www.esa.int/esaCP/SEMYGYF098G_index_0.html>.

System. Industrial partnering within the prime/subcontractor structure tends to be innovation inefficient. The strict contractual control in the flow-down of requirements, with the inevitable segmentation between the different players might invite innovation within each industrial partner, but it does not encourage joint innovation work, as evidenced by the weak or non-existent contractual framework for joint exploitation of possible joint inventions. Prime-contractors impose mechanisms for a degree of joint management in projects, but rarely –if ever– mechanisms for joint innovation. Consequently all possible innovation benefits of having assembled a highly qualified team for common purpose are wasted. None of the cross-fertilisation benefits described above is reaped, except perhaps at the integration stages, where novel ways of putting different types of equipment together might yield a degree of innovation.

Cross-fertilisation averseness between sub- and prime-contractors can be attributed to the difficulty of controlling pre-existing proprietary information necessary for the innovation processes and the lack of framework for effective joint invention and joint exploitation. Yet it is to some extent absurd that this averseness is true even between different companies within the same industrial grouping working together on a specific project. The customer can play a decisive role in forcing interactive innovation within the prime/subcontractor team, since the customer could insist that within specifically critical or interesting technology domains of the project joint ventures must be formed rather than allowing segmented and fragmented approaches with several companies working on distinct parts of the ultimate solution which will only be put together by a contractor higher up in the contractual chain. The customer can insist (1) on the higher level contractors setting up Technology Petting Zoos to the benefit of all, (2) that the prime-contractor should share substantive technical information, not rely solely on interface documentation, (3) on an adaptive contractual framework that accommodates unexpected innovation across corporate boundaries. In a sense the customer can insist on the setting up of a virtual skunk works involving all players in the consortium, with a pre-defined sharing of the benefits of the eventual innovations, and adequate confidentiality clauses limiting the propagation of the information beyond the partners and the purpose of the project. Low level contractors, however, tend to suspect prime contractors will appropriate pre-existing technical information necessary for innovation despite contractual agreements to the contrary. This might mean that extensive sharing of technical information can only be instituted at the same level of the contractual chain and between partners who are genuinely relevant for innovation, and that therefore the higher level contractors will have asymmetrical information potentially making their management of the lower level contractors more difficult, as these might also join together in informal alliances aiming at resisting the involvement of the higher level contractor. However, a high degree of information asymmetry exists already now between higher and lower level contractors and the only thing different when creating communality of interest at a given level of the contractual chain is that the asymmetry between same level contractors, currently assured by the exchange of interface information only, is lifted.

It is true to say that when efforts are made to increase the permeability of corporate boundaries in the interest of innovation, like above, than it increases the inducement for industrial grouping to rely only on expertise from within their industrial group, and this might ultimately counteract technical excellence and local innovation dependent on independent SMEs. This can be counteracted to some extent with measures such as ESA's 'Best Practices', but even if one does not want to go the full way towards free information flow within a project consortium then it is worth for the customer to consider which parts of the project he will not allow to be segmented into separate packages of work without ensuring that mechanisms are in place to ensure free flow of information for this part of the project even if several non-related companies are involved in the execution.

Systems engineers might argue that already specifications put boundaries on what can be separated in execution and although the engineers may be correct, that sort of inseparability is driven by management concerns not by innovation concerns, and innovation concerns might call for much larger packages to be treated together, and might dictate that elements of very different disciplines are connected through innovation mechanisms. The Altitude and Orbital Control Systems (AOCS) element might be seen as imposing requirements on the power sub-system, but they are normally seen as separable packages of work. From an innovation perspective this might not be so. Value chains are human constructs and innovation patterns might not fit, something which is increasingly realised in other industries, including in car manufacturing with its enormous R&D budget, and hence cross-boundary arrangements are often pursued.[44]

2.2 Closed In, Open Out

Many university or government-owned research institutes have a fairly inward looking culture combined with a strong drive to disseminate research results as openly and widely as possible. Proprietary means of protecting innovation are increasingly used in order to secure research funding streams yet the research institute culture is one of 'publish or perish'; is inherently one wanting to spread the word about research results and innovation. Furthermore a dependence on public funding often entails an obligation to make results freely or liberally available.

Historically, the most prominent institute eschewing commercial pressures of any sort has been the Institute of Advanced Study (IAS), located close to Princeton University. The very top of the scientific community has been accommodated there, including Albert Einstein and Robert Oppenheimer, yet assessments of the IAS have been mixed at best. The IAS offers ideal surroundings for top-tier research – beautiful location, a mass of highly intelligent people, a socially secure environment – a sort of modern version of Plato's Academy. Nonetheless, unlike Plato's Academy which was an astounding producer of ideas, the IAS is often seen as too comfortable to stimulate ground-breaking research and innovation.[45] Highly innovative people entering do not stop being innovative, but might be less so, despite the highly stimulating environment.

Other research institutes retain stellar reputations despite possibly inward looking cultures, one reason possibly being that a person does not enter as a superstar, but might end up being one. However, an environment in which a person has grown professionally and personally has often a sustaining growth effect; innovation-conducive rituals and attitudes develop. And an environment where achievement is required to succeed might stimulate even the ones that already did so.

2.2.1 And Space?

ESA's Networking/Partnering Initiative (NPI), established in 2006, offers support to research carried out by institutes and universities in advanced technologies with space applications. The NPI aims to enhance research relevant to space applications and to take advantage of potential spin-ins for space from technologies originally developed for areas like consumer electronics, material sciences, and developments in nano- and micro-technologies.[46] According to ESA, this leverage of technology is necessary to bridge the gap between technologies used for space applications and the ones used in industrial or domestic applications. In recent years, the discrepancy in technology level between both sectors has widened because space environment requirements can impose constraints that prevent direct re-use of a number of common technologies in society. These constraints can often be overcome, providing there is a strong cooperation between space agencies, research institutes, universities and industry.[47] In this process, ESA gives preference to NPIs that originate from outside the space sector. Proposals can be submitted by doctoral or post-doctoral staff from universities or research organisations of ESA Member-States. Once accepted by the NPI, a proposal will be offered support as follows:[48]

- Co-funding – The NPI can co-fund research up to 50% or €30,000 per year for a doctorate degree or post-doctoral investigations.
- Access to ESTEC laboratories: NPI participants are able to use ESTEC facilities for a minimum of six and a maximum of 12 months.
- Technical support – NPI participants gain access to ESA experts with whom they can discuss proposal concepts and verify their potential for space applications.
- Networking – NPI participants will be able to search for industrial partners for further cooperation and build 'innovation networks' through ESA links.

When a proposal is selected after the application process, ESA enters into a contractual arrangement with the university or research institute concerned. All the while the researcher will remain employed or inscribed at his or her own institute or university.

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[44] Wyman, Oliver. "Car Innovation 2015." 17 Jan. 2012 <http://www.car-innovation.com/study-content.html>.

[45] Trenner, Richard "The Ultimate Ivory Tower" 21 Feb. 1999 The New York Times 25 May 2012 <http://www.nytimes.com/1999/02/21/nyregion/the-ultimate-ivory-tower.html?pagewanted=all&src=pm>.

[46] "Networking/Partnering Initiative" 16 Feb. 2010. European Space Agency 24 Feb. 2012 <http://www.esa.int/esaMI/Technology/SEM4KVWPXPF_0.html>.

[47] "ESA launches new initiative to foster research" 6 Dec. 2006. European Space Agency 24 Feb. 2012 <http://www.esa.int/esaCP/SEM8889L6VE_index_0.html>.

[48] "Networking/Partnering Initiative" 16 Feb. 2010. European Space Agency 24 Feb. 2012 <http://www.esa.int/esaMI/Technology/SEM4KVWPXPF_0.html>.

Although the NPI initiative is a good way to stimulate cooperation and understanding between research institutes, universities and the space sector, the need for more extensive engagements remains. National space technology institutes in several European countries attract significant funding, but neither the European Union nor ESA has set up an institute entirely dedicated to space technology innovation. ESA is highly involved in space technology involvement, of course, and funds many activities in this domain, but the actual work is in industry, university or governmental institutes in member states – reflecting ESA's traditional role as enabler of industry and national research facilities. This is true even for the activities of ESA's Advanced Concepts Team.

Assuming that innovation is very much about leveraging diversity in order to enhance serendipitous discovery, there are strong arguments in favour of establishing some form of a "European Space Technology Innovation Institute", entrusted both 'basic research' and sustaining technology innovation as in-house tasks, and drawing not only on different disciplines but also on different backgrounds and national approaches. This is, of course, in contradistinction to ESA's Technology Research Programme (TRP), which is based on a contracting approach. Such a novel institute would break the 'geographical return' logic around which ESA is built and could be seen as competition for national space technology innovation institutions. Still, few argue that the space domain is overstocked with technology research institutions; surely complementarities would tend to develop, and smaller European countries with comparatively little space technology research would have an opportunity to get involved by participating at the European level. It should be noted that this is especially relevant with the prospect of further ESA enlargement. In fact, even if a fully European institute could not be formed for the reasons mentioned, there are reasons why countries without strong national space technology research institutions might want to join forces and create an institute which would serve their joint interest in being involved in cutting edge innovation.

2.3 Open In, Closed Out

2.3.1 Knowledge Brokers

Innovation-seeking companies have started using brokers who play the role of a matchmaker between a "seeker" of solutions to specific, well defined scientific problem and the so-called "solvers" of these problems. Seekers are commonly R&D intensive corporations, and the solvers are individual scientists, engineers or small research laboratories around the world. The solvers are often 'micro-specialists' with knowledge and skills that allow them to solve seeker problems independently. Working with knowledge brokers is often seen as an appealing option for solvers, who are drawn by lucrative payment, scientific challenge, and the opportunity to enhance their professional reputation and value. The first business concept that appeared was the technology broker, followed by knowledge brokers and virtual knowledge brokers. The concept of a technology broker was first introduced by Hargadon and Sutton[49], designers at IDEO; the largest product design consulting firm in the U.S. They showed how the innovation outcome of a company could benefit from inter-industrial and inter-organisational technology exposure.[50]

Recently, technology brokers have been associated with the more general concept of knowledge brokering.[51] Moving beyond design consulting firms (such as IDEO) and invention labs (such as Edison's Menlo Park Laboratory) to strategic consulting firms (such as McKinsey & Co.) and knowledge management practices of highly innovative multinational organisations (such as Boeing and Hewlett Packard), the concept of technology brokering can be extended to other forms of organisational knowledge. In this broader view, knowledge brokers may be defined as 'intermediaries … between otherwise disconnected pools of ideas. They use their in-between vantage points to spot old ideas that can be used in new places, new ways and new combinations'.[52] Knowledge brokerage enhances the dynamic capabilities of the firm in markets characterised by rapid and abrupt technological change.[53] In these dynamic market contexts, knowledge creation, integration, and reconfiguration become vital to sustaining competitive advantage.[54] Knowledge brokers support innovation by

[49] Hargadon, Andrew, and Robert Sutton "Technology Brokering and Innovation in a Product Development Firm." Administrative Science Quarterly 42.4 (1997): 716–749.
[50] Verona, Gianmario, Emanuela Prandelli, and Mohanbir Sawhney. "Innovation and Virtual Environments: Towards Virtual Knowledge Brokers." Organization Studies 27 (2006): 765.
[51] Hargadon, Andrew, and Robert Sutton. "Building an Innovation Factory." Harvard Business Review 78.3 (2000): 157–166.
[52] Ibid.
[53] Eisenhardt, Kathleen M., and Jeff A. Martin. "Dynamic Capabilities: What are They?" Strategic Management Journal 21.10–11 (2000): 1105–1121.
[54] Teece, David J., Gary Pisano, and Ami Shuen. "Dynamic Capabilities and Strategic Management." Strategic Management Journal 18.7 (1997): 509–533.

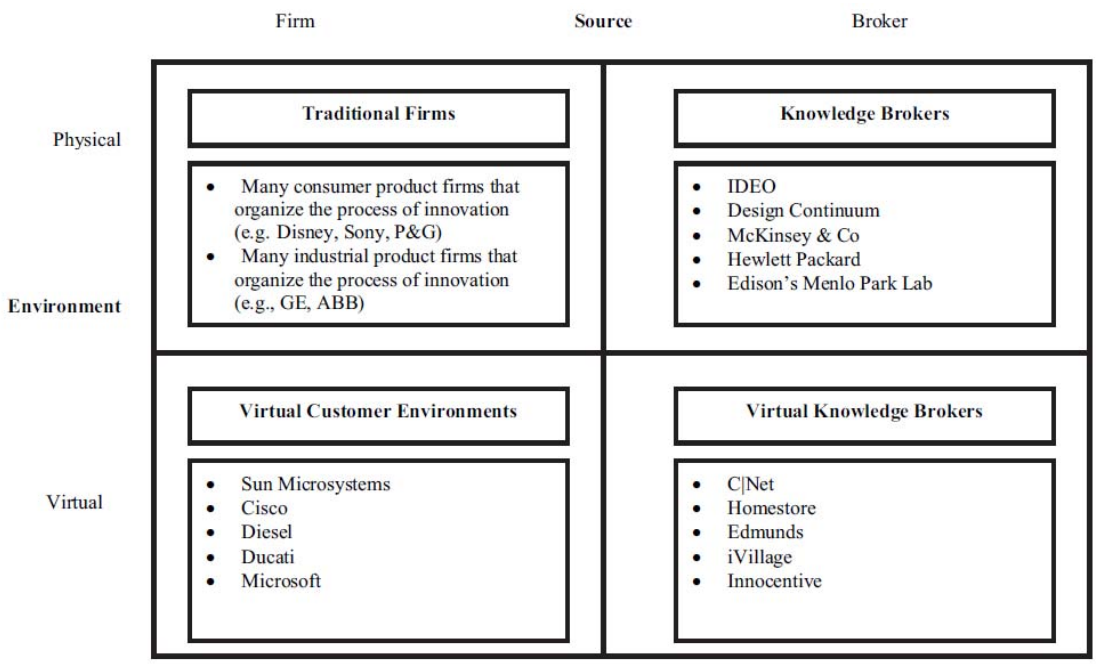

Figure 1: Examples of Operators that Exploit Different Mechanisms in the Management of Innovation.[55]

connecting, recombining, and transferring to new contexts already existing ideas. [56]

Going beyond their traditional role as intermediaries who work on behalf of customers to facilitate transactions[57,58], some infomediaries have evolved into virtual business brokers by working on behalf of firms to facilitate customer knowledge import to support innovation. Community operator Liquid Generation is a good example. Liquid Generation provides information to firms interested in marketing to the so-called "Generation Y", a population segment with growing economic importance. When the company was founded in August 2000, the original plan was to operate a portal and generate revenue through advertising and merchandise. Soon the firm realised the real business opportunity was selling marketing information on the fickle needs and preferences of this hard-to-reach population.[59]

Hargadon and Sutton identified four tasks performed by brokers to support clients in managing innovations: (1) capture good ideas; (2) keep ideas alive; (3) imagine new uses for old ideas; (4) put promising concepts to the test.[60] Sawyney et al. analysed the role of brokers with regards to innovation support. They call the actors that engage in mediating innovation "innomediaries" and identified three different modes in which brokers can engage in building a community. The first model is the customer network operator, where the core function assumed by the customer network operators is to create a network of customers and provide access to a specific segment of the customer base. The second is the customer community operator, where these innomediaries build and operate online communities for specific interests, lifestyles, or around specific products. The third is the innovation marketplace operator, where these brokers operate a market place where more than a single company engages in sourcing information.[61]

2.3.2 InnoCentive

InnoCentive Inc. is an American enterprise that has helped commercial, government and

[55] Verona, Gianmario, Emanuela Prandelli, and Mohanbir Sawhney. "Innovation and Virtual Environments: Towards Virtual Knowledge Brokers." Organization Studies 27 (2006): 765.
[56] Verona, Gianmario, Emanuela Prandelli, and Mohanbir Sawhney. "Innovation and Virtual Environments: Towards Virtual Knowledge Brokers" Organization Studies 27 (2006): 765.
[57] Hagel, John III, and Mark Singer, eds. Net Worth: Shaping Markets When Customers Make the Rules. Boston: Harvard Business School Press, 1999.
[58] Kaplan, Steven, and Mohanbir Sawhney. "E-Hubs: the New B2B Marketplaces." Harvard Business Review 78.3 (2000): 97–105.
[59] Verona, Gianmario, Emanuela Prandelli, and Mohanbir Sawhney. "Innovation and Virtual Environments: Towards Virtual Knowledge Brokers" Organization Studies 27 (2006): 765.
[60] Hargadon, Andrew, and Robert Sutton. "Building an Innovation Factory." Harvard Business Review 78.3 (2000): 157–166.
[61] Sawhney, Mohanbir, Emanuela Prandelli, and Gianmario Verona. "The Power of Innomediation." MIT Sloan Management Review 44 (2003): 77 – 82.

non-profit organisations to better innovate through open innovation and crowdsourcing, strategic consulting services, and Software-as-a-Service (SaaS) solutions.[62] The company describes itself as an open innovation and crowdsourcing pioneer that enables organisations to solve problems by connecting clients to diverse sources of innovation, including employees, customers, partners, and the world's largest problem solving marketplace: their platform website.[63] The main idea is that by a posting on the InnoCentive website, a corporation's innovation challenge can be addressed by actors beyond the institution's boundaries. Anyone can access the site and work on a challenge and the corporation compensates whoever solves it best.

InnoCentive makes use of a Challenge Driven Innovation (CDI) methodology, a cloud-based technology platform with millions of potential users.[64] Challenge Driven Innovation is an overall innovation framework that accelerates traditional innovation outcomes by leveraging open innovation and crowdsourcing along with defined methodology, process, and tools to help organisations develop and implement actionable solutions to their key problems, opportunities, and challenges.[65] The platform advertises challenges from a wide range of fields, including chemistry, life sciences, physical sciences, engineering & design, business and entrepreneurship.[66]

As of 2012, the total number of registered solvers has risen to more than 250,000 from almost all countries in the world.[67] The company has extensive relations with scientific organisations and involves scientists from each discipline it deals with on a regular basis. This diverse group of people finds ways to describe problems in a manner that is general enough to attract a broad audience, but yet is specific enough that it provides enough information to actually get a solution.[68] In contrast to many other online platforms, InnoCentive can be characterised as a "solver" community rather than a user community. This labelling is positive in terms of network stability, since the relationship between the company and the solver shows more signs of reciprocity compared to most user communities.

Acting as a knowledge broker, InnoCentive aspires to fundamentally transform the economics of innovation and R&D through rapid solution delivery and the development of sustainable open innovation programmes.[69] InnoCentive's model drastically reduces innovation costs. In a traditional R&D environment, organisations have to hire expensive qualified personnel regardless of whether they are able to solve every problem they encounter and they have to be paid for success as well as failure. In the new CDI model, millions of potential solvers are available to work on specific challenges and only one out of all of those solvers is actually compensated[70].

When a solver submits a solution to InnoCentive it is done under an agreement posted on the website that they must accept before they are able to see the final details of the challenge. This provides a solid legal basis for eventual exploitation. The agreement contains the following conditions: (1) InnoCentive ensures that solutions sent to them by solvers will remain confidential; (2) solvers communication with InnoCentive – usually about proposed approaches to a solution – also remain confidential; (3) when solvers submit solutions they give a 90-day option to a seeker company to choose their solution. When a solution is chosen the benefitting company gets hold of the IPR related to the invention, as the inventor sells his IPR in exchange for the sum rewarded to the best innovator.[71]

2.3.3 And Space?

NASA is the only space agency that has used InnoCentive as a tool for accelerating innovation. Analysing evaluation reports that detail outcomes from testing the Pilot Program[72] can help gain a better understanding of the

[62] "InnoCentive Investigation of the Challenge Driven Innovation Platform at NASA: An Evaluation of the Open Innovation Pilot Program between NASA and InnoCentive." 2 Feb. 2012. Innocentive <http://www.nasa.gov/pdf/572344main_InnoCentive_NASA_PublicReport_2011-0422.pdf>.
[63] "About Innocentive" Innocentive 2 Feb. 2012 <https://www.innocentive.com/about-innocentive>.
[64] Ibid.
[65] Ibid.
[66] "InnoCentive Challenges" InnoCentive 1 Feb. 2012 <https://www.innocentive.com/ar/challenge/browse>.
[67] "Fact-Stats" Innocentive 2 Feb. 2012 <http://www.innocentive.com/about-innocentive/facts-stats>.
[68] Allio, Robert J. "CEO interview: the InnoCentive model of open innovation" Strategy & Leadership 32.4 (2004): 4–9.
[69] "InnoCentive Challenge Platform" InnoCentive 1 Feb. 2012 <http://www.innocentive.com/innovation-solutions/innocentivework>.
[70] "Challenge Driven Innovation" InnoCentive 1 Feb. 2012 <https://www.innocentive.com/seekers/challenge-driven-innovation>.
[71] Darren, J. Carroll. "Distributed R&D Case Study: InnoCentive" Presentation. Managing Innovation: Emerging Trends. Massachusetts Institute of Technology, Massachusetts, U.S., 3 Mar. 2005.
[72] "NASA Innovation Pavilion" InnoCentive 31 Jan. 2012 <https://www.innocentive.com/ar/challenge/browse?pavilionName=NASA&pavilionId=8&source=pavilion>.

agency's experience.[73] The 13-month pilot programme was conducted between September 2009 and September 2010. The main cooperation took place between the NASA Johnson Space Centre and InnoCentive; however the reach of the programme expanded to include a challenge from the Langley Research Centre and collaboration on two challenges with the Glenn Research Centre. More specifically, the pilot programme was used to investigate the utility and value for NASA of InnoCentive's approach and platform. As part of the post pilot programme evaluation, InnoCentive and NASA surveyed over 2,900 solvers who participated in these challenges, and conducted interviews with challenge owners, their support teams, and the winning solvers.[74]

The InnoCentive process bridges internal and external resources so that NASA and its challenge owners can act on the solutions quickly and with legal protection. Participants mentioned benefits like cost savings, more effective use of established resources, increased diversity in thinking, efficient process for IP transfer, a more innovative culture, and improved ability to frame problem statements or research needs.[75]

This collaborative, open approach to innovation positively influenced the public's opinion of NASA. Evaluation reports yielded initial evidence of positive public opinion through press releases and social media interest in stories of winning solvers. A total of 98% of the solvers reported to be interested in working on further NASA Challenges.[76]

As to the influence on the desired behavioural changes to support a culture of innovation of NASA, the evaluation report highlights the importance of creating an environment of acceptance of the solution as an initial step. Strong leadership, consistent objectives, and recognition for early adopters are mentioned as major features in this process. The second step involves scaling up open innovation methodologies in all processes, including the development of an internal challenge-based platform. According to the report these initiatives should gradually lead to a change in structure and systems of innovation.[77]

In the conclusions and recommendations of the report, it is stated that "Pilot Challenges clearly demonstrates that InnoCentive is a viable platform for finding quality solutions to research and technology gaps of NASA". The InnoCentive Marketplace showed positive results across all levels of technical development and complexity, indicating potential for broad adoption by the agency. Finally, the report mentions that InnoCentive's CDI model can be used also to commercialise or distribute unused or public domain information of NASA.[78]

The InnoCentive platform is not used by ESA, the EU or any European space industry, and no other similar platform appears to have been utilised. This should, perhaps, be changed. The utility of the InnoCentive platform needs to be mapped in terms of the activity profiles of the users, but ESA would seem to be able to use it particularly for conceptual challenges before actual projects arise and in very early phases. ESA could also insist on the platform being used by contractors both for break-through and evolutionary innovation. The EU could deploy the platform for its general innovation activities, and would reap the additional benefit of reaching out to interested citizens in a proactive fashion. Especially in light of the further deployment of the IAP Programme, the tool seems particularly relevant.

Considering the low costs and small risks, industry should ultimately embrace crowdsourcing as an integral part of its innovation paradigm since it activates an important stakeholder community, allows for new alliances with 'micro-specialists' or underutilised expertise, and will drive down cost. The use of such platforms could enhance industry involvement with conceptual or disruptive innovation and, with proper timing, sustain existing innovation activities in a variety of fields.

Since large institutions and industry sometimes face difficulties managing a portfolio with many different kinds of innovation, the use of physical innovation and knowledge brokers could also be optimised. Knowledge management systems are helpful in this respect, but the human element can not be eliminated in creating links across corporate barriers. Hence, innovation will only be leveraged effectively if a corporate function exists which not only makes information easily accessible, but searches for links between innovation in one field and new product opportunities in other fields.

Spin-in of non-space technologies to the space field is obviously an important activity in which all major space entities are involved.

[73] "InnoCentive Investigation of the Challenge Driven Innovation Platform at NASA: An Evaluation of the Open Innovation Pilot Program between NASA and InnoCentive." 2 Feb. 2012. Innocentive <http://www.nasa.gov/pdf/572344main_InnoCentive_NASA_PublicReport_2011-0422.pdf>.
[74] Ibid.
[75] Ibid.
[76] Ibid.
[77] Ibid.
[78] Ibid.

Considering that most technology development is taking place outside of the space domain, it might be questionable whether enough is invested in spin-in activities and in technology observatories, where the only success criterion is to detect non-space technologies for space use, and whether the linking to actual project activities is effective enough.

2.4 Open In, Open Out

2.4.1 Citizen Science

Citizen science involves volunteer members from the public in scientific research projects as scientific investigators, data collectors or analysts to solve real-world problems. Active engagement in scientific work differentiates citizen science from other forms of public participation in scientific research where volunteers take less active roles such as providing computing resources for projects or participating as a subject in a research study. Citizen science is related to long-standing programmes employing volunteer monitoring for natural resource management[79], and is often employed as a form of informal science education or outreach to promote public understanding of science[80]. Citizen science has been practiced since the 18th century and since then the term has often been used when some aspect of the data collection or analysis is beyond the capacity of the core science team but is doable by a distributed network of volunteers. Citizen science is a long-time component in weather data collection projects, bird and other animal censuses.

Recently citizen science has come to use a web-enabled model of operations as an involvement hub. Data storage and web-technology make it easier for volunteers to get access to data and social technologies like forums and blogs. These technologies are allowing communities to form around a shared interest in scientific research outside of the formal and geographical constraints of a university, institute or private entity. The forms of participation usually involve contributing data according to an established protocol, or completing structured recognitions, classification or problem-solving tasks that depend on human competences.[81] Citizen science has a number of benefits for the various communities. For the scientific researchers it allows them to complete projects which would be otherwise impossible to complete. For volunteers it provides them with a satisfactory way of spending free time and a sense of contribution to science. For educators, it offers the opportunity to increase learning, and promote the idea that everyone can do science.

In the use of citizen science methodologies, one should be careful about the caveats implicitly present in this technique. Especially the reliability of the information processed or provided might be of concern, although often repeated processing of data by volunteers provides a degree of security by the mere fact of repetition by different individuals.

2.4.2 Citizen Science Typology

There are various typologies of citizen science and most of them focus on integrating public participation in different steps of scientific research through contributory, collaborative and co-created projects.[82] The categorical breakdown of projects, from that point, fans out into sub-classifications action, conservation, investigation, virtual and education.[83,84] For the sake of innovation in space sector, virtual projects and education projects are relevant.

In science-oriented virtual projects, all project activities are IT-mediated with no physical elements whatsoever. Projects are often in the field of astronomy, palaeontology, and proteomics, the large-scale study of proteins. Examples of such projects are Stardust@home and Galaxy Zoo. Projects of this nature often employ game-like task designs in order to maintain volunteer interest and motivation to participate. Validation efforts are based on replication, multiple reviews or ratings combined with sophisticated algorithmic identification and prioritisation of items for expert review. These types of pro-

[79] Firehock, Karen, and Jay West. "A brief History of Volunteer Biological Water Monitoring Using Macroinvertebrates." Journal of the North American Benthological Society 14.1 (1995): 197–202.

[80] Brossard, Dominique, Bruce Lewenstein, and Rick Bonney. "Scientific Knowledge and Attitude Change: The Impact of a Citizen Science Project." International Journal of Science Education 27.9 (2005): 1099–1121.

[81] Cho, Adrian, and Daniel Clery. "Astronomy Hits the Big Time." Science 323.5912 (2009): 332.

[82] Bonney, Rick, Heidi Ballard, Rebecca Jordan, Ellen McCallie, Tina Phillips, Jennifer Shirk, and Candie C. Wilderman., eds. Public Participation in Scientific Research: Defining the Field and Assessing Its Potential for Informal Science Education. A CAISE Inquiry Group Report. Washington D.C.: Center for Advancement of Informal Science Education, 2009.

[83] Wiggins, Andrea, and Kevin Crowson. "Developing a Conceptual Model of Virtual Organisations for Citizen Science." International Journal Organisational Design and Engineering 1.1-2 (2010): 148-162.

[84] Wiggins, Andrea, ed. From Conservation to Crowdsourcing: A Typology of Citizen Science, 4-7 Jan. 2011, 44th Hawaii International Conference on System Sciences, Kauai, U.S. Syracuse, NY: School of Information Studies.

jects are formed through top-down organising by academics. Financially they are typically supported by public funds and have no sustainability mechanisms beyond grants. Virtual projects take advantage of advanced technology tools and make extensive use of reputational rewards and friendly competition.[85]

Project	URL	Type	Description
ReClam the Bay	www.reclamthebay.org	Action	Restoring local bay's clams and oysters
Shermans Creek Conservation Association	www.shermanscreek.org	Action	Protecting local creek
Did You Feel It?	earthquake.usgs.gov/eqcenter/dyfi	Conservation	Collecting earthquake intensity data
Twitter Earthquake Detection Program	recovery.doi.gov/press/us-geological-survey-twitter-earthquake-detector-ted/	Conservation	Collecting real-time earthquake data
Missouri Stream Team Program	www.mostreamteam.org	Conservation	River conservation
Spotting the Weedy Invasives	www.rci.rutgers.edu/~trails	Conservation	Locating invasive plants
Invasive Plant Atlas of New England	nbii-nin.ciesin.columbia.edu/ipane	Conservation	Creating regional invasive plant database
Northeast Phenology Monitoring	www.usanpn.org	Conservation	Monitoring phenology (seasonal life cycles)
What's Invasive	www.whatsinvasive.com	Conservation	Locating invasive plants
Monarch Larvae Monitoring Project	www.mlmp.org	Investigation	Collecting monarch butterfly distribution data
Who's Whoo-ing	www.mianus.org/owlcall	Investigation	Mapping suburban owl habitats
Community Collaborative Rain, Hail and Snow Network	www.cocorahs.org	Investigation	Collecting precipitation data
Great Sunflower Project	www.greatsunflower.org	Investigation	Collecting pollinator service (bee) data
Firefly Watch	www.mos.org/fireflywatch	Investigation	Collecting firefly distribution and activity data
Gravestone Project	www.goearthtrek.com/Gravestones/Gravestones.html	Investigation	Measuring weathering to study acid rain
SnowTweets	www.snowtweets.org	Investigation	Mapping snow depth
eBird	www.eBird.org	Investigation	Collecting bird observations
The Lost Ladybug Project	www.lostladybug.org	Investigation	Collecting data about ladybug distribution
Bay Area Ant Survey	www.calacademy.org/science/citizen_science	Investigation	Collecting data on local ants
FoldIt	www.fold.it	Virtual	Proving human superiority at protein folding
The Open Dinosaur Project	opendino.wordpress.com	Virtual	Creating dinosaur limb bone measurement database
Stardust@home	stardustathome.ssl.berkeley.edu	Virtual	Finding interstellar dust particles
Galaxy Zoo	www.galaxyzoo.org	Virtual	Classifying images of galaxies
Project Implicit*	implicit.harvard.edu/implicit/research	Virtual	Examining hidden biases
The Smell Experience Project*	psych-institute.med.nyu.edu/research/submit-story	Virtual	Collecting stories about changes in sense of smell
Perfect Pitch Test*	perfectpitch.freehostia.com/info_eng.html	Virtual	Determining whether perfect pitch differs by timbres
What on Earth	www.whatonearth.org.uk	Education	Collecting images of organisms for identification
Radio Jove Project	radiojove.gsfc.nasa.gov	Education	Learning about radio astronomy
Fossil Finders	www.fossilfinders.org	Education	Learning about Devonian fossils
Globe at Night	www.globeatnight.org	Education	Learning about light pollution

* These projects are not considered citizen science because participants are subjects rather than collaborators; they are included for completeness.

Table 1: Examples of Citizen Science Projects.[86]

[85] Wiggins, Andrea, ed. From Conservation to Crowdsourcing: A Typology of Citizen Science, 4-7 Jan. 2011, 44th Hawaii International Conference on System Sciences, Kauai, U.S. Syracuse, NY: School of Information Studies.

[86] Ibid.

Education projects can be further divided into projects that focus on formal or informal learning opportunities. Examples are Globe at Night and the Radio Jove Project. The educational projects typically focus on biology, astronomy, and palaeontology with an emphasis on outreach, learning and developing scientific inquiry skills rather than generating scientifically valid results. Top-down organising is a feature of these projects and most involve multiple partner organisations. Because of public involvement, education projects often have substantial funding. The Radio Jove Project is completely self-sustaining even though it received initial public funding. Education projects use technology to support simple to complex data entry tasks.[87]

Zoo Universe

The Zoo Universe Project is often referred to as the next major step in developing astronomy citizen science. This project provides a framework for new citizen science projects, enabling any science team to make use of the platform for their own projects with minimal effort and development activity. Currently active Zoo Universe projects include Galaxy Zoo II, Galaxy Merger Zoo, the Milky Way Project, Supernova Search, Planet Hunters, Solar Storm Watch, Moon Zoo and Old Weather.[88]

Major improvements in detector and computer technology resulted in the doubling of available scientific data approximately every year, but the actual population of professional scientists available to process and interpret the data grows much more slowly. This discrepancy in relative processing capacity, referred to as "*data deluge*", creates the need for new methods to maximise scientific output of large surveys and databanks.[89]

A good example of citizen science being used to address a shortage of fully-trained scientists in the field of space is the Galaxy Zoo project. Starting in June 2007, the cloud-based project asked users to look at images of galaxies from the Sloan Digital Sky Survey (SDSS) and to record the shape and direction of rotation of millions of galaxies by selecting one out of six options.[90]

To ensure quality control, users are taken through a simple tutorial about galaxy types then tested on the material to ensure that they have enough basic skill to produce reliable classifications.[91] Each image is evaluated by multiple volunteers, with algorithms flagging low-consensus items for professional review. The site also offers a blog authored by the astronomers and forums for discussion amongst participants providing multiple occasions for the engagement of the volunteers.

One million galaxies have now been classified by a quarter of a million volunteers approximately 200 times each, increasing thereby the overall reliability of the results.[92] Galaxy classifications are being used by astronomers to understand the dynamics, structure, and evolution of galaxies through cosmic time, and are thereby used to understand the origin, state, and ultimate fate of our universe.[93]

Extended use of citizen science offers many advantages for volunteers, the education community, the scientific community, and society as a whole. The main benefits for the scientific community include:[94]

- Coordinated networks of amateur astronomers allow measurement reports taken over a wide area or very short timescale. However, this advantage is less relevant for Galaxy Zoo, where the data is provided by the scientific community towards the crowd.
- Finding rare objects that can be identified only by visual inspection; i.e. "finding the needle in the haystack".
- Quick, accurate analysis of large datasets. In case of the Galaxy Zoo, the original sample of nearly 900,000 galaxies was classified by volunteers multiple times within one week.
- Serendipity: citizen science can stumble across new and unexpected discoveries.

[87] Ibid.
[88] Way, Michael J., and Catherine Naud, ed. Proceedings of the 2011 New York Workshop on Computer, Earth and Space Science, Feb. 2011, New York, U.S., New York, NY: Goddard Institute for Space Studies, 2011.
[89] Raddick, Jordan M., Georgia Bracey, Karen Carney, Geza Gyuk, Krik Borne, John Wallin, and Suzanne Jacoby. "Citizen Science: Status and Research Directions for the Coming Decade" The Astronomy and Astrophysics Decadal Survey (2010): 46.
[90] "The story so far" Galaxy Zoo, 3 Feb. 2011 <http://www.galaxyzoo.org/story>.
[91] "How to take part" Galaxy Zoo, 3 Feb. 2011 <http://www.galaxyzoo.org/how_to_take_part>.
[92] Way, Michael J., and Catherine Naud, ed. Proceedings of the 2011 New York Workshop on Computer, Earth and Space Science, Feb. 2011, New York, U.S., New York, NY: Goddard Institute for Space Studies, 2011.
[93] Ibid.
[94] Raddick, Jordan M., Georgia Bracey, Karen Carney, Geza Gyuk, Krik Borne, John Wallin, and Suzanne Jacoby. "Citizen Science: Status and Research Directions for the Coming Decade" The Astronomy and Astrophysics Decadal Survey (2010): 46.

The main benefits for society are:[95]

- Improved public perception of science and scientists, who are often regarded as indifferent and distanced from everyday life. In this respect, citizen science can "rebuild and rekindle some of the public trust lost in institutional science".[96]
- Increase public exposure to the concepts and vocabulary of the subject being studied, which allows for meaningful public participation and discussion with science. This could lead to increased engagement in political forums, science likely to be more supported in schools and, more involvement in entertainment.

2.4.3 Open Source Software

Open source software (OSS) is software free of charge and open to modification. Open source software development projects are internet-based communities of software developers collaborating to develop software that they or their organisations need. Well known examples of open source software are the GNU/Linux computer operating system, Apache server software and the Perl programming language.

Before the influence of the open innovation paradigm, the "private investment" model assumed that returns to the innovator results from ownership and efficient regimes of intellectual property protection. The "collective action" model assumes that under conditions of market failure, innovators collaborate in order to produce a public good. The open source software development phenomenon shows that users can programme to effectively solve individual and shared problems while freely revealing their innovations completely absent appropriating private returns from selling the software.

In the early days of computer programming, commercial packaged software was a rarity. If somebody wanted a particular programme for a particular purpose he or she typically wrote the code or hired someone to do it. Much of the software development in the 1960s and 1970s was carried out in academic and corporate laboratories by scientists and engineers. These individuals found it a normal part of their research culture to freely give and exchange software they had written, to modify and build upon each other's software both individually and collaboratively, and to freely give out their modifications in turn.

In 1969 the U.S. Defense Advanced Research Project Agency (DARPA) established the Advanced Research Projects Agency Network (ARPANET), the first transcontinental, high-speed computer network. This network eventually grew to link hundreds of universities, defence contractors and research laboratories. Later succeeded by the internet, it also allowed programmers to exchange software code and other information widely, easily and cheaply.

Software authors interested in preserving the status of their software as "free" software could use their own copyright to grant licenses on terms that would guarantee a number of rights to all future users. They could do this by simply affixing a standard license to their software that conveyed these rights. Basic rights transferred to those possessing a copy of free software include the right to use it at no cost, the right to study its source code, to modify it, and to distribute modified or unmodified versions to others at no cost.

Commercial software vendors typically sell the code they develop and sharply restrict employee and contractor access to the source code of their software products. Consequently, only insiders have the information required to further modify and improve that proprietary code.[97,98,99]

Most who download open source software are free riders. Only a relatively small portion actually contributes to a project by developing the code. Open source projects do not pay participants for their services, and the motivations and characteristics of contributors vary. Most are strongly motivated by a personal or business use for the code that they develop. Others are motivated by the intrinsic rewards of programming, like learning and recreation. Most contributors are experienced professional programmers. Some are independent actors and others are employees of organisations that support their participation.[100]

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[95] Ibid.

[96] Carr in Raddick, Jordan M., Georgia Bracey, Karen Carney, Geza Gyuk, Krik Borne, John Wallin, and Suzanne Jacoby. "Citizen Science: Status and Research Directions for the Coming Decade" The Astronomy and Astrophysics Decadal Survey (2010): 46.

[97] Meyer, Marc H., and Luis Lopez. "Technology Strategy in a Software Products Company" Journal of Product Innovation Management 12.4 (1995): 194–306.

[98] Young, Greg, Ken G. Smith, Curtis M. Grimm. "'Austrian' and Industrial Organization Perspectives on Firm-Level Competitive Activity and Performance" Organization Science 7.3 (1996): 243–254.

[99] Conner, Kathleen R., and Coimbatore K. Prahalad. "A Resource-Based Theory of the Firm: Knowledge versus Opportunism" Organization Science 7 (1996): 477–501.

[100] Lakhani, Karim R., and Robert Wolf, eds. Does Free Software Mean Free Labor? Characteristics of Participants in Free and Open Source Communities. Boston: Boston Consulting Group, 2001.

Example: Apache Server Software

Apache server software is used on computers that host web pages and provide appropriate content as requested by internet browsers. In a period of four years and after modifications and improvements though many user contributions, Apache has become the most popular web server software on the internet, gathering many industry awards for excellence. Despite strong competition from commercial software developers such as Microsoft and Netscape, it is currently used by some 60% of the millions of websites worldwide. Apache continues to be user-modified with the release of new versions coordinated by a central group of 22 volunteers.

Open source software developers and communities are of interest to organisational theorists for two major reasons. First, open source software projects present a novel and successful alternative to conventional innovation models. This alternative presents interesting puzzles for and challenges to prevailing views regarding how innovations “should” be developed, and how organisations “should” form and operate. Second, open source software development projects offer opportunities for an unprecedented look into the development of software itself. By the very nature of the way these projects operate, detailed and time-stamped logs of most interactions among community members and of project outputs are automatically generated. These logs are publicly available and open to the inspection of any researcher without special permission. This simple fact makes OSS development projects valuable as research sites for many types of studies. For instance, research revealed that often the development was controlled by a small group, but received occasional error correction from a much larger group of developer-users.[101]

Open Source Software plays an increasingly important role in all industrial sectors. Although much of the recent OSS debate has focused primarily on desktop applications (Open Office, Mozilla Firefox, etc.), its strengths are the tools and infrastructure underlying the internet and web services, software like GNU/Linux, Apache, Bind, and the networking protocols for data transfer, email, the World Wide Web, file transfer, etc. This suggests OSS may have an important role to play in the secondary software sector (i.e. domains where software is used as a component in other products, such as embedded software in the automotive sector, consumer electronics, mobile systems, telecommunications, and utilities (electricity, gas, oil, etc.)). These observations illustrate the most relevant advantages of OSS with regard to a feature that is relevant to all forms of software – i.e. interoperability and collaboration as well as appropriate software strategies. Enterprises use OSS for internal system development and administration and externally as part of their products or solutions. Industry representatives have become increasingly aware of the benefits OSS provides. For instance, OSS is expected to increase software quality, reduce development and maintenance costs for the individual users, decrease vendor lock-in, facilitate rapid evolution of the software, and encourage reuse of software.

OSS industry usage depends on ease of installation, ease of use, maturity and quality, and lack of criticality or reliability with regard to production or mission critical systems. There are four ways how industry uses OSS: (1) internally for infrastructural purposes, e.g. Linux, Apache, MySQL; (2) internally for standalone-applications and tools, e.g. CVS, BugZilla; in products: small components, e.g. libraries; (3) in large components, e.g. embedded Linux, MySQL; and (4) for customers in consulting services.

2.4.4 Wiki Platforms

A wiki (from wikiwiki, meaning “fast” in Hawaiian) is a group of linked web pages created through incremental development by a group of collaborating users, and the software used to manage the set of web pages.[102] According to Ward Cunningham, the first person to develop a Wiki in 1995, the Wiki design is based on eleven principles.

Principle	Explanation
Open	If a page is found to be incomplete or poorly organised, any reader can edit it as he/she sees fit.
Incremental	Pages can cite other pages, including pages that have not been written yet.
Organic	The structure and text content of the site is open to editing and evolution.
Mundane	A small number of (irregular) text conventions will provide access to the most useful (but limited) page mark-up.

[101] Mockus, Audris, Roy T. Fielding, and James D. Herbsleb. “Two Case Studies of Open Source Software Development: Apache and Mozilla” ACM Transactions on Software Engineering and Methodology 11.3 (2002): 309–346.

[102] Wagner, Christian “Wiki: a Technology for Conversational Knowledge Management and Group Collaboration” Communications of the Association for Information Systems 13 (2004): 265–289.

Universal	The mechanisms of editing and organising are the same as those of writing so that any writer is automatically an editor and organiser.
Overt	The formatted (and printed) output will suggest the input required to reproduce it. (e.g., location of the page.)
Unified	Page names will be drawn from a flat space so that no additional context is required to interpret them.
Precise	Pages will be titled with sufficient precision to avoid most name clashes, typically by forming noun phrases.
Tolerant	Interpretable (even if undesirable) behaviour is preferred to error messages.
Observable	Activity within the site can be watched and reviewed by any other visitor to the site.
Convergent	Duplication can be discouraged or removed by finding and citing similar or related content.

Table 2: The Eleven Wiki Design Principles, According to Ward Cunningham.[103]

Wikis (or Wiki platforms) are operated through Wiki software. Wiki software can be described as: "collaborative software that runs a wiki, i.e., a website that allows users to create and collaboratively edit web pages via a web browser. A wiki system is usually a web application that runs on one or more web servers. The content, including all current and previous revisions, is usually stored in either a file system or a database." Wiki structure and operational mode are characterised by content-management features, scripting, semantic annotation, mobile access and, offline viewing and editing.[104]

Currently, there are plenty of active Wikis with varying success. Some Wikis recruit many users, achieving sustainability with established role distributions, frequent updating and an efficient fight against vandalism, while others focus on attracting contributors. All of them endeavour to survive within what some authors call "the wikisphere"; the collection of all Wikis on the internet.[105]

On a more abstract level, Wikis can be regarded as part of a conversational technology with a permanent and searchable transaction record, characterised by a facilitated end-user management structure.[106] This is particularly useful to enable the so-called many-to-many communication as opposed to most online communication forms in which only one person is at the producing or receiving end. Wikis can be highly relevant for innovation because of this broad communication reach.

From a user point of view, wikis can be divided into three categories, according to accessibility:[107]

- Public wikis: wikis that can be read by anyone; usually they can be edited by anyone as well, though sometimes registration is required.
- Enterprise wikis: software meant to be used in a corporate (or organisational) context, especially to enhance internal knowledge sharing, with a greater emphasis on features like access control, integration with other software, and document management.
- Personal wikis: Software that is specifically designed for running personal wikis.

The public wikis are the focal point of "open in, open out" innovation, but the private sector is engaging more often in the use of enterprise wikis. Findings indicate that corporate wikis appear to be sustainable and have been shown to: (1) enhance professional reputation, (2) make work easier, and (3) improve organisational processes.[108] In addition, Wiki platforms have been suggested to facilitate stakeholder integration in requirements engineering.[109]

2.4.5 And Space?

Wikis, generally speaking, can increase knowledge, information exchange and understanding within the community and hence are conducive for innovation. Using wikis as an explicit knowledge management tool might streamline space-related innovation processes by avoiding losing time on solving problems which have already been solved or investigating ideas which have already

[103] Cunningham, Ward. "Wiki Design Principles" 3 Feb. 2012 <http://c2.com/cgi/wiki?WikiDesignPrinciples>.
[104] Ibid.
[105] Roth, Camilla, Dario Taraborelli, and Nigel Gilbert, eds. Measuring Wiki Viability: An Empirical Assessment of the Social Dynamics of a Large Sample of Wikis, 8 Sept. 2008, Porto, Portugal. Wikis4SE'08 Workshop, 2008.
[106] Wagner, Christian. "Wiki: a Technology for Conversational Knowledge Management and Group Collaboration." Communications of the Association for Information Systems 13 (2004): 265–289.
[107] "Wiki software" Wikipedia, 4 Feb. 2012, <http://en.wikipedia.org/wiki/Wiki_software>.
[108] Majchrzak, Ann, Christian Wagner, and Dave Yates, eds. Corporate Wiki Users: Results of a Survey, 21–23 Aug. 2006, Odense, Denmark. International Symposium on Wikis, 2006.
[109] Ferreira, David, and Alberto Rodrigues da Silva, eds. Wiki Supported Collaborative Requirements Engineering, 8 Sept. 2008, Porto, Portugal. Wikis4SE'08 Workshop, 2008.

proven not to lead anywhere. Wikis can be innovation outreach tools allowing 'mass communication' between staff directly charged with innovation projects, other non-hierarchically involved staff and even external sources. Wikis can be part of the crowd sourcing tool box.

As Wikis can be a tool for collective discovery and innovation for groups that can be predefined or completely open, they are highly relevant for space where individual projects might want to resort to wikis in order to overcome corporate barriers in the consortia and even create a more interactive dialogue with the customer. Wikis can be combined with dialogue strings, thus recording both the creative process and the current state of play. Wikis can be a very good tool to connect innovators among themselves, and to link an innovator community to user communities, such as specific space projects.

NASA is already operating a wiki site.[110] The goal was to find clever ways to push NASA's capability through sharing knowledge, data, and ideas across the organisation. The idea to make the wiki came from a need to access better corporate information resources in order to find solutions to problems engineers at NASA often face, which required very specialised information. Often such knowledge is locked up in paper or digital form by individual engineers. The wiki collected this pre-existing material and placed it in a wiki database. In a sense this is classical knowledge management. What the wiki adds is the possibility for the addressed community to input as well as just receive the output.

Recently, ESA started using its first wiki in beta version. By means of the Navipedia project, the agency wants to become the reference for Global Navigation Satellite Systems (GNSS) general knowledge on the internet. The initiative is defined as an electronic repository of knowledge related to GNSS. As a common entry point, it enables users to access updated information of the existing GNSS Systems, applications, receivers and fundamentals.[111]

Turning then to citizen science methodologies it is clear that they are already deployed effectively in many space related fields, such as astronomy. Given that ESA space science projects operate on open access to data, after a first period of exclusivity for the directly involved researchers, it might, however, be questioned whether ESA as a central entity could not itself foster more citizen science by the use of the new internet tools. What is more, particularly ESA with is public mandate could use the crowd sourcing capabilities now available to foster technical innovation with public participation, allowing the ensuing innovations to also stay in the public domain.

The advantages of using OSS within the space community might not only lie in cost reduction but also in increased development speed and participant diversity. When software is not mission critical, such as for ground processing and data analysis, the open source approach seems suitable to decrease cost and maximise innovation, although it will remain a challenge to have the evolving source code properly documented. Even mission critical software could still be part of an open source paradigm if changes in the actual operational or flight software would only take place after the usual excruciating centrally controlled review and authorisation process, and proper production of documentation. NASA has a long history of releasing source code openly in support of its exploration missions. One of the projects currently being undertaken at NASA is an open source space mission design and analysis application called the General Mission Analysis Tool (GMAT). This project is a collaborative development since 2005. NASA, other space agencies, academia, private industry, Thinking Systems Inc., Air Force Research Lab and others actively contribute to its development. Since NASA currently spends a lot of funding on proprietary closed mission trajectory planning software (in 2010 the Navigation and Mission Design Branch spent $800k on software licenses alone), some NASA personnel states that this product has the potential to fundamentally shift the business model behind NASA mission planning.[112]

For ESA open source approaches resonate particularly well with its public mandate and the interest to share benefits as much as possible. In this respect it should be noted that a derived benefit from open source approaches is that source sequences might be cut-and-pasted into entirely different software contexts and for entirely different uses; thus one more way investment in space can benefit non-space society.

110 "The NASA Wiki Space" NASA Academy 10 May 2011 <http://www.nasa.gov/offices/oce/appel/ask-academy/issues/volume4/AA_4-4_AI_interview_jon_verville.html>.

111 "About Navipedia" 18 Jan. 2012 European Space Agency 5 Jun. 2012 <http://www.navipedia.net/index.php/About_navipedia.>.

112 Skytland, Nick. "Space Mission Design for Everyone." 28 Jul. 2011 Open NASA 17 Mar. 2012 < http://open.nasa.gov/blog/2011/07/28/space-mission-design-for-everyone/>.

3. Beyond the Open/Closed Paradigm

This report has taken as it point of departure how innovation flows in and out of the innovating entity. There are, however, methods or approaches to innovation which do not fit easily into this analytical approach, but which can be deployed in different innovation scenarios or which require special mention.

3.1 Ecosystems

Product ecosystems, made highly visible by Google and Apple, are becoming increasingly popular. A product ecosystem combines a rigorously closed control of the ‘out’, of the core product, but invites other open or closed players to be part of the ecosystem, allowing the core product to benefit from the surrounding ecosystem both in terms of market position and in terms of its further development. The ecosystem is thus an innovation input for the core product. However, the inverse is also true. The surrounding product ecosystem owes its existence in the marketplace to the core product, and developments in the core product and in other ecosystem products reverberate innovation-wise throughout the ecosystem.

A broader term, encompassing also the product ecosystem, is the innovation ecosystem. This might have ‘closed’ elements and can be defined as the dynamic system of interconnected institutions and persons that are necessary to create, store and transfer the knowledge, skills and artefacts which define a product domain. This ecosystem includes a range of actors from industry, academia, industry, foundations, scientific organisations, and government at all levels.

The four basic knowledge flows among actors in an innovation ecosystem are:

1. interactions among enterprises;
2. interactions among enterprises, universities and public research laboratories;
3. diffusion of knowledge and technology to firms;
4. movement of personnel.

Attempts to link these flows to industrial performance show that high levels of technical collaboration, technology diffusion and personnel mobility contribute to the improved innovative capacity of enterprises in terms of products, patents and productivity.

The innovation ecosystem is conceptually analogous to the biological ecosystem observed in nature. A biological ecosystem is a complex set of relationships among the living resources, habitats, and residents of an area, whose functional goal is to maintain a state of equilibrium. An innovation ecosystem models the economic dynamics of the complex relationships that are formed between actors or entities whose functional goal is to enable technology development and innovation.[113] In this context, the actors would include the material resources and the human capital that make up the institutional entities participating in the ecosystem. Their key feature is the flow of technology and information among people, enterprises and institutions.

Innovation ecosystems can be analysed at different levels: sub-regional, national, pan-regional and international. While the national level may be the most relevant due to the role of country-specific interactions in creating a climate for innovation, international technology flows and collaborations are taking on growing significance. Just like the innovation process, ecosystems can be viewed as generating both new knowledge and new technology that is moved from basic discovery research to the marketplace.

The innovation ecosystem approach has taken on increased analytical importance in the technology field due to three factors:

- Recognition of the economic importance of knowledge: Over the last few years the relative importance of knowledge has been recognised as human capital and necessity for innovation. The study of innovation ecosystems focuses on flows of knowledge. Analysis is increasingly directed to improving performance in “knowledge-based economies”, i.e. economies which are directly based on

[113] Jackson, Deborah J. “What is an Innovation Ecosystem?” National Science Foundation 1 Feb. 2012 <http://www.erc-assoc.org/docs/innovation_ecosystem.pdf>.

the production, distribution and use of knowledge and information.[114]

- Increasing use of systems approaches: Innovative firms are seen as operating within a complex network of co-operating and competing firms and other institutions, building on a range of joint ventures and close linkages with suppliers and customers.
- The growing number of institutions involved in knowledge generation: There are many channels through which knowledge can flow between these institutions and a variety of approaches to measuring these flows.

The rise of the innovation ecosystem in the technology sector necessitates policies on networking systems that emphasise improving interplay amongst actors and institutions within innovation ecosystems. Such policies stress the role of joint research activities and other technical collaboration among enterprises and with public sector institutions. These policies recognise the importance of informal flows of knowledge and access to technical networks.

Enhancing firm capacity to innovate is another policy priority. From an innovation ecosystems perspective, this means improving enterprise ability to access appropriate networks to find and identify relevant technologies and information and to adapt such knowledge to their own needs. The purpose is to improve the ability of firms to acquire information and technology, either domestic or foreign, and to absorb it on a continuous basis.

Future research will focus on defining indicators for mapping interactions in innovation ecosystems as well as the structural linkages within successfully innovative firms and countries. Existing indicators are at an early stage of development and do not approach the robustness of more conventional innovation indicators such as R&D expenditures, patents, production and trade in high-technology products. A main goal is to improve international studies by encouraging individual countries engaging in innovation ecosystems analysis to focus first on measuring a core set of knowledge flows using similar indicators. At the same time, specific analyses will be directed at the understanding of certain types of flows in innovation ecosystems, namely human resource flows, institutional linkages, industrial clusters, and innovative firm behaviour.

[114] Organisation for Economic Co-operation and Development. The Knowledge-based Economy. General Distribution OCDE/GD(96)102. Paris: OECD, 1996.

3.2 Apple

Innovation ecosystems introduce a new set of strategy and management challenges. They allow what Prof. Adner, advocate of a new strategy for innovation, calls a "focal innovator" – the firm that plays the main role in the ecosystem – "to coordinate and integrate inputs from scores of upstream component suppliers as it simultaneously coordinates implementation by downstream [so-called] 'complementors' across the customer/user community".[115] However, they also tie firms in a more complex way, with "longer chains of intermediaries who all must agree to adopt the innovative vision and larger sets of complementors who must overcome their own innovation challenges for the focal firm's efforts to matter".[116] The size of technological challenges faced by suppliers and complementors and their location in the innovation ecosystem relative to the focal firm influence value creation and competitive advantage of the focal innovator. While component challenges determine whether a focal firm can produce its product, complementor challenges affect the ability of customers to fully utilise a product even after it is ready. Finally, early movers are proven to be in a privileged position, thus for those companies that come later the challenges increase significantly.[117] This is why, for many firms, such attempts at innovation result in costly failures.

Apple Inc. has managed to overcome all the above-mentioned obstacles to success. It has built an enduring innovation ecosystem that harnesses personnel creativity, stimulating new ideas and launching successful, profitable innovations. To seize opportunities in the marketplace, Apple leverages its diverse culture, innovation processes, partners and networks in a way that few other corporations are able to imitate. In the words of Bruce Nussbaum, Managing Editor of Businessweek, 'innovation integration' (or integrative innovation) is at the heart of Apple's success.[118]

[115] Adner, Ron. "Upstream, Downstream in an Innovation Ecosystem." Tuck Forum May 2009, <http://www.tuck.dartmouth.edu/news/articles/upstream-downstream-in-an-innovation-ecosystem/>.
[116] Adner, Rod. "Innovation Ecosystems: Is there a Cost to Collaboration?" Tuck Forum Mar. 2011 <http://www.tuck.dartmouth.edu/news/articles/innovation-ecosystems-is-there-a-cost-to-collaboration/>.
[117] Ibid.
[118] Nussbaum, Bruce. "Apple's Innovation Strategy: More than McBook Air." Businessweek 16 Jan. 2008. <http://www.businessweek.com/innovate/NussbaumOnDesign/archives/2008/01/apples_innovation_strategy_more_than_macbook_air.html>.

Established in 1976 with only one product, the Apple I PC, to sell, Apple is now a multinational corporation with cash reserves that in 2011 surpassed even those of the U.S. government. After a sales shortfall in the mid-1990s, however, many analysts considered Apple a 'dead end.' During his first public speech after returning to Apple in 1997, Steve Jobs, one of the three Apple founders, recognised that Apple's problems were caused by the incompatibility of Mac products with other PCs.[119] Despite the company's reputation for making the world's finest PCs, very little software or add-on gear worked with the Mac. Jobs stated that, since Apple lives in an ecosystem, it needs help from other partners and it needs to help other partners.[120] In other words, Apple had decided to adopt an ecosystem approach. Increased compatibility with Microsoft followed.

In 1998, the iMac was successfully launched. Subsequent revenues allowed Apple to purchase several companies to create a portfolio of professional and consumer-oriented software.[121] In 2001 and 2003 respectively, Apple introduced the iPod and iTunes, forever changing the way people buy, hear and organise music. Following the new ecosystem approach, it created also a Windows-compatible version of iTunes. Rather than hurt Mac sales, as some feared, Windows compatibility opened the floodgates for iPod sales. Apple reached another milestone when the company switched from PowerPC processors made by IBM to Intel's far more popular chips. This made it possible for Macs to run Windows and made it far easier for software developers to adapt their programmes for Apple's products.

With the launch of the iPhone in 2007 Apple made its first entry into a pre-existing mass market. The same year it changed its name from Apple Computer, Inc. to Apple Inc. to reflect an expanding company product platform. More companies were signing on to create Apple-compatible products. In 2009 the iPad was introduced. An industry of iPhone and iPad apps is blossoming to such an extent that Apple has now acquired a firm to sort the immense offer of apps, currently around 500,000. Apple's online iTunes Music Store (iTMS) has become the world's third-largest music retailer, delivering music and videos to iPhones, iPods, iPads, Macs, Windows based applications, etc. The Apple strategy of diversity and convergence is noticeable, leading to product fluidity at the centre of the ecosystem which is highly innovation enriching all across the system.

3.2.1 Apple's "Complementors" Strategy

To better understand how Apple managed to create the successful iPhone innovation ecosystem, Professor Adner compares its case with Finnish telecommunications giant Nokia. He notes that, long before Apple, Nokia envisioned applications software on phones as a key element for the success of its main products. Thus, in 1998, it created the Symbian operating system to pursue an ecosystem approach. The attempt to convince developers to create applications for the system failed due to high customisation costs and an unattractive market path. While prioritising product strategy, Nokia put complementors in the periphery.[122]

Apple did exactly the opposite. When it decided to pursue an ecosystem approach, it put emphasis on developers, giving them a prominent role in product advertising and throughout new product launches. The sheer volume of existing iPhone users at the time of the App Store launch in 2008 was a further incentive for developers to enter Apple's ecosystem.[123]

Since the competition has shifted from products to ecosystems, the rules of competition have changed. Adner states: "when we depend on others for our success, the ways in which we prioritise opportunities and threats, how we think about market timing and positioning, indeed the very ways in which we measure and reward success all need to change to explicitly account for this dependence".[124] Apple has put partial product success responsibility in the hands of complementors. This way, the multinational company has been able to integrate the innovation process at the periphery of its ecosystem with its own innovation process in a way that they appear inseparable.

Apple's strength lies also in the 'network effect' created by its products.[125] The more

[119] Burrows, Peter. "Welcome to Planet Apple: How the High-Tech Maverick Became a Global Trendsetter." Businessweek 19 July 2007 <http://www.businessweek.com/magazine/content/07_28/b4042058.htm>.
[120] Ibid.
[121] Sarkar, Pia. "Friends and Foes: Despite Squabbles, Apple and Adobe Have Benefited from One Another." San Francisco Chronicle 25 Feb. 2002 <http://www.sfgate.com/cgi-bin/article.cgi?file=/chronicle/archive/2002/02/25/BU107610.DTL&type=tech>.
[122] Adner, Rod. "Innovation Ecosystems: Is there a Cost to Collaboration?" Tuck Forum Mar. 2011 <http://www.tuck.dartmouth.edu/news/articles/innovation-ecosystems-is-there-a-cost-to-collaboration/>.
[123] Ibid.
[124] Ibid.
[125] Sharpe, Nicola F., and Olufunmilayo B. Arewa. "Is Apple Playing Fair? Navigating the iPod FairPlay DRM

iPod, iPhone, and now iPad are sold, the more Apple's network increases its value, for complementors are more and more eager to develop complementary products.

3.2.2 Apple's "Lock-in" Practices

Utilising the so-called 'lock-in' practices, that bind a customer to a company's product ecosystem by various means and consequently create barriers to market entries, Apple exploits its network by allowing selected partners to profit from it and making it difficult or impossible for others to do the same. iTunes was famously used to direct customers to iPods and iPhones, creating an uproar, for instance, in France. This shows that networks may both enhance and inhibit competition.[126]

When Apple puts up market entry barriers for firms outside the ecosystem, it also constrains firms on the inside. To be part of Apple's ecosystem, firms have to give up part of their independence in everything from design to identity to pricing. After having seen what happened in the music industry, suppliers of TV shows, movies, and other video content have their own reasons for being wary of joining the Apple ecosystem.[127]

Information and communication technology platforms like the iPhone, iPad, and Google's Android, demonstrate innovation ecosystem evolution. To benefit from an ecosystem in the past, physical presence in that place and time was necessary. Today any entrepreneur with a good idea can launch a business application for the iPhone or Android platforms and, regardless of geographical location, it can become a success.[128] Even if almost 90% of today's innovation ecosystems are still based on successful examples of geographical concentration of entrepreneurs, investors, talent and/or universities, the internet is now rapidly changing the paradigm, making geographical location less important.[129]

3.2 Google

Google describes its mission as follows: "Organise the world's information and make it universally accessible and useful".[130] Unlike many other companies, Google can afford such a broad mission and subsequent innovation demands. Google's search-based advertising is a phenomenally profitable product that provides a financial buffer for many projects that do not seem, at least at first glance, very profitable.[131] Google X lab, discussed in chapter two, is an example of how such a project fits in with Google's overall strategy. To see how the company tries to achieve its mission, a brief overview of its particular search-based innovation ecosystem is presented.

3.2.1 Network and Infrastructure

Theoretical frameworks on innovation ecosystems describe a system where knowledge and technology is moved from the initial discovery phase to the marketplace. For Google, both results of this innovation process are fused in the form of information processing, software development and cloud-based applications for users.

While the internet is available to every company, Google has invested heavily to construct a proprietary platform that supports new and growing online services. The company's open source network infrastructure allows new computer clusters to plug in and be used and recognised instantly around the globe. This infrastructure platform can support an entire product-development life cycle efficiently: Google engineers can launch prototype applications on its cloud while simultaneously testing and marketing them to the global user community. Testing and marketing have become virtually indistinguishable from one another, creating a unique relationship with consumers who in fact become an essential part of the development team as new products take shape and grow.[132]

3.2.2 Ecosystem Control

Google plays the key role within its own innovation ecosystem, in which it is both owner and operator. As a result, the company is able to control the platform's evolution and claim a disproportionate percentage of the value created within it.[133] Google can exert total control to enhance services like Gmail, Google Maps, AdWords, and the advertising placement system AdSense. Moreover, the

Controversy." Northwestern Journal of Technology and Intellectual Property 5.2 (2007): 330-350.

[126] Ibid.

[127] Ibid.

[128] Andersen, Jorn B. "What are Innovation Ecosystems and How to Build and Use Them." Innovation Management 16 May 2011 <http://www.innovationmanagement.se/2011/05/16/what-are-innovation-ecosystems-and-how-to-build-and-use-them/>.

[129] Ibid.

[130] "Company" Google 14 Feb. 2012 <http://www.google.com/about/company/>.

[131] Iyer, Bala, and Thomas H. Davenport. "Reverse Engineering Google's Innovation Machine" Harvard Business Review 86.4 (2008): 58–69.

[132] Ibid.

[133] Ibid.

company has perfect continuous awareness of, and access to, the by-product information of all transactions performed through the platform. As a result, the company is able to control the platform's evolution and claim a disproportionate percentage of the value created within it.[134]

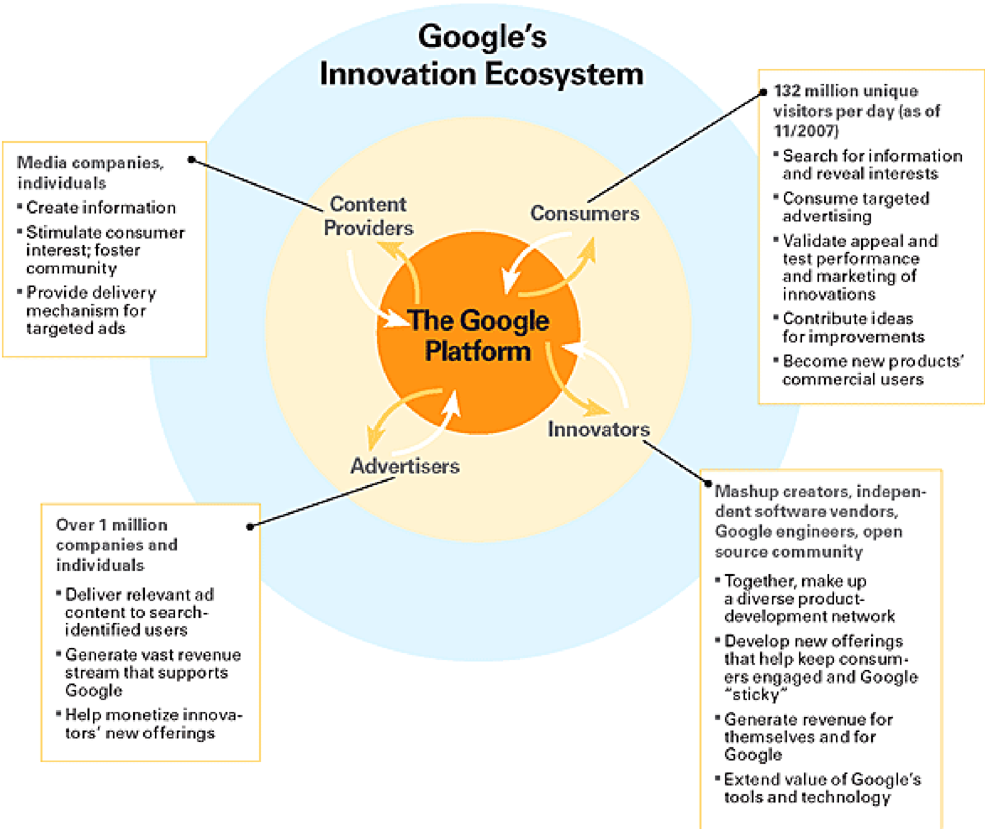

Figure 2: Google's Innovation Ecosystem: Visualisation.[135]

3.3 Lego

Danish company Lego is one of the most famous brands in children's toys. Since it opened in 1932, Lego grew into a global and successful business throughout the 20th century. By late 1990s, however, the company had begun to run into difficulties and faced bankruptcy; in parallel more competitive players were introduced to the market and a large section of its traditional market, young boys, was drawn into the world of computer games. In response, a new CEO was appointed and a financial injection was provided to allow time for a turnaround strategy. The subsequent transition helped make Lego profitable again by 2006, with increasing profit margins in the years following. Success was credited to cost-cutting in areas like supply chain and factory location, but also to a rethinking of the product development strategy. Changing the latter involved a total redefinition of the role of users, shifting from passive consumers to designers participating in the product innovation process.[136]

Changing the interaction mode with consumers and users is an excellent example of innovative firm behaviour. This section will briefly characterise its implications on, and interaction with, the company's innovation ecosystem.

3.3.1 Innovation Management at Lego

A new structure for coordinating innovation activities is central to Lego's reorientation in the market. Currently the innovation policy is managed by the Executive Innovation Governance Group. This group, led by Lego managers, takes a broad view of innovation that include powerful business drivers like new products, pricing plans, community building, business processes, and channels to market. Lego distributes responsibilities for innovation in all areas across four groups and expects

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[134] Ibid.
[135] Ibid.

[136] Tidd, Joe, and John Bessant. "Managing Innovation: Case Studies" 14 Feb. 2009 <http://www.managing-innovation.com/case_studies/Lego.pdf>.

different degrees of innovativeness from each of them.[137] At the same time, Lego is becoming a stakeholder-driven brand that wants to incorporate long-term sustainability as a goal into its business model.[138]

3.3.2 Consumers and the Ecosystem

Finding many possible combinations for a few Lego bricks has always allowed users an involved role in the Lego concept. Since 2000 Lego has been gradually putting the user-linked approach at the centre of its strategy. Initially, the first work happened internally, as Lego wanted to improve production efficiency by creating digital models of all the bricks and other components they produced. This enabled them to explore innovative product options via computer-aided design. The first product option involving open interaction with costumers was called Lego Mosaic, which allowed users to upload pictures to the company's website. The software digitalised the image and calculated the bricks required to make a physical mosaic using multiple colours.[139]

The second phase of this trend has been opening up the design process to outsiders. Mindstorms, a technologically-based kit with programmable bricks, sensors, actuators and a simple user programming language, was one of the first products in this category. In 2004, Mindstorms NXT – as the name implies, a new generation of this product line - was introduced. Lego, now using an open innovation approach, commissioned a software firm to design a simpler programming language. This succeeded and it turned out that a growing number of users were hacking the source software and developing applications and extensions to the original code. Rather than controlling or restricting this behaviour, the company identified and selected some key developers by running competitions. A growing user community began setting up websites and Lego was able to gain substantial leverage on the original design.[140]

All these new initiatives are forms of branding and design crowdsourcing[141], and each benefitted Lego through fostering community-building, innovation and sale revenues. It seems that the Lego ecosystem can mimic the more general mechanical engineering processes, with virtual prototyping and testing preceding the actual physical construction, all thanks to the combination of its virtual and physical presence.[142]

By following a customer-powered path and opening up their innovation ecosystem to their users, Lego has proven that a more open approach with respect to innovation can really benefit companies.

3.4 And Space?

ESA has built an innovation ecosystem around itself. This ecosystem is dominated by the three system integration companies, which are themselves surrounded by industrial grouping of subsidiaries. A considerable number of SMEs belong to the ESA ecosystem without hardwired association with any of the three system integrators, thus the centre of the ecosystem is clearly ESA.

Despite potentially competition-distorting effects, system integrators rely on a subsidiary structure to manage their sub-ecosystem, which limits choice and is looked at reluctantly by ESA. ESA's 'best practices' is designed to counteract subsidiary favouritism by system integrators. The alternative for system integrators would have been to build their own looser ecosystems and make them 'sticky', thereby lessening capital requirements, eliminate conglomerate management challenges and being able to occupy the richest part of the value chain, instead of sharing it with subsidiaries, as is the case now.

Building technical dependencies requires a very strong position in the market, as shown by Apple and Google, yet the system integrators have that, since there are so few and ESA's institutional demand must be fulfilled by European contractors. So the system integrators are quite sticky because of their position vis-à-vis ESA and that stickiness would to some extent remain even in the commercial markets.

The system integrators would, of course, also have to make efforts to increase stickiness, and the tool for that is to a large extent the

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137 Robertson, David, and Per Hjuler. "Innovating a Turn-around at LEGO" 14 Feb. 2012 <http://www.gintana.com/govern/harvardbusinessreview_lego.pdf >.
138 The LEGO Group "Progress Report" 14 Feb. 2012 <http://cache.lego.com/upload/contentTemplating/AboutUsAboutUsContent/otherfiles/download6777A03AA55057F7EE86D771CA3A1D79.pdf>.
139 Tidd, Joe, and John Bessant. "Managing Innovation: Case Studies" 14 Feb. 2009 <http://www.managing-innovation.com/case_studies/Lego.pdf>.
140 Ibid.
141 "Examples of Open Innovators" Open Innovators 14 Feb. 2012 <http://www.openinnovators.net/list-open-innovation-crowdsourcing-examples/>.
142 Smith, Rich. "Lego Engineering" 14 Feb. 2012 <http://www.symscape.com/blog/lego-engineering>.

participatory innovation schemes discussed in various contexts earlier in this report. Joint intellectual property is, for instance, a factor of enormous stickiness, as would be the opening up of the design of standard platforms to a possibly select group of 'complementors', the latter, of course, under the strict control of the system integrator in question.

One not very likely reason for system integrators relying on the subsidiary model could, of course, be that this would be the optimum capital allocation, even if profit rates might be less than at system integrator level. This would assume that capital at system integrator level is abundant, and it is not, but would also assume that in the conglomerate situation the subsidiary would be as profitable as if it was independent. This is also hardly the case in most situations. Sharing physical and administrative infrastructure might invite thoughts of rationalisation benefits, but this is mostly a mirage. Ultimately the rationale comes down to 'security in numbers' or a collectivistic approach. The conglomerate becomes 'too big to fail' and the subsidiary gets a sort of insurance cover by being part of the conglomerate. The conglomerate is more forgiving than the market and by bundling companies within a conglomerate the collective gains a critical mass which moves a customer more effectively than if the customer could pick and choose different companies in a free market for different steps in the process, as traditional free-market capitalism would demand.

In other words, a conglomerate structure means higher industrial stability, more heritage knowledge but less innovation. In the trade-off between stability and efficiency and innovation, Europe has chosen stability.

ESA should carefully consider whether current industrial ownership paradigms for intellectual property – where IP rights generated under ESA industrial contracts remains largely with the industrialists – could be revised for the better. The alternative, more closely aligned with publicly funded research policy, would be to build a key technologies platform open to all European industry, thus providing a tool for broad participatory development and innovation. Access to the platform could be controlled and limited to recognised European entities to form a genuine European space technology ecosystem.

4. Concurrent Design Facilities as Innovation Tool

One of the latest approaches in product development is concurrent engineering. Concurrent engineering is based on the parallelisation of tasks in which functions of design engineering, manufacturing engineering and others are integrated to reduce the time required to design a new product. Concurrent engineering involves two concepts.

The first concept is that all elements in a product's life-cycle, from functionality, producibility, assembly, testability, maintenance, environmental impact and finally disposal and recycling, should be taken into consideration in the early design phases.[143] The second is that the described design activities should all be occurring at the same time. The concurrent engineering approach is based on five key elements: a process, a multidisciplinary team, an integrated design model, a software infrastructure and a state-of-the art facility accommodating all actors at the same time and enabling cooperation by allowing all to work off one large screen, whilst still having access to separate work-stations. Concurrent engineering is a closed innovation process.

In a study of 700 firms over a five year period performed by management consult Booz revealed that new products accounted for 28% of company growth.[144] The failure rate of new products introduced in the market remained in the 33-35% range between 1963 and 1981.[145] Based on a generalised success curve, about 3000 raw ideas are required to produce one new commercially successful industrial product.[146] New products are very costly and only one of seven new product ideas are carried to the commercialisation phase.[147] Consequently, the successful product must return the cost of six failed product ideas in addition to its own development cost. Concurrent engineering approaches have – because of their integrated development process – the potential to increase success rate and lower associated failure costs.

4.1 ESA's Concurrent Design Facility

Concurrent engineering has been introduced for space mission assessment and design. In June 1994 the NASA Jet Propulsion Laboratory (JPL) opened the Project Design Centre (PDC) in order to develop and implement new tools and processes for engineering of space systems.[148] The European Space Agency's Concurrent Design Facility (CDF) was established at ESTEC in November 1998 for the same purpose on an experimental basis.

The ESA CDF "is a systematic approach to integrated product development that emphasises the response to customer expectations. It embodies team values of co-operation, trust and sharing in such a manner that decision making is by consensus, involving all perspectives in parallel, from the beginning of the product life-cycle". The concurrent engineering approach as an alternative to classical approaches takes full advantage of today's information and communication technologies and provides better designs in a shorter period of time. The disciplines typically utilised in the ESTEC CDF are: systems, infrastructure, mission analysis, propulsion, altitude and orbit control, structures/configuration, mechanisms/pyrotechnics, thermal, power, command and data handling, communications, ground systems and operations, simulation, cost analysis, risk assessment, and programme management. The conceptual model of the design process is shown in Figure 3. Space systems have many interdependencies between components. This means the definitions of a component will affect other components and vice versa, affecting the complete system. In order to find the optimal solution it is important to identify the impact and opportunities of these interactions at an early

[143] Kusiak, Andrew, ed. Concurrent Engineering: Automation, Tools and Techniques. New York: Wiley-Interscience, 1992.
[144] Booz Allen Hamilton Inc., ed. New Product Management for the 1980's. New York: Booz, Allen & Hamilton Inc., 1982.
[145] Ibid.
[146] Stevens, Greg A., and James Burley. "3000 Raw Ideas = 1 Commercial Success." Research Technology Management 40.3 (1997): 16-27.
[147] Booz Allen Hamilton Inc., ed. New Product Management for the 1980's. New York: Booz, Allen & Hamilton Inc., 1982.
[148] Smith, Jeffrey L. "Concurrent Engineering in the Jet Propulsion Laboratory Project Design Center." La Cañada Flintridge: California Institute of Technology, 1998.

stage; this can be done though concurrent engineering in the CDF.

The process starts with meetings involving a restricted number of specialists (customer, team leader, system engineer) in order to refine and formalise the mission requirements, define the constrains and establish the design drivers and to estimate the resources needed. Then, the design process is conducted in a series of meetings with all specialists present. This interactive process addresses all aspects of system design simultaneously, which reduces design time and risk of incorrect or conflicting design assumptions as each major decision is discussed and agreed with all specialists present.

The concurrent design facility concept is innovation friendly in the sense that it can be highly creativity-inducing to have all relevant innovation players in one room, with all resources available and a central wiki-type projection of the state-of-play. The concurrent design facility is in the final analysis a tool helping to focus the minds of a team, and as such it can be highly relevant far beyond mission design; can be applied as an innovation tool for space and non-space innovation and can be used iteratively as an integral part of the innovation tool box made available to a given innovation team.

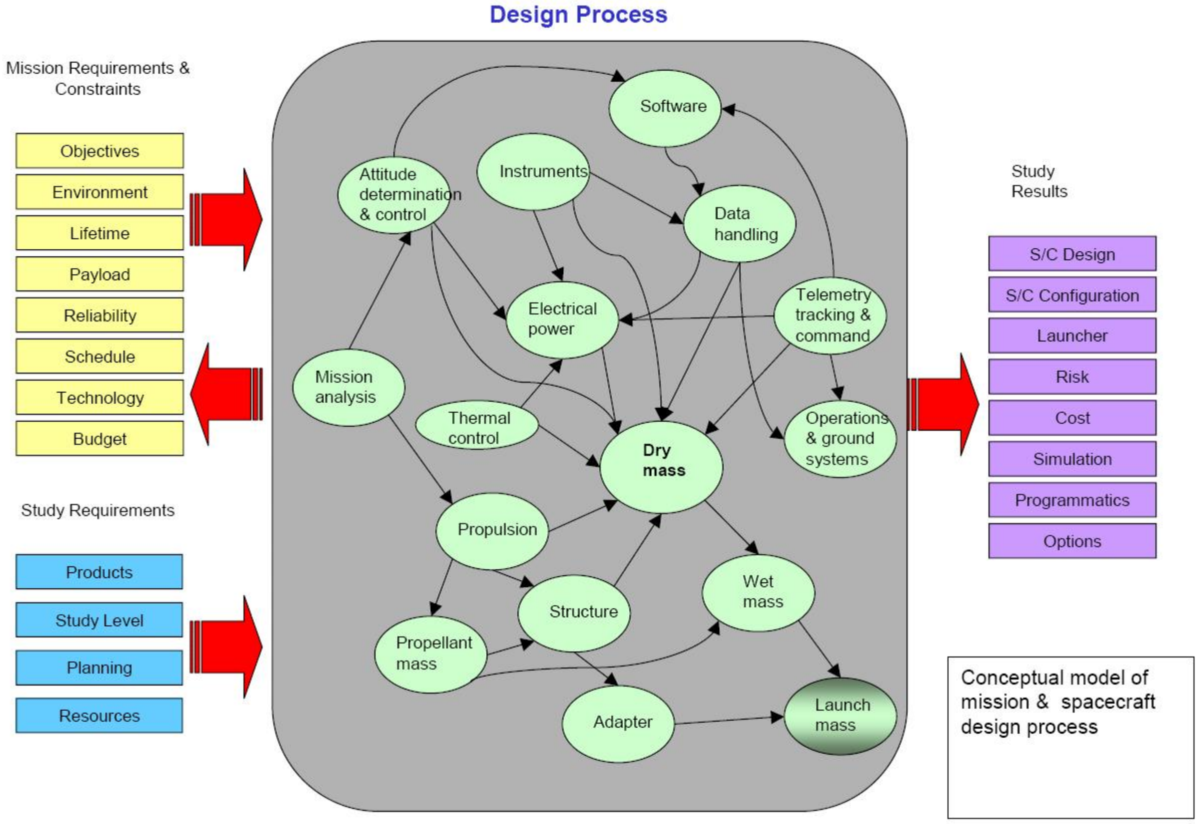

Figure 3: Conceptual Model of the Mission and Spacecraft Design Process [149]

[149] Bandecchi, Massimo, Bryan Melton, and Franco Ongaro. "Concurrent Engineering Applied to Space Mission Assessment and Design." ESA bulletin 99 (1999).

5. Industry, Institute, University Interfaces

Success born of close university-industry ties has been the focus of recent studies[150,151,152] on innovation, serving as a testament to a growing relevance of collaborative innovation sources. Many of these relationships are initiated and maintained as formally established inter-organisational arrangements, such as research and development alliances[153] or innovation centred collaboration along the supply chain[154]. University-industry links are traditionally focused on intellectual property transfer including patenting, licensing and commercialisation. Considering the diffusion of technology transfer offices and science parks between universities and industry, perhaps it is no coincidence that universities are increasing patent production[155], have shown increased revenues from patents[156], increased researchers involvement in entrepreneurship[157], and increased industry funding[158]. Linking public research organisations such as universities and scientific institutes with industry is considered a source of 'real world' perspectives for universities that might otherwise be very focused on theoretical work.

The collaborative relationships usually consist of joint research, joint publishing, contract research, financing of university research assistants by firms, staff movement between universities and training co-operation in education and of corporate staff at universities.[159] Less formal social relationships between employees of different organisations can also impact knowledge creation and dissemination. The Massachusetts Institute of Technology (MIT) Technology Licenses Office encourages maintaining relationships with companies even if no particular project is being pursued; since MIT has around 500 invention disclosures reported each year, their innovation portfolio is constantly evolving.[160]

Research partnerships	Inter-organisational arrangements for pursuing collaborative R&D
Research services	Activities commissioned by industrial clients including contract research and consulting
Academic entrepreneurship	Development and commercial exploitation of technologies pursued by academic inventors though a company they partly own
Human resource transfer	Multi-context learning mechanisms such as training of industry employees, postgraduate training in industry, graduate trainees and secondments to industry, adjunct faculty
Informal interactions	Formation of social relationships and networks at conferences, etc.
Commercialisation of property rights	Transfer of university-generated IP (such as patents) to firms, e.g. via licensing
Scientific publications	Use of scientific documentation within industry

Table 3: University-Industry Links[161]

[150] Perkmann, Markus, and Kathryn Walsh. "University-Industry Relationships and Open Innovation: Towards a Research Agenda." International Journal of Management Reviews 9.4 (2007): 259-280.
[151] Perkmann, Markus, and Kathryn Walsh. "Engaging the Scholar: Three Types of Academic Consulting and Their Impact on Universities and Industry." Research Policy 37.10 (2008): 1884-1891.
[152] Bekkers, Rudi, and Isabel M.B. Freitas. "Analyzing Knowledge Transfer Channels between Universities and Industry: To What Degree Do Sectors also Matter?" Research Policy 37.10 (2008): 1837-1853.
[153] Hagedoorn, John, and Jos Schakenraad. "Leading Companies and Networks of Strategic Alliances in Information Technologies." Research Policy 21.2 (1992): 163–190.
[154] Harabi, Najib M. "Innovation through Vertical Relations between Firms, Suppliers and Customers: a Study of German Firms." Industry and Innovation 5.2 (1998): 157–181.
[155] Nelson, Richard R. "Observations on the Post-Bayh–Dole Rise of Patenting at American Universities." Journal of Technology Transfer 26.1–2 (2001): 13–19.
[156] Thursby, Jerry G., Richard Jensen, and Marie C. Thursby "Objectives, Characteristics and Outcomes of University Licensing: a Survey of Major U.S. Universities." Journal of Technology Transfer 26.1 (2001): 59–72.
[157] Shane, Scott, ed. Economic Development through Entrepreneurship: Government, University and Business Linkages. Cheltenham: Edward Elgar Publishing, 2007.
[158] Hall, Bronwyn H., ed. Proceedings of the 6th International Conference on Technology Policy and Innovation, 12-15 Aug. 2002, Kansai, Japan. Ashland, OH: Purdue University Press.

[159] Schartinger, Doris, Christian Rammer, Manfred M. Fischer, and Josef Fröhlich. "Knowledge Interactions Between Universities and Industry in Austria: Sectoral Patterns and Determinants." Research Policy 31.3 (2002): 303–328.
[160] "For Industry" MIT Technology Licising Office 6 Jun. 2012 http://web.mit.edu/tlo/www/industry/inquiries.html.
[161] Perkmann, Markus, and Kathryn Walsh. "University-Industry Relationships and Open Innovation: Towards a

Sectors with low R&D ratios such as energy, basic metals, construction and agriculture have the highest concentrations of university-industry collaborative R&D.[162] In science-based sectors such as pharmaceuticals, biotechnology and chemicals, with strong complementarities between academic research and industry R&D, industries tend to rely on collaborative research (open science channel) as well as research services (contract research and consulting).[163]

Although some industrial sectors like pharmaceuticals and biotech naturally lend themselves to a heavy dependency on the hard sciences, industry-university relationships are actually much more expansive. They are, for example, often utilised to address food production and management, medical equipment, petroleum, metals, and navigation equipment.[164] Sectors emphasising incremental improvement and innovation rather than scientific breakthroughs, such as mechanical engineering or software development, tend to prefer research services only.

Size and research capabilities of a particular industrial entity may play a role. The influence of research coming from universities on industrial R&D is disproportionally greater for start-ups than for mature corporations. Firms which invest a lot in R&D are more prone to have absorptive capabilities to learn and interact with universities.[165] University departments with greater focus on applied research and on technological development seem to interact more with industry. Departments with higher level of private financing might be more willing to support technology transfer to industry in contrast to those that mostly receive public finding.[166] Individual researcher characteristics also impact the technology transfer process. Researchers with more experience in industry-university collaborative research, with higher number of patents, as well as with more entrepreneurial skills seem to be more willing to support knowledge transfer to industry.[167]

Regardless of potential setbacks through reluctant researchers or university department tendencies, technology transfer processes are a key component the innovation process. University Technology Transfer offices, especially in the U.S., often serve as the powerful link between university-bred inventions and investors who would take a product to market. More than just a legal broker ensuring adherence to IP regulations and investor safety, modern technology transfer offices are essentially innovation consultants; part of their charter is to turn innovations into tangible products while making university research sustainable. When an invention is disclosed, a tech transfer office will launch into an assessment phase which involves ensuring protection of the intellectual property while marketing to find the best licensee, which is usually a partnership with an existing business or a start-up. Tech transfer offices continue to be involved when an invention is licensed to a suitable party and oversees revenue-gathering from that invention, which is then reinvested in research and education at the original university.[168]

Tech transfer give universities more power to negotiate what happens with their inventions, balancing the desire to profit and benefit society without diminishing the importance of traditional research science; ideally, the appreciation for basic research so central to academia's identity and long-term mission will balance the vast, lucrative potential that comes from bringing research results to market. In terms of U.S. universities, tech transfer offices have been enormously successful in maintaining this balance and in serving as a pillar for U.S. technical dominance. Stanford's primary objective is not to license an invention so as to maximise revenues but to promote its widest possible use.[169]

Luckily, the two things appear to coincide. The U.S. government pays for approximately 85% of Stanford's research and Stanford has produced revenues that greatly exceed gov-

Research Agenda." International Journal of Management Reviews 9.4 (2007): 259-280.

[162] Schartinger, Doris, Christian Rammer, Manfred M. Fischer, and Josef Fröhlich. "Knowledge Interactions between Universities and Industry in Austria: Sectoral Patterns and Determinants." Research Policy 31.3 (2002): 303–328.

[163] Perkmann, Markus, and Kathryn Walsh. "University-Industry Relationships and Open Innovation: Towards a Research Agenda." International Journal of Management Reviews 9.4 (2007): 259-280.

[164] Cohen, Wesley M., Richard R. Nelson, and John P. Walsh. "Links and Impacts: the Influence of Public Research on Industrial R&D." Management Science 48.1 (2002): 1–23.

[165] Cohen, Wesley M., Richard R. Nelson, and John P. Walsh. "Links and Impacts: the Influence of Public Research on Industrial R&D." Management Science 48.1 (2002): 1–23.

[166] Colyvas, Jeanette, Michael Crow, Annetine Gelijns, Roberto Mazzoleni, Richard Nelson, Nathan Rosenberg, and Bhaven N. Sampat. "How Do University Inventions Get into Practice?" Management Science 48.1 (2000): 61–72.

[167] Zucker, Lynne G., Michael R. Darby, and Jeff S. Armstrong. "Commercializing Knowledge: University Science, Knowledge Capture, and Firm Performance in Biotechnology." Management Science 48.1 (2002): 138–153.

[168] "The Technology Transfer Process at a Glance." Stanford University Office of Technology Licensing 6 Jun. 2012 <http://otl.stanford.edu/documents/process.pdf>.

[169] Wiesendanger, Hans. "A History of OTL: Overview." Stanford University Office of Technology Licensing 6 Jun. 2012 <http://otl.stanford.edu/about/about_history.html.>.

ernment investment.[170] Out of 504 innovation disclosures received by the Stanford OTL office over the 2010-2012 fiscal year, 600 technologies emerged that generated income from the release of 101 licenses. Gross royalties stood at $66.8 million with $2.4 million generated from liquidated equity.[171] In 2010, MIT reported 26 companies started through their Technology Licenses Office, either via venture capital and/or with a minimum of $50K funding from other sources.[172] In 1999, University Technology Managers reported that at the end of the fiscal year, over 21,000 licensing agreements were created along with 2,922 new business ventures, and 12,324 patent invention disclosures. Collectively, these investments generated $862 million in royalties and pumped $40.9 billion into the U.S. economy.[173]

Following the success of a major U.S. university like Stanford quickly points to the importance of a proactive tech transfer office in optimising innovation potential through revenues and reinvestment as well as a nod to the Bayh-Dole Act (BDA) legal framework underlying each partnership. The BDA gives universities independent ability to enter "into contractual arrangements to perform research in collaboration with private industry and to license the patented inventions discovered through these collaborations and other federally funded research programs."[174] Under the BDA, government entities can collect royalties from licensing partners, although the scope of the royalty rate is not specified.[175] Even though inventors do see some dilution of individual IP rights under the BDA framework, working through quality technology transfer offices appear to preserve and even promote fiscal benefits. In 2010, over 13 million U.S. dollars were distributed to inventors working under the jurisdiction of the MIT Technologies Licensing Office.[176]

Individual European countries' disparate reactions to the BDA show a deep lack of consensus even though more "central" European entities like the EU have been vocal in calling for system reform in favour of strengthening knowledge transfer mechanisms — or tech transfer-esque institutions within universities — and generally pushing for clarity within IP law itself.[177] The differences between Europe and the U.S. centre on IP law clarity and different academic cultural norms.

Many leading European countries have "access to the same technology, experienced similar standards of living, were governed by similar political systems, and actively and substantially funded government research projects"[178]. This lends support to the idea that IP law salience and differing attitudes towards academic research are key determinants in analysing Europe's frailty in generating revenues from licensing innovation.

Germany and the UK have passed legislation similar to the BDA and quickly benefited. In Germany, as of 2002, "the German Employed Inventor's Act revoked the long-standing privilege for employees of universities, such that a university now can lay claim to inventions created by its employees with government funding".[179] Germany earned over 16 million euro from licensing revenues in 2003 but that notwithstanding, EU reports note that "despite these efforts, there is under-utilisation of technology and lack of cohesive technology transfer policies."[180]

Sweden has explicitly rejected the adaptation of BDA-style legislation; "since 1949, Swedish intellectual property laws stipulated that researchers retain all rights to their inventions."[181] In France, it is still unclear who may claim ownership to innovations born of state-funded research institutions, and no specific measures have been taken to encourage large public facilities to use technology-transfer style partnerships to commercialise.[182]

A great number of European governments and leaders have called for a clear patent system that encompasses larger communities — or perhaps even unites the globe under a single policy — in order to address prosecu-

[170] Ibid.
[171] Ibid.
[172] "Frequently Asked Questions." MIT Technology Licensing Office 6 Jun. 2012 <http://web.mit.edu/tlo/www/about/faq.html>.
[173] Siepmann, Thomas J. "The Global Exportation of the U.S. Bayh-Dole Act." University of Dayton Law Review 30.2 (2004): 209-243.
[174] Ibid.
[175] Ibid.
[176] "Frequently Asked Questions." MIT Technology Licensing Office 6 Jun. 2012 <http://web.mit.edu/tlo/www/about/faq.html>.
[177] Siepmann, Thomas J. "The Global Exportation of the U.S. Bayh-Dole Act." University of Dayton Law Review 30.2 (2004): 209-243.
[178] Ibid.
[179] Economic Policy Committee, Working Group on Research and Development. Report on Research and Development, Final Annex A: Detailed Reports of Visits to Member States and US/Canada and Examples of Good Practice, EPC/ECFIN/01/777-EN, A21 final on 22 Jan. 2002. Brussels: European Union.
[180] Ibid.
[181] Ted Agres. "Euros for Discoveries? European Scientists Follow Their US Counterparts to the Market." 29 Apr. 2012 <http://www.the-scientist.com/yr2002/apr/prof1_020429.html>.
[182] Siepmann, Thomas J. "The Global Exportation of the U.S. Bayh-Dole Act." University of Dayton Law Review 30.2 (2004): 209-243.

tion costs.[183] A country's entire patent regulation scheme can be upended by weak intellectual property laws and expensive patent prosecution.[184] Clearer patent laws in and of themselves would likely be a huge step in getting universities excited about actually using the tech transfer mechanism; after all, "if legal scholars cannot interpret the laws surrounding intellectual property in this context, it is unlikely that scientists can either."[185]

A 2002 EU report cited European academic culture as a possible barrier to successfully commercialising innovations. The report listed continued over-reliance on a 'linear' approach to innovation that assumed supply side investments would automatically produce marketable inventions, and research paper production being a preferred barometer for academic success rather than patents.[186]

University-industry ties, especially in the context of the Stanford case study conducted here, owe a great debt to the legal framework of the BDA, which brings the importance of an active, science-minded legislature in sharp relief. Mindful, timely legislation paired with a willingness to pour massive amounts of U.S. federal capital into the sciences can not be underestimated, and reflects a fundamental national policy tenant that connects innovation with economic well being. This vast federal support for innovation is what enables tech transfer offices to profit, having adapted an entrepreneurial, business-savvy approach to collaboration.

Although there are drawbacks to adapting IP legislation emulating the BDA, it is difficult to ignore that although "some discoveries made by U.S. government laboratories were patented, the opportunity to exploit intellectual property gains from government funded research was largely ignored by private industry before the BDA was enacted".[187]

In summary, university-industry links are more nuanced than merely "technology transfer" and "knowledge transfer". There are interaction channels and mechanisms across various industries. Patents and other university generated IPs are only moderately important for innovation processes when compared with relationship-based mechanisms. University-generated knowledge is not limited to scientific breakthroughs and radical innovations and is relevant to all stages of the innovation cycle. Industry motives for participating in university-industry partnerships vary, but they are not limited to the generation of and access to innovative commercial products.

5.1 University-Industry and Academic Consulting

Academic consulting is a service provided by academics to external organisations on commercial terms to resolve problems and to generate or test new ideas.[188] There are three types of academic consulting: opportunity-driven, commercialisation-driven and research-driven.[189]

Opportunity-driven consulting involves academics solving specific known problems rather than suggesting new project ideas or pioneering new design configurations.[190] Academics are typically motivated by monetary incentives to pursue this type of consulting. From the industry perspective, it is an opportunity to access a specific pool of expertise. This relationship is different than other university-industry relationships because it mo-

[183] Economic Policy Committee, Working Group on Research and Development. Report on Research and Development, EPC/ECFIN/01/777-EN, 32 final on 22 Jan. 2002. Brussels: European Union.
[184] Economic Policy Committee, Working Group on Research and Development. Report on Research and Development, Final Annex A: Detailed Reports of Visits to Member States and US/Canada and Examples of Good Practice, EPC/ECFIN/01/777-EN, A21 final on 22 Jan. 2002. Brussels: European Union.
[185] Siepmann, Thomas J. "The Global Exportation of the U.S. Bayh-Dole Act." University of Dayton Law Review 30.2 (2004): 209-243.
[186] Economic Policy Committee, Working Group on Research and Development. Report on Research and Development, EPC/ECFIN/01/777-EN, 32 final on 22 Jan. 2002. Brussels: European Union.
[187] For recent publications on the debate, see: Sidebottom, Diane M. "Updating the Bayh-Dole Act: Keeping the Federal Government on the Cutting Edge." 30 Pub. Cont. L. J. 225 (Winter 2001) (contending that the BDA actually increases the evils it was meant to address rather than remove the evils); Peter, Arno S., and Michael H. Davis. "Why Don't we Enforce Existing Drug Price Controls? The Unrecognized and Unenforced Reasonable Pricing Requirements Imposed Upon Patents Deriving in Whole or in Part From Federally Funded Research." 75 Tul. L. Rev. 631 (2001) (citing abuses of the BDA and the negative costs it inflicts); Eisenberg, Rebecca S. "Public Research and Private Development: Patents and Technology Transfer In Government-Sponsored Research." 82 Va. L. Rev. 1663 (1996) (stating much opposition to the theoretical premise of the BDA itself); Mark G. Bloom, Mark G. "University Licensing: Past, Present and Into the New Millennium." 2002 Licensing Update § 7.06 (contending that the BDA is largely responsible for creating the competitive edge the U.S. now enjoys in the intellectual property market).
[188] Perkmann, Markus, and Kathryn Walsh. "Engaging the Scholar: Three Types of Academic Consulting and their Impact on Universities and Industry" Research Policy 37 (2008): 1884-1891.
[189] Ibid.
[190] Cohen, Wesley M., Richard R. Nelson, and John P. Walsh. "Links and Impacts: the Influence of Public Research on Industrial R&D." Management Science 48.1 (2002): 1–23.

bilises expertise that is typically confined within academia itself. It is often seen to be of less academic value and as not directly contributing to research and teaching; the activity requested by clients does not constitute research but the application of scientific knowledge to a specific problem.[191]

Commercialisation-driven consulting is linked to academics' efforts to commercialise their own technologies.[192] Such academics, however, are unlikely to be objective judges of their technology and the risks associated with it. Often university inventors retain their university position and engage with the commercialising entity through a consulting, contract research, or personnel exchange and advisory board role. Commercialisation-driven consulting will likely skew the research interests of an academic as they are a follow-on activity from the inventive activity. Established companies might benefit as the commercialisation might allow them to accelerate development along an already chosen path and spin-in technology.

Research-driven consulting pertains to academics maintaining a consulting relationship with firms that support the research. This type of consulting is typically used by large firms in research-intensive sectors who want to inform and validate the direction of their R&D and long term product development efforts. This is not a novel practice, a report of 1995 showed that in all industries, pharmaceuticals excluded, over half of a sample of industry relevant academics said that the problems and ideas they worked on in their government-funded research often emerged from consulting.[193] Academics are drawn to this type of consulting if they want insight into industry challenges or access to certain research facilities. Companies choose research-driven consulting to extend in-house research capacity and create emerging technologies.[194]

[191] Salter, Ammon J., and Ben R. Martin. "The Economic Benefits of Publicly Funded Basic Research: a Critical Review." Research Policy 30.3 (2001): 509–532.
[192] Agrawal, Ajay. "Engaging the Inventor: Exploring Licensing Strategies for University Inventions and the Role of Latent Knowledge." Strategic Management Journal 27.1 (2006): 63–79.
[193] Mansfield, Edwin. "Academic Research Underlying Industrial Innovations: Sources, Characteristics, and Financing." Review of Economics and Statistics 77.1 (1995): 55–65.
[194] Santoro, Michael D., and Alok K. Chakrabarti. "Firm Size and Technology Centrality in Industry-University Interactions." Research Policy 31.7 (2002): 1163–1180.

5.2 Professor-Consultant

The role of academia in university-industry relationships is usually embodied by the professor-consultant whose professional identity remains connected with the university even though he or she may spend a comparable amount of time working for a private company. Both the university and industry involved tend to view this relationship as mutually beneficial. The professor-consultant's role as a part-time industry player improves the quality of the university itself and student experiences therein, bringing practical knowledge and contemporary business culture and practice into the academic community.[195] From an industry perspective, knowledge flowing back into academia from professor experience in the private sector will translate into producing better employees in the future; theoretically, the professor-consultant will prepare students to work in a way relevant and actually tailored to the industry.

5.2.1 Part-Time Professor

The equation changes slightly when a professor's primary professional identity remains with their original private employer. In the Dutch tradition, the title of 'Extraordinary Professor' (now 'Part-time Professor', after a 1986 reform) is held by those professors whose primary employer is an industry or research institute. Hiring such a person allows a university to bring in specialised expertise that otherwise would not be available. This practice can be traced back to the seventeenth century. During the 1970s, the role of the part-time professor became an explicit subject of Dutch science policy. An OECD Report on Dutch science policy published in 1973 stressed the importance of the part-time professor's special role in the Dutch system. "[The] institution of part-time professors [...] offers the opportunity of carrying out research at institutes or laboratories attached either to universities or industrial firms. More than 20% of all Dutch universities professors are involved in non-university research in this way"[196]. The report also stated that, despite the fact that Dutch universities carried out less contract-research compared to other countries, a close relationship existed between industrial and academic

[195] Treviño, Ana C. ed. The Multiple Roles and Benefits of Working Part-time as a Professor and Part-time Partnership with Industry. Monterrey: ITESM Center for Knowledge Systems, 2000.
[196] OECD Report cited in Steijn, Frans V. "Part-time Professor in the Netherlands: Old Wine in New Bottle?" European Journal of Education 20.1 (1985): 57-65.

research thanks to the institution of the extraordinary professor.[197]

Many universities today hire part-time professors with dominant industry identities to better incorporate this productive information-sharing paradigm. Newcastle University and Newcastle Science City hire professors of practice, successful businesspeople or distinguished representatives of industry appointed for a part-time period who continue to run their own companies during their time at the university. This practice is geared toward "transforming academic research into business practice" and "[b]ringing industrial connections to the University."[198] Part-time professors are also prevalent at Stanford University. Consulting appointments at Stanford for Assistant and Associate Professors are typically for one year with the option to renew.[199]

The use of contingent faculty in higher education in the United States has grown tremendously over the past three decades, mostly for budgetary reasons.[200] A statistical survey sponsored by the U.S. Department of Education revealed that by 2003, when the survey was conducted, approximately half of the respondents representing faculty employed part-time reported that they held a full-time job outside university that they considered their primary occupation.[201]

The titles of Extraordinary Professor, Professor of Practice, and Consulting Professor are conferred to individuals who hold a full-time position outside university (industry, business or governmental agencies) and are appointed as part-time professors *because* of their non-university experience. This kind of university-industry relation provides universities and students with a window to industry expertise, culture and needs. It helps shape student competency in accordance to industry's needs so that students are better prepared to satisfy labour market requirements once they graduate. There is a high possibility that, thanks to the personal relationships with part-time professors with industrial connections, the best students will be able to find a direct path to employment.

5.2.2 Full-Time Professors Engaged Part-Time in Outside Work

Regular, full-time professors working outside university on a part-time basis is becoming more important for American universities. At Harvard, for example, "consultancies, advisory engagements, service on for-profit and not-for-profit boards, translational ventures, and numerous other outside activities provide opportunities for faculty to direct their expertise and learning to socially useful applications. Faculty members' collaboration with outside organisations and communities furthers Harvard's mission of societal service and also benefits the university. Such interactions promote intellectual exchange, enhance professional development, spawn further discovery, and augment and renew the vitality of the university".[202] At University of California, "a faculty member may pursue compensated outside professional activities that advance or communicate knowledge through interaction with industry, the community, or the public, and through consulting or professional opportunities. Such activities give the individual experience and knowledge valuable to teaching, research, and creative work activity and/or provide a university-related public service".[203]

Stanford University Prof. Cheriton, a computer science professor, is also a chief scientist at Arista Networks, a company he co-founded. Some universities explicitly prohibit this kind of in-depth private involvement outside the university itself. For example, the University of Notre Dame prohibits "full-time members of the faculty … from having active ownership of, and/or managerial involvement in, a business/professional enterprise".[204] In general, outside work is strictly regulated by universities to avoid conflicts of interest. Consequently there is a high possibility that

[197] Ibid.
[198] Ibid.
[199] "Stanford University Faculty Handbook 2010." 1 Mar. 2012 Stanford University <http://facultyhandbook.stanford.edu/pdf/University%20Faculty%20Handbook%202010.pdf>.
[200] Monks, James. "Who Are the Part-time Faculty? There Is No Such Thing as a Typical Part-timer" Academe Online 2 Mar. 2012 <http://www.aaup.org/AAUP/pubsres/academe/2009/JA/Feat/monk.htm>.
[201] Forrest Cataldi, Emily, Mansour Fahimi, Ellen M. Bradburn, and Linda Zimbler, eds. National Study of Post-secondary Faculty (NSOPF:04) Report on Faculty and Instructional Staff in Fall 2003. Washington D.C.: National Center for Education Statistics, 2005.
[202] "Harvard University Policy on Individual Financial Conflicts of Interest for Persons Holding Faculty and Teaching Appointments. As approved by the President and Fellows of Harvard College on May 26, 2010." Harvard University 5 Mar. 2012 <http://provost.harvard.edu/policies_guidelines/Harvard_University_fCOI_policy.pdf.>.
[203] "University of California General University Policy Regarding Academic Appointees." University of California 5 Mar. 2012 <http://www.ucop.edu/acadpersonnel/apm/apm-025-07-01.pdf>.
[204] "University of Notre Dame Faculty Handbook." University of Notre Dame 5 Mar. 2012 <http://facultyhandbook.nd.edu/university-policies/outside-activities/.>.

many engagements are not disclosed to university administrators.[205]

In sectors like aerospace, biotechnology and computer science, research outputs are utilised as inputs to further research and technology development, while problems arising in technology development lead to other follow-on research activities.[206] Since research is "recursively intertwined with technological development", academics are an irreplaceable source of knowledge for technology developers.[207] If professors are able to balance long-term goals of academic research with more short-term industry objectives—assuming conflicts of interests are avoided—academics in research-intensive industry sectors on a part-time basis may be a positive way to integrate university-industry R&D.

5.2.3 Historical & Cultural Influences on University-Industry Relations

The Unites States serve as a great indicator that healthy relationships between the academic community and industrial sector produces an economy rich with innovations and productive information exchange. Japan, conversely, is something of a cautionary tale. In Japan, interaction between academia and the private sector is highly restricted and may affect both the quality of university teaching and the competitiveness of industry at global level.

According to a 2007 study by the World Intellectual Property Organisation (WIPO), university-industry relations are considerably affected by the historical and cultural background of individual countries.[208] WIPO reported that in Japan many of the best universities are traditionally state-owned and, till mid-1990s, were usually separated from the private sector. "Universities believed that they must be allowed to pursue truth, free from the interests of external agencies such as government and business"[209]. They had little interest in working with business or helping industry to solve technical problems. By the late 1990s, however, Japanese firms became drastically less competitive. With new threats posed by accelerating Korean and Chinese industrialisation, Japan moved to fundamentally transform its university-industry relationships. Japan understood that decreased university competitiveness was a result of inadequate interaction with industry and began to consider partnering with university as a necessity. "Utilising the most advanced knowledge developed by universities in a speedy fashion became a matter of the highest priority" for the entire nation. Japan still approaches these kinds of partnerships cautiously. Its fear that academic and educational missions may be hindered if they become too dependent upon commercial interests is still strong. Nonetheless, many universities are changing their approach to the matter and trying to find a balance between challenges and opportunities which relation with industry may bring.[210]

Some European countries face similar issues.[211] Most European universities are state-owned and some show the same wariness towards academic-industrial partnerships as their Japanese counterparts. Comparative studies show that European students have at least the same level of knowledge as their U.S. colleagues, but their innovativeness in application of this knowledge is significantly lower.[212] This can be explained by a dearth of university-industry interaction of the past decades that have caught universities unprepared to cope with the development pace of the new economy.

China has a long history of positive industry-university relationships. Chinese Communist regimes have always prioritised production, and all national institutions, universities among them, had to contribute by collaborating with industry. Industry-university relationships, however, were not formally regulated and this situation did not change until 1985, when the Central Committee of the Chinese Communist Party passed the Decision on the Reform of Scientific and Technological Systems. Considered a turning point in Chinese science and technology policy, this

205 Perkmann, Markus, and Kathryn Walsh. "Engaging the Scholar: Three Types of Academic Consulting and their Impact on Universities and Industry" Research Policy 37 (2008): 1884-1891.

206 Nathan Rosenberg (1992), cited in Perkmann, Markus, and Kathryn Walsh. "Engaging the Scholar: Three Types of Academic Consulting and their Impact on Universities and Industry" Research Policy 37 (2008): 1884-1891.

207 Perkmann, Markus, and Kathryn Walsh. "Engaging the Scholar: Three types of Academic Consulting and their Impact on Universities and Industry" Research Policy 37 (2008): 1884-1891.

208 "Technology Transfer, Intellectual Property and Effective University-Industry Partnerships: The Experience of China, India, Japan, Philippines, the Republic of Korea, Singapore and Thailand." 2007 World Intellectual Property Organization (WIPO) 7 Mar. 2012 <http://www.wipo.int/freepublications/en/intproperty/928/wipo_pub_928.pdf>.

209 Ibid.

210 Ibid.

211 Since Japan had taken European countries (and Germany in particular) as a model to modernize itself, the evolution of its institutions followed closely that of those countries. See Reischauer, Edwin O., ed. Japan, Past and Present. Rutland: Charles E. Tuttle Company, 1956.

212 Bavec, Cene. "University and the ICT Industry in Search for Innovativeness." University of Primorska, Slovenia 23 Feb. 2012 <http://www.scholze-simmel.at/starbus/r_d_ws2/bavec.pdf.>.

decision allowed universities to shape their research programmes and to transfer technology in relation to the market situation, and to provide economic incentives to those who worked more. "The role of the government changed from direct intervention and control to guidance and oversight, setting laws and regulations under which universities could decide on their own course of action".[213]

5.3 And Space?

The space sector encourages university-private partnerships for space science and earth observation with Announcement of Opportunity Instruments. ESA provides the platform for a satellite or probe, but scientific instrumentation is provided by universities and institutes after a degree of competition under the umbrella of an ESA-issued 'Announcement of Opportunity'. Universities and institutes must often deploy significant innovation activities in order to be able to deliver the instrument required for the scientific purposes of the overall mission. What is noteworthy is that the innovation that might be achieved through the provision of the Announcement of Opportunity Instrument will normally not be widely shared within the space community or even within the space science or Earth Observation community. What is achieved with the Announcement of Opportunity system is that the academic world becomes involved in the practicalities of space flight, and that is good, what is clear is, however, that no highly interactive relationship is established between the academics providing instruments and industry or other academics in terms of the technical innovation involved, unless the latter are part of an academic consortium providing the instrument. A lot of interaction takes place on the use and interpretation of the data ultimately coming from the instruments, but this does not extend to possible technical innovation. A comparative analysis of the innovation effectiveness of industrial versus Announcement of Opportunity approaches could be interesting but goes beyond the scope of the present Report.

ESA has also set up a range of programmes and initiatives (Basic Technology Research Programme, General Support Technology Programme and StarTiger) aimed at innovation in the technology development process, sometimes in cooperation with academia. Furthermore, ESA's Advanced Concepts Team was created in 2002 at the European Space Research and Technology Centre in Noordwijk in order to foster advanced research on space systems, innovative concepts and working methods by engaging in collaborative research with academia.[214] The research is intended to build strategic capacity for ESA's long term planning in fundamental physics, energy systems, propulsion, mission analysis, biomimetics, artificial intelligence, nanotechnologies and informatics & applied mathematics.[215]

Both ESA and industry remain able to attract top-notch talent. It could thus be argued that the university-space application link is not so crucial for innovation. This is, however, not correct. The world of space is insular and all tools available to decrease insularity should be deployed in the interest of efficiency, innovation and broad based support. ESA and industry involve academics to consult on specific issues or challenges, but ESA has not attempted to use the American-style linkage of academics to space practitioners through long term continuous professional involvement. There are many examples of the inverse situation occurring: practitioners holding part-time academic positions or being 'extra-ordinary professors'. The reason for this asymmetry might be cultural, similar to Japan in the past. However, in innovation terms there is a certain danger if the interaction-bridge is unidirectional, only from practitioner to academia. Actually the opposite route is the most auspicious in an innovation sense – a point not lost on Silicon Valley, which uses particularly Stanford University as an innovation pool.

[213] "Technology Transfer, Intellectual Property and Effective University-Industry Partnerships: The Experience of China, India, Japan, Philippines, the Republic of Korea, Singapore and Thailand." 2007 World Intellectual Property Organization (WIPO) 7 Mar. 2012 <http://www.wipo.int/freepublications/en/intproperty/928/wipo_pub_928.pdf>.

[214] "The Advanced Concepts Team" European Space Agency 28 Feb. 2012 <http://www.esa.int/gsp/ACT/index.htm>.

[215] Ibid.

6. Big and Small Companies and Innovation

ESA's ecosystem, composed of large system integrators and subcontracting SMEs, dominates the European space sector. The nature of Europe's space ecosystem raises the question of whether there is a difference in how big and small companies innovate and how they manage innovation.

First, the distinction between sustaining and disruptive innovation should be recalled. Sustaining innovation pushes technology forward along a fairly predictable path. Disruptive innovation is far less predictable in terms of utilisation and development path; it normally creates new – still inefficient – markets. Often the invention's technical performance and reliability are weaker than established products in the same general field – and with higher cost per performance unit. For organisations, giving birth to disruptive innovation requires to move into unknown territory and experiment with new processes that largely elude systemisation. Thus typically, disruptive innovation has been considered the domain of start-up entrepreneurial ventures, which reject the processes and infrastructure of the large established companies in favour of flexible, discovery based approaches to commercialising novel technologies.[216]

There are several reasons why is it worth to focus a bit more on this discrepancy. First of all, the relative importance of these start-ups in space sector should be increasing because of the commercialisation of space activities and changing business practices like spin-offs and university-industry relationships. Second, the typical life-cycle of companies will inevitably alter a given innovation model over time. Third, the conglomerate structure of European space sector might have a considerable impact on the innovation structures of companies in the event of acquisition or corporate merger.

In an article on entrepreneurial models, Freeman and Engel, two researchers of the Lester Center for Entrepreneurship and Innovation, conceive this difference as the result of a combined set of inherent company characteristics in terms of (1) organisational attributes, (2) the role of the innovator, and (3) the operating environments for respective types of companies.[217]

Figure 4 illustrates what the authors mean by the differences in organisational attributes between start-ups and mature corporations. The underlying idea is that the operational modes of companies are – to a large extent – shaped by their corporate cultures, which in turn are largely determined by the phase in their development. As a consequence, smaller companies are more inclined to cultivate an innovation-friendly environment. This effect is amplified by the role and leeway of the innovator. In start-ups, innovators are more likely to act as entrepreneurs, since the limits imposed by the corporate structure and financing are smaller than they are in mature corporations. The latter group is often characterised by a relative abundance of resources, which makes innovators more prone to act like a manager because of the greater need for managerial oversight and direction.[218]

Big companies often master sustaining innovation very well. They have both the resources and expertise to advance well-known technologies to new heights, and are often very successful doing so. IBM has been very successful in introducing innovative mainframe computers. The PC was disruptive technology when it was introduced; IBM mastered this technology as well even if it to some extent cannibalised IBM's mainframe business. Yet, already with the laptop IBM started to become shaky, and now having left both the laptop and the PC market, IBM has avoided having to confront disruptive technologies such as the iPad and handheld devices from Apple and the like.

Despite the success of Apple and IBM, it will likely remain axiomatic that sustaining innovation is most frequently performed in a large company and disruptive technologies are the domain of start-ups. Start-up companies are often forced to be risk tolerant, necessarily

[216] O'Connor, Gina Colarelli, and Christopher M. McDermott. "The Human Side of Radical Innovation" Journal of Engineering and Technology Management 21 (2004): 11 – 30.

[217] Freeman, John, and Jerome S. Engel. "Models of Innovation: Startups and Mature Corporations." California Management Review 50.1 (2007): 94 – 119.

[218] Freeman, John, and Jerome S. Engel. "Models of Innovation: Startups and Mature Corporations." California Management Review 50.1 (2007): 94 – 119.

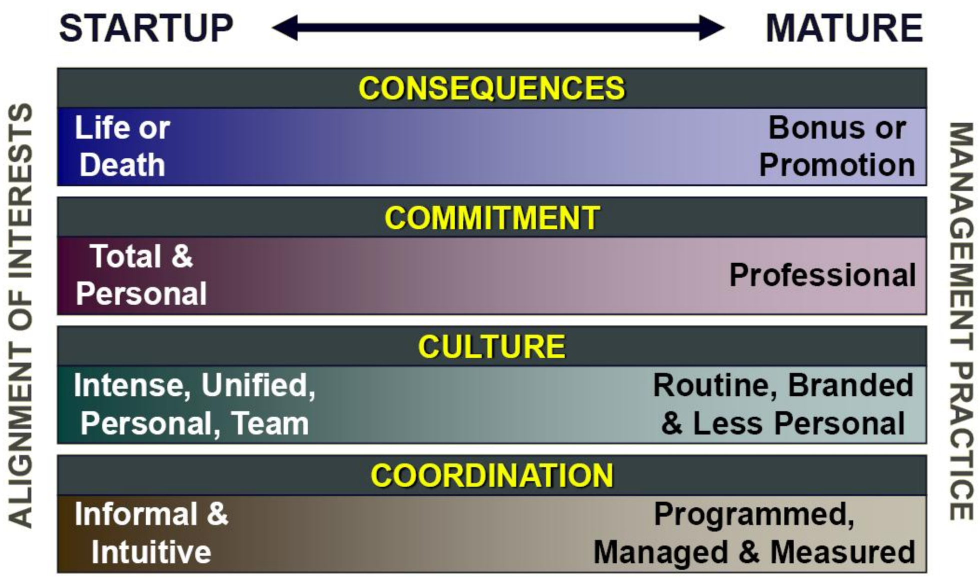

Figure 4: Organisational Attributes in Start-Ups versus Mature Corporations.[219]

highly focused on one or only a few products. This puts start-ups in an ideal position to chase new markets and new applications for their products without engaging in eternal resource competition with sustaining innovation within a larger firm, or having to fear cannibalising other product lines of the firm. Single-mindedness and ruthless pursuit of opportunity are the hallmarks of market entrants.

Surrey Satellite Technology Ltd. (SSTL) is a good example of a market entrant possessing disruptive technology —here, small satellite technology— which began as a small project in a university setting (so an example of successful university-industry innovation). Now SSTL is an independent part of Astrium, and this may be a sign that SSTL's disruptive technology has moved into the domain of being the basis for sustaining innovation, as ultimately happens to all successful disruptive technologies. Yet, if one looks at the miniaturisation of electronics in general and the large number of cubesat and cansat projects being developed, one may wonder whether a new disruptive technology wave might be coming which will challenge not only the large satellite platforms but also the smaller satellites, which were disruptive but are now becoming mainstream. Perhaps in some instances even small is too large!

In terms of innovation theory, it is important to remember that to the extent technology development is predictable it is, per definition, sustaining. Disruptive innovation always contains a large element of unpredictability, and this is one of the reasons it is very important to establish ecosystems around emerging technologies in order to exploit all the possible different routes to the market. This has not really been done for small satellite technology, and is perhaps one of the causes why small satellite technology still has quite a ways to go before having reached its full potential. For cansat and cubesat technology there is an urgent need to set up a proper technology information platform where enthusiasts and professionals can find masses of open information and exchange ideas on how to further such promising technology far beyond the domain of universities and amateurs. A task for the space agencies?

The launcher business is a good case study through which to discuss disruptive and sustaining innovations. Most would argue that Space-X and the Falcon launcher will become disruptive technology, but that conclusion is questionable since SpaceX founder and CEO Elon Musk is introducing only a perfection of already known technology and methodologies. Where the Tesla Motors electric car is clearly disruptive innovation, the Falcon might be a sustaining innovation that has been packaged as disruptive. The same may be true for Paul Allen and Stratolaunch. Disruptive technologies do not enter the mainstream market first but open new markets and thereafter, perhaps, conquer existing markets. Paul Allen's approach of flying launches is certainly radical innovation, but not necessarily disruptive as it still plays to an existing market.

[219] Engel, Jerome S. "Model of Innovation: Start-Ups and Mature Corporations." Presentation. Inside Innovation Conference. University of California, Berkeley. November 2007.

Sustaining innovation is normally a comfortable battlefield for technology incumbents, which can master tremendous resources and bring great expertise to bear. Space-X and Stratolaunch might still be stared down by Boeing, Lockheed Martin and EADS, or perhaps by Russian and Chinese industry. They might have enlivened the proceedings, but ultimate victory is far from certain.

True disruptive launcher innovation might come from space tourism. Space tourism embodies many of the characteristics of disruptive innovation, including high initial costs, simpler technology and a different market. If space tourism becomes prevalent, its performance trajectory will probably eclipse that of the traditional launcher industry, despite the latter's great capacity for sustaining innovation. Space tourism might ultimately become as disruptive to the gigantism of current launchers as the handheld device was for PCs.

Space agencies are deeply involved in sustaining innovation but the question is whether and how space agencies can also play a role in disruptive technologies, before these technologies have transformed themselves into sustaining innovation. If disruptive technologies are by nature unpredictable, how to capture them? One method is to go beyond merely supporting or updating existing technologies, and focus more on what society needs before society itself knows it. That is exactly what Steve Jobs did; pursuing innovative ways to use existing technology that create their own demand.

Space agencies can open new markets for disruptive technologies by predicting and specifying needs without a complete plan for meeting these needs. This is arguably what is happening in space science, which has a history of setting out very demanding goals. No matter how one might see the innovation role of space science, one could ask if space agencies could not go one step further and put up miniaturisation needs which will *demand* disruptive innovation, and hence give birth to it. Could space agencies not set space transport goals which could only be met by disruptive innovation? President Kennedy's famous 'We choose to go to the Moon' speech was in the final analysis a catalyst for immense disruptive innovation in many fields, including some quite far from the space business! President Obama has chosen the inverse path in ordering NASA to create game changing technologies without hard destination and a fixed time horizon, but it is doubtful that game changing technologies can be ordered in this fashion. If a customer like NASA can do anything at all in game changing technologies, it is probably by demanding the impossible within a timeframe which sustaining innovation cannot meet. The customer can open a new market, going to the Moon, but can not dictate disruptive innovation. Disruptive innovation is energised by new markets, and can be fostered. It cannot be dictated.

What large companies with a large technology inventory can do is to look for possible tell-tale signs of disruptive innovation: simpler technology, lower performance, higher performance unit price, possible ultimate challenge to the company's other product lines, yet undetermined market possibilities, and then spin-off such a technology into highly independent units, not subject to a continuous battle for resource against company units operating in the more comfortable domain of sustaining innovation. Large companies need to be able to create small firms as homes of disruptive innovation, and set them as free as at all possible.

6.1 What Role Management in Sustaining and Disruptive Innovation?

Kodak claims to have invented digital photography, but has recently gone bankrupt. Schumpeter's creative destruction can be very cruel. Are there lessons to be learnt from this; lessons to be learnt from IBM no longer producing PCs but still producing mainframes? One lesson from IBM might be that you coolly analyse which business lines can still be fitted into the corporate frame, and you exit those that cannot. That is too simple, however. Companies are fuelled by self-preservation, and when you exit business lines you must have other product lines that can carry the company. In the case of IBM this was services, which was radical invention, if not disruptive even. But the point is still that when you quit a business line you need somewhere to go, and that is where creative destruction comes in and the need for innovation in order to avoid destruction. Kodak might have recoiled at the notion of moving from film to digital photography, film being so tightly connected with Kodak's name and culture. But also, can a filmmaker transform itself into a camera maker, particularly when the camera makers in a sense used to be the customers? The bridge to cameras for Sony was digital hardware, a far easier shift than going from producing a commodity to producing hardware, and on top of that hardware where there are very strong incumbents. In the later phases it was not for want of trying that Kodak failed in digital photography. Perhaps there was no rational way for Kodak to escape in the face of disruptive innovation, which did not only challenge a given product, but eliminated in a very short time the entire commodity dependency on which Kodak's business model was built. Similarly, oil companies might find alternative energy sources not only disruptive but destructive in the future.

The space business innovation schema has played out somewhat differently. Consolidation of prime contractors in Europe into two dominant groups is consistent with markets relying on sustaining innovation. The entry of OHB System is also not as existential a threat for others as it would have been if OHB would have brought disruptive technology to the table. SSTL's technology was disruptive, but was – through the acquisition by EADS Astrium – brought "into the family" of prime contractors, which is a bit unusual. As mentioned above, it remains to be seen whether the market will yield a commercial champion of cansat and cubesat technology, possibly hand in hand with an independent challenge to SSTL's pre-eminence in small satellite technology.

At lower levels of the value chain in space there has been more pressure from innovation, including disruptive such, which interestingly has facilitated vertical integration and the building of large industrial structures around the two 'original' primes. At first glance such vertical integration might be understood to be unhelpful for disruptive innovation and helpful for sustaining innovation. The vertically integrated firms get access to the resources of the 'mother company' and cross-fertilisation between entities should abound in a well managed conglomerate to the benefit of sustaining innovation, although Daimler-Benz in the 1990s is a cautionary tale in this respect. In contrast, disruptive innovation must find new markets and normally that does not favour membership of a conglomerate. Yet, the conglomerate setting can be helpful if played well. This is particularly so in space where the future of new technology depends critically on acceptance by primes, space agencies and satellite manufacturers.

Disruptive innovation within a conglomerate can only be successful, however, if a careful balance is kept in favour of the potential of disruptive innovation. Disruptive innovation is inherently a threat for other business lines in a conglomerate, and possibly desired suppression of such technology will often not be successful, since the staff identifying with it will be disaffected and will leave and create rival firms, if they see neglect within the conglomerate. Then you have created a potentially existential threat instead of having seized a business opportunity; a gift from Hell! But the conglomerate can be helpful if it opens up the long term path for the disruptive technology towards its other product lines, particularly in non-obvious fields. Apple is a master example of how to manage wave after wave of radical and often disruptive innovation in a fashion which at first sight undercuts its existing business, but provides long term benefit for the company. The iPhone was certainly not good news for the iPod seen in isolation, nor was the iPad for the MacBook.

It seems almost simple-minded to suggest that larger companies should always keep innovation inventories, not only containing new innovative ideas, but, critically, listing also old ideas that were not picked up at the time. When done, such inventories should be reviewed by a relevant management committee regularly, and companies would be well advised to have periodic innovation audits done by technology generalists from outside the firm. One of the biggest challenges for large firms is to effectively connect the internal dots between different innovative technologies, but also between innovations and potentially new markets internal to the company. Whether genuine and comprehensive standard information technologies à la knowledge management databases are always deployed well might be doubted.

Management is in the key position to foster innovation of whatever form and has a special responsibility to make sure that the benefits are harvested. This means that companies and other significant actors should not only concentrate on technology mapping, but should also look at the opportunistic elements of innovation, and generate innovation strategies and plans which do not lock them in, but allow the firms to seize opportunity when it presents itself. Serendipity management is key for successful harvesting of innovation benefits, and this is true also in the space domain.

Space agencies can, of course, assist serendipity by engaging in the cross-fertilisation process by (1) having regular innovation conferences to stimulate innovators to look across barriers, (2) by having internal and external observatories and, (3) by themselves using the internet to collect ideas. Doing so will benefit both the agencies and the market place.

6.2 Innovation in Development Projects

Development projects in space are risky and of long duration. Naturally both customer and supplier try to minimise risk, and one element of this is to be rather unresponsive to innovation. Yet, in the early phases of developments great benefits can be potentially harvested through innovation, whereas significant innovation in later phases is to be avoided except for emergency cases. As development heats up, innovation is, of course, an ingredient but one to be limited as much as possible. Development projects are hence innovation hostile, for good reasons. This is even true for space science projects, where instruments are mostly custom-made, and often in university labs. The more innovation will be required, the more schedule margin will have to be built in, and even universities prefer to put known pieces together in novel forms, rather than having to do innovation from scratch. This explains why technology readiness levels (TRLs) should be analysed well before the Phase-Bs of development contracts are started, and why the schedule and cost consequences of possible low TRLs must be carefully calibrated before work starts.

The role of innovation is completely different in the early phases of development projects, particularly in the pre-Phase A's and when concept studies are undertaken. The reason for this is that innovation in these phases will still have a fighting chance to get to a decent TRL before the full development project is defined and takes off. Where innovation later in projects should be frowned upon, innovation in early phases should be encouraged. This might imply setting up a crowdsourcing team in competition to pure industrial teams, or might imply directing industry to use all the 'open in, closed out' mechanisms discussed elsewhere in this Report. It might also mean that the proposals coming out of industrial concept studies and pre-Phases A should be required by the customer to be multipronged, e.g. to have one conservative solution, one innovative solution, and one highly innovative solution; alternatively, that the contractor would get additional payments if such creative alternatives could be proposed.

In the space business unquestionably the customer has the authority to be very directive, and if resource allocation theory is correct in suggesting that the customer is ultimately the one allocating the resources also of the supplying industry, then space is a very auspicious place for the public purse to foster innovation. This is so because in early phases the customer can then impose his innovation requirements and industry will comply, since following the customer lead is the time-honoured way to make money. It is perhaps not always easy for the customer to insist on innovation in early phases and abhor innovation in later ones, but that is a balance that should be learnt, instead of allowing the innovation shyness of later phases to permeate also the early phases where it is unwarranted.

7. The Importance of Location

In 2001, Allen J. Scott suggested that a paradox of the contemporary economy was two apparently opposed processes; globalisation and the reinforcement of the role of regional economies.[220]

Scholarship involving clusters, regional innovation systems, industrial districts, and local agglomeration of firms has emphasised that local knowledge spill-overs created by face-to-face transmission of knowledge are preferable to those created at international, or even at national level.[221,222,223] This is true for several reasons: (1) tacit knowledge can be transmitted without distortion in local communication; (2) knowledge transmission is cheaper within regions than between regions; (3) more channels for knowledge transfer, such as conferences, participation in local associations, and face-to-face meetings are available. On the other hand an equally consistent literature reveals a strong tendency toward the globalisation of innovation.[224,225] According to this school of thought, knowledge spill-overs occur frequently at international level through international trade, international direct investment, international technology transfer and alliances and acquisitions.[226] Firms constantly access important global linkages without the assistance of local clustering institutions.[227] Local agglomerations are considered important more because they supply labour and general business support services rather than as an important source of knowledge and innovation.[228] Others have stressed that only certain 'players' inside a cluster have access to information channels and the ability to exploit them.[229] More recent works introduce the concept of 'gatekeeper', usually a big firm ('leader firm') inside a cluster, which represents the only player who has the ability to connect the external knowledge channels with those of the cluster.[230] Studies on congresses, conferences, trade fairs and project meetings, which do not need permanent geographical proximity to occur, underscores the important role of this kind of proximity for knowledge transfer and innovation.[231]

In-between the above-described currents, Torre argues that while permanent geographical proximity is not necessary for knowledge transfer, it is not correct that innovation can always occur through distant interaction. Certain stages of the innovation process require actors to meet for the effective transfer of knowledge.[232] Therefore, geographical proximity, at least in a temporary form, remains essential.

7.1 Location in the Aviation Industry

The European aviation industry encompasses both a dispersed and an agglomeration model. Airbus is famously dispersed as is Eurofighter, whilst French military aircraft production is more centralised. The dispersion model is clearly politically motivated, but can be argued to have certain innovation

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221 Audretsch, David B., and Maryann P. Feldmann. "Knowledge Spillover and the Geography of Innovation." Handbook of Regional and Urban Economics, Volume 4. Eds. J. Vernon Henderson and Jacques-François Thisse. Amsterdam: Elsevier, 2012. 2713-2739.
222 Fallah, M. Hosein, and Sherwat Ibrahim. "Knowledge Spillover and Innovation in Technological Clusters."Current Issues in Technology Management 4.9 (2005): 1 – 16.
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226 Niosi, Jorge, and Majlinda Zhegu. "Aerospace Clusters: Local or Global Knowledge Spillovers." Industry and Innovation 12.1 (2005): 1-25.
227 Giblin, Majella, ed. A Balancing Act: Managing the Global-local Dimension of Industrial Clusters through the Mechanism of 'Lead' Organizations. Galway: Centre for Innovation & Structural Change, 2009.
228 See Niosi, Jorge, and Majlinda Zhegu. (2005) and Giblin, Majella (2009).
229 Giuliani, Elisa "The Selective Nature of Knowledge Networks in Clusters: Evidence from the Wine Industry." Journal of Economic Geography 7 (2007): 139-168.
230 Morrison, Andrea. "Gatekeepers of Knowledge within Industrial Districts: Who They Are, How They Interact." Regional Studies 42 (2008): 817-835.
231 Bathelt, Herald, and Nina Schuldt. "Between Luminaires and Meat Grinders: International Trade Fairs as Temporary Clusters." Regional Studies 42 (2008): 853-868.
232 Torre, André. "On the Role Played by Temporary Geographical Proximity in Knowledge Transmission" Regional Studies 42 (2008): 869-889.

benefits as well. By operating in different environments but having critical mass in all of them, Airbus gets access to very different innovation environments and engineering cultures. Thus Airbus has in a sense created something close to its own self-sustaining innovation ecosystem. Dassault in France tends to bundle more, which reflects the traditional production efficiency paradigm. As the Dassault activities are also considerably less extensive than those of EADS, it might also be argued that Dassault gets maximum innovation benefit from its activities through agglomeration. Stated differently, it might be true to say that a dispersed model only brings palatable innovation efficiency if there is such an amount of critical mass that it can be spread around in such a fashion that each centre will, on its own, have sufficient critical mass.

7.2 NASA and Location

Two structural network trends can be distinguished in terms of geographic dispersion of NASA centres: balanced distribution of NASA centres as seen from a national perspective and regional specialisation on local, state or interstate level.

All major states in terms of economic performance and population (California, Texas, and Florida), and strategic regions (Washington D.C. and the North-East area in general) host important NASA centres. From an economic point of view, this can be explained by the availability of skilled labour, infrastructure and overall accessibility. Beyond that, geographical distribution allows the space sector to be integrated in major regional economies throughout the country and creates balanced development, which improves NASA's political image. It increases outreach through involvement, which might raise more societal support for the use of public funding. Geographic proximity between NASA technology and firms using the technology increases the rate of innovation in the private sector.

Centres hosting launch facilities are situated at lower latitudes in order to make use of the existing centrifugal force from Earth's rotation, which results in lower launching costs. As rockets are (mostly) launched eastwards to include this rotation velocity, launching sites are built near the shoreline or deserted areas. Even after the termination of the space shuttle program, Kennedy Space Center (KSC) at Cape Canaveral in Florida remains NASA's major launching facility. Other sites with research and testing facilities for launchers and propulsion, and also the Johnson Space Center (JSC) for human space flight, are situated in the same general Southeast area (Texas – Mississippi – Alabama).

The North-eastern part of the U.S. is a cluster of knowledge & research at universities and institutions, capital, labour, accessibility and concentration of political institutions. This strategic region hosts four NASA centres: Glenn Research Center, Goddard Space Flight Center, Langley Research Center, and the NASA HQ. Except for the headquarters in Washington D.C., these sites tend to be specialised in space applications that benefit society directly (space weather, remote sensing & global monitoring, etc.), overall concept design & development of spacecraft and, research in horizontal technologies (energy, material science, communications technology, biomedical technologies, etc.).

The three remaining NASA centres are situated near the West coast and Los Angeles and San Francisco in particular. Whereas the centres in the Northeast have specialised in space applications and Earth-monitoring, the Jet Propulsion Laboratory, Dryden Flight Research Center and the Ames Research Center focus on science missions for solar system exploration through the use of robotic probes, life sciences (incl. life detection instruments), space exploration concepts and satellite development for astronomy and astrophysics.

Although the rationale of balanced distribution combined with regional specialisation and local technology leverage through various programs seems to embed NASA and space in the regional economies, questions remain about the effectiveness of this approach with respect to open innovation. In 2009, the U.S. National Research Council pointed out serious shortcomings in the agency's approach on Regional Technology Transfer Centers (RTTCs) and the distribution of awards under the Small Business Innovation Research Program (SBIR). For instance, despite documentation by NASA of numerous individual success stories, there were no compelling studies substantiating the contribution of the regional infrastructure to innovation and technological change — either to spin-out or spin-in uses. NASA personnel listed poor management, lack of clear objectives, too little emphasis on SBIR, and location patterns that do not reflect the economics of regions to explain this disappointing performance. As a result, much of the Innovation Partnership Program's infrastructure was reorganised in recent years to focus on its mission of leveraging technology for

NASA's Mission Directorates, programs, and projects.[233]

7.3 Location in the European Space Environment

Europe's institutional and industrial space sector landscape is characterised by extreme decentralisation. The European Space Agency has five establishments in five different states and a number of centres and sites in different countries. Industry is highly fragmented with industrial capabilities present in all ESA member states and beyond. Even the two big system integrators have integration centres in different countries.

ESA's decentralised structure reflects political choices, not innovation concerns. Innovation, however, might have been served by this approach anyway. The decentralisation creates a multitude of innovation clusters across Europe, creating an opportunity for rich innovation amidst the great diversity of European innovation cultures. Structurally Europe seems well-positioned to cultivate new ideas, but whether this innovation potential is actually realised remains a concern. As in aviation, space necessitates a certain overall critical mass to become an innovation anchor tenant. This is clearly not always the case in the space business, where innovation sometimes suffers as a result of the pursuit of other valuable political goals. This loss is exacerbated by the insularity of space culture itself, as well as the reluctance to embrace crowd-sourcing methodologies and the sharing of intellectual property.

The critical mass rationale can also be inverted. If an existing innovation critical mass is relevant for space, space can have an innovation outpost in that non-space innovation environment. That is the logic of ESA's new presence at the Harwell Oxford Campus, where scientists and researchers have access to world class facilities of over 150 high-tech organisations.[234] When centres of excellence are built in different Member States than either there must be space-innovation critical mass or there must be a surrounding non-space critical mass on which the space-related centre of excellence can draw. Only in this fashion will innovation outcomes be optimised in a geographical sense.

[233] Wessner, Charles W. "An Assessment of the Small Business Innovation Research Program at the National Aeronautics and Space Administration" 12 Jan. 2012. U.S. National Research Council <http://www.nap.edu/catalog/12441.html>.

[234] "ESA BIC Harwell" 11 Apr. 2012 European Space Agency 27 Apr. 2012 <http://www.esa.int/esaMI/Business_Incubation/SEMOUDOWXGG_0.html>.

8. Technology Platforms and Key Enabling Technologies

European Technology Platforms (ETPs) are forums hosted by the EU that bring together hundreds of representatives from industry, academia, civil society, and state departments to define research policies and action plans in a number of technological areas. Through ETPs, the EU aims to stimulate growth, competitiveness and sustainability in the medium to long term by developing and updating research agendas through dialogue among industrial and public researchers and national government representatives.[235] The EU has created a prioritised category called "Key Enabling Technologies" (KETs)[236] to strengthen industrial and innovation capacity.[237] Especially for smaller companies like technology spin-offs and start-ups, these platforms offer research and market-orientation opportunities for the future. Since many of these companies are, from a geographical perspective, clustered in science parks, table 6 in annex 10.3 identifies all relevant Key Enabling Technology Platforms for European Science Parks.

ESPI report 24 pointed out that KETs should be considered for incorporation in ESA's research and development programmes in order to realise the technology leverage opportunities and enabling capacities offered by these strategic technology domains.

Despite the benefits of ETPs, the sheer extent of their control over agenda-setting raises the issue of whether or not ESA and the EU should accept their findings as always best for innovation-specific investment. Key Enabling Technologies as a tool to steer attention and public investment are, after all, a classical planned economy concept. Innovation stemming from this tool is necessarily conventional wisdom innovation and will thus typically be sustaining innovation. Public funding stimulating key enabling technologies will always enter into competition with public funding from other countries and regions, meaning that there are no easy pickings in such hotly contested fields. Such contests are nevertheless necessary, but demanding. For Europe to become a nanotechnology leader, an immense effort would be required, especially considering that the United States and Asia have poured a prodigious amount of capital into the same field in rigorous pursuit of the same technology. Still, it would be industrial suicide for Europe to neglect its own nanotech capabilities.

Can societies have a role in stimulating serendipitous innovation is ultimately the question. If so, the public purse must be extremely risk-tolerant, not something easily achieved. Those responsible for allocating serendipity funds must have a high degree of independence — in an immutable fund structure, for instance — otherwise risk-adverse bureaucracy will likely impede the effort. Capital allocation in this field can not be collectivistic as collective decision-making will always trend towards conventional wisdom.

Liberal economies already have plenty of venture capital funds that pick up projects when a certain technical and commercial feasibility is established, even if the project is still very risky. For public funds to be relevant for serendipity innovation there must be even more risk tolerance involved than in venture capital. It takes a society which understands the deep importance of serendipitous innovation for its wealth preservation to accept a 1:100 or 1:1000 likelihood of success!

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[235] CORDIS. "European Technology Platforms (ETPs) are industry-led stakeholder fora charged with defining research priorities in a broad range of technological areas." 5 Oct. 2011 European Commission 3 May 2012 <http://cordis.europa.eu/technology-platforms/>.

[236] Key Enabling Technologies, abbreviated as KETs, include the fields of nanotechnology, micro- and nanoelectronics, advanced materials, biotechnology and photonics.

[237] "Information and Communication Technologies" European Commission 3 May 2012 <http://ec.europa.eu/enterprise/sectors/ict/key_technologies/index_en.htm>.

9. Conclusions and Recommendations

9.1 Findings and Conclusions

This report started out by making the case for the recognition of innovation economics as an economic paradigm. Today, innovation is a dynamic term of strategic importance in industrial policy and management. The introductory chapter of the report explored the major concepts and authors in the academic literature surrounding innovation and innovation economics. Schumpeter's concept of creative destruction showed that, by its very nature, innovation should not be touted as a universal benefit but as a complex, disruptive force creating opportunities and challenges to actors in the economic system. In the short term, innovation creates winners and losers. In the long run it is the engine of economic growth, upgrading quality of life and technological progress. Drucker emphasised the need of being mindful of human psychology and the individuals behind the inventions when spurring innovation, indicating that – despite its complex character – innovation is something that can be stimulated and fostered when managed well.

Because of the many-sidedness of the concept, its components and dimensions can be labelled and categorised in different ways. One way is to look at the market in which the innovation operates, making a distinction between sustaining innovation, operating in existing markets, and disruptive innovation, which establishes new markets and over time often displaces others. In this view, space should be understood as a hotbed for sustaining innovation mainly, due to the planned and risk-averse structure of the technology development cycle shaping a space mission or project.

Regarding space and innovation economics, it is very hard to capture – let alone quantify – all interacting factors leading to innovation, especially because of the unpredictable – yet essential – role of serendipity in this process.

9.1.1 Typology by In- and Outflow

The first aim of this report was to analyse the flow of information between different players in the innovation process, and to underscore the criticality of such flows for the optimisation of innovation. As an approach, different examples of innovation management were categorised based on whether an innovator invites outside active participation or not, and whether innovation is commercialised as proprietary or is made openly available. This methodology made way for four different configurations of innovation to be discussed:

Innovation projects classified in the *"Closed In, Closed Out"* category are characterised by their non-participatory, often secluded nature throughout the development process and the restricted or commercialised use of resulting intellectual property rights.

- On an inter-organisational basis this can assume one of many forms of industrial partnering, in which external collaboration should bring synergy in terms of market access, costs & skills. Based on their needs and strategic planning, organisations choose to develop either explorative or exploitative types of collaboration.
- This type of innovation can take the form of skunk works: highly focused, geographically separated and hierarchically and procedurally liberal working environments, staffed by cross-functional teams of young professionals. The NASA Technology Petting Zoo and Google X Lab were discussed as examples of the skunk works format.
- In both cases, it was clear that these projects made up only a small proportion of the overall innovation activities, showing that this kind of innovation management is typically part of a wider innovation strategy where some of the research performed can even be peripheral to the organisation or company's core business.

"Closed In, Open Out" innovations present a structure consistently displayed at many research institutes, both university and government owned. They are characterised by a fairly inward looking culture combined with a strong drive to disseminate information in academia and to the public. The Institute of Advanced Study near Princeton University, a traditional example of this kind of innovation structure, was taken as an example.

- The report identified the absence of any ESA or EU-supported European institute dedicated to space technology innovation. Despite the political rationale for this in terms of industrial policy, arguments are made that there are reasons to support creating such an institute, if only to join the forces of countries without strong national space technology research institutions.

"Open In, Closed Out" innovation practices are characterised by their participatory input process and restricted or commercialised use of resulting intellectual property rights. The degree of participation openness throughout the development, however, is very much dependent upon the method of external knowledge gathering.

- Companies use knowledge brokers to find solutions for well defined scientific problems or organisational challenges. These knowledge brokers, acting as intermediaries between solutions-seekers and problem-solvers, often have extended networks with individual scientists, engineers, experts or small research laboratories around the world. By connecting, recombining and transferring knowledge, they enhance corporate capacity to innovate and compete. "Innomediaries" are increasingly supported by different models for community building.

- Companies or organisations can open innovation challenges to the public through crowdsourcing platforms. One such example is the InnoCentive platform, which connects solution seekers with an online community of millions of problem solvers worldwide. Benefits of this approach include lower costs, more diverse solution sets, and in the end the retained ownership over derived intellectual property. To date, NASA is the only institutional actor in the space field that has experience with the InnoCentive platform to crowdsource challenges.

"Open In, Open Out" modalities of innovation build upon open participation and free use. Online platforms of this category deliver promising perspectives in terms of information and knowledge management, dissemination and accessibility.

- Through citizen science, researchers can increase processing capacity at low cost in science-oriented virtual projects such as Galaxy Zoo. Citizen science benefits participating volunteers, the education community, the scientific community, and society as a whole.

- Open source software (OSS) developers and communities present a novel and successful alternative to conventional innovation models. They also offer opportunities for an unprecedentedly clear look into their detailed inner workings. For the space sector, OSS can be particularly useful because it is stable and incurs low development costs.

- Wikis, operated through Wiki software, are flexible tools to exchange information and amplify understanding within a community. In terms of knowledge management efficiency, they might be useful to streamline innovation processes throughout their development. NASA is already operating a wiki site to push its capability by sharing knowledge, data, and ideas across the organisation. ESA is experimenting with one in the field of global navigation satellite systems.

9.1.2 An Extended Analytical Framework

In a second phase, the analytical framework of this report was expanded in order to discuss other methods or approaches towards innovation. The term "ecosystem" was the first concept investigated in this fashion.

- "Innovation ecosystem" was defined as the dynamic system of interconnected institutions and persons necessary to create, store and transfer knowledge, skills and artefacts which define a product domain. Typically, it combines total company control over the ultimate commercialisation of the central product, but allows a wide range of actors –at different levels– to take part in the ecosystem. This allows the core product –or its company as the focal innovator– to benefit from the surrounding ecosystem in terms of market position and future development and the surrounding ecosystem to feed off the innovations in the core product and interlinked applications.

- Enacting an ecosystem business model entails additional strategy and management challenges in terms of supply-chain coordination and implementation by down-stream complementary products or services across the customer/user community. Profitable and innovative ecosystems at Apple and Google, however, provide evidence that this can be done successfully and without companies losing control. The Lego case study proved that even in times of serious crisis, keen reorientation combined with ecosystem building can put a company back on track.

- In the space business ESA has built an ecosystem around itself. But because of ESA's particular industrial policy, in which generated intellectual property rights remain largely with industrialists, questions raised on whether the ecosystem is leveraged in the most optimal way.

Another systems innovation approach discussed was the use of concurrent design facilities, exemplified by ESA's Concurrent Design Facility. Design engineering, manufacturing engineering and other functions are integrated through a parallelisation of tasks that reduces the overall time required to plan and design a new product. These facilities can serve as a tool for both space and non-space innovation.

Open innovation, networked and interactive innovation concepts between universities and industry play a strong role in creating innovation. University-industry relationships are being developed accordingly and can assume various forms. Exchanging knowledge between the 'real world' and institutes and universities can be enhanced by different forms of academic consulting, by the part-time professor coming from the outside and by its opposite, the ordinary professor who works part-time outside university. The kind of legal doctrine dictating where and how IP rights are allocated between academia and industry has a large impact on the profitability and widespread use of a particular innovation. One explicit example of a mutually beneficial such relationship is the Announcement of Opportunity Instruments for space science, where ESA provides the platform for a probe or satellite, but the scientific instrumentation is provided by universities and institutes.

Generally speaking, sustaining innovation has been the strength of large companies while disruptive technologies have remained corralled within upstarts. Because of this, upstart companies are often forced to be more risk tolerant and are more inclined to focus on a select group of products and their success in the marketplace. Disruptive innovation is always unpredictable; this is one reason it is important to establish ecosystems around emerging technologies in order to exploit all possible routes to the market. The challenge for large companies, both within the space sector and outside, is to leverage their portfolios of possibly disruptive innovation in a nimble fashion, allowing the relentless focus of upstarts to be deployed even in a larger corporate setting.

Looking then at the development cycle in space projects, it was clear that innovation is ideally integrated in conceptual studies. Innovations are often not welcome in later stages of projects, since they tend to add to risk and cost. For space it is of critical importance to be able to reconcile upstream revolutionary or disruptive innovation with the risk-averseness required in later phases of projects.

Finally, the report looked at the seemingly contradictory process of globalisation and reinforcement of regional economies. In fact, the process only appears to be contradictory. In reality, regional concentration is a response to globalisation since regional concentration normally leads to higher competitiveness in the global marketplace. The two parallel tendencies are, in any event, altering the way firms and organisations can tap into knowledge networks and exploit development and market opportunities. From a geographical perspective, Europe is characterised by decentralised agglomeration. This model, which can be found in both aviation industry and space, seems to serve innovation because of the diversity it brings. However, it is important to note that critical mass is nevertheless necessary to create innovation clusters on the regional level, and hence decentralisation can not take precedence over agglomeration. The two must go hand-in-hand.

9.2 Recommendations and Open Points

This report acknowledged that the space industry operates in a highly vertically integrated environment, meaning that innovation often gets stuck within a corporate stovepipe. Space businesses must be aware that innovation and technology development are happening much more rapidly and with a more profound impact outside its own backyard. The report offers the following conclusions regarding European space industry and policy:

- Skunk works is a demonstrated excellent way to structure industrial innovation and can be set up to make leeway for an environment flexible enough to allow for integration of unplanned discoveries. In light of skunk works successes from other leading space and industry actors, sustained support for endeavours like the ESA StarTiger initiative would be beneficial.
- Current industrial partnering structures and practices tend to limit innovation potential, truncating cross-fertilisation benefits and joint innovation. For these reasons, powerful customers should be encouraged to modify contractual supply frameworks to include clauses on innova-

tion-friendly initiatives such as joint ventures for innovation management, technology petting zoos for large contractors and the obligation to share higher amounts of substantial technological information. ESA in particular has, by means of its 'Best Practices', a suitable instrument for project segmentation into custom-made separate work packages. This instrument should be used to push innovation-facilitating larger work packages, combining disciplines that in strict project logic could be kept apart, but which should be kept together if the objective is also to encourage cross-disciplinary innovation.

- Establishing a "European Space Technology Innovation Institute" should be considered. Such an institute could be entrusted with basic research and sustaining technology innovation as in-house activities. To lever diversity, it should draw on different disciplines, backgrounds and national approaches. This is especially relevant with the prospect of ESA enlargement, as future Member-States might want to familiarise their industry with space technology development.
- Considering NASA's positive experience with InnoCentive and crowdsourcing, ESA, the EU and industry should develop similar capabilities. ESA could also insist on such platforms being used by contractors, both for break-through and sustaining innovation.
- The use of physical innovation or knowledge brokers can be further optimised. This could be done by making information accessible in a logically ordered way, and by proactively looking for links between innovation in one field and new product opportunities in other fields. Innovation outreach functions are likely indispensible for both the innovation environment within a company and to identify external licensing opportunities. Considering that by far most technology development is taking place outside the space domain, special attention should be given to spin-in opportunities and technology observatories.
- Wikis are powerful tools for improving knowledge and information exchanges; European space actors could set up internal wiki platforms to gather and disseminate specialised data and pre-existing material to staff. In a wider context they can be used as a tool for collective discovery, and are therefore highly relevant where individual projects might want to overcome corporate barriers in the consortia and even create a more interactive dialogue with customers or the public.
- Given numerous examples of positive experiences with citizen science in space related fields, it is worth considering whether ESA - as a central entity - could foster more citizen science through an online interface. Given its public mandate, ESA could also use the crowd sourcing capabilities to foster technical innovation with public participation, and even leave the ensuing innovations in the public domain.
- Development speed and participant diversity are the major advantages of Open Source Software (OSS) for space community use. For software that is not mission critical, an OSS approach would be a good way to decrease costs, maximise innovation and create spin-out opportunities to benefit non-space society. For mission critical software, OSS can also be deployed; source code copies might be made freely available, yet introduction of change into the actual operation or flight software would only take place after the usual excruciating centrally controlled review and authorisation processes, and proper production of documentation.
- ESA should seriously question whether it community interests best to leave most intellectual property generated under ESA-financed industrial contracts with the individual industrialists. The alternative, more closely aligned with publicly funded research policy, would be to build a key technologies platform open to all European industry, and therefore a tool for broadly participatory development and innovation. Access to the platform could be controlled and limited to recognised European entities, thus forming a genuine European space technology ecosystem.
- The Announcement of Opportunity Instruments is discussed as an example of university involvement in actual space science projects. The winning instruments, however, are delivered to ESA as a 'box' that must comply with extensive interface requirements, and although ESA may have good visibility of the innards of the box, the innovation remains stove-piped. Whether such restrictive practices are always in the best interest of stakeholders as a whole, or even in the best interest of the providing university or institute is debatable. For this

reason, a comparative analysis of the innovation effectiveness of industrial versus Announcement of Opportunity approaches could be considered.

- Linking academics and space practitioners through long-term continuous professional involvement of academics within ESA or industry seems unexplored. The reason for this might be cultural; there is a certain danger when the interaction-bridge is unidirectional, only from practitioner to academia. The opposite direction, where industry taps into the education and research knowledge pools, is the most auspicious innovation option and should therefore be actively developed.
- It is essential to establish ecosystems around emerging technologies in order to reap all innovation benefits related to their disruptive character. This has not really been done in the small satellite field such as for cansat and cubesat technology. There might be a need to set up a true technology information platform where enthusiasts and professionals can find masses of open information and exchange ideas on how to further develop such promising technology far beyond the domain of universities and amateurs. Space agencies could play a pro-active role in this respect.
- Space agencies can open new markets for disruptive technologies by predicting and specifying needs without identifying a concrete way to meet these needs. This is arguably what is happening in space science, which has a history of setting out very demanding goals and accepting a very high degree of innovation as necessary within the projects in order to get there. No matter how one might imagine space science's role in innovation, one can ask if space agencies should not go one step further and put up miniaturisation needs which will demand disruptive innovation, and hence give birth to it.
- Large companies with an extensive technology inventory can look for tell-tale signs of disruptive innovation and create spin-off entities without subjecting them to a continuous battle for resources against other company units promoting established products. Large companies need to be able to create small firms as homes of disruptive innovation, and transform them into independent companies as soon as at all possible.
- Companies and other actors in the European space sector should go beyond technology mapping to generate innovation strategies and dynamics which encourage unplanned innovation. Serendipity management is a key for successfully harvesting of innovation benefits, and this is true also in the space domain.
- Space agencies can encourage the likelihood of serendipitous discoveries by having regular innovation conferences to encourage innovators to look beyond traditional market and scientific barriers, by having internal and external technology observatories, and by themselves using the internet as a technology management and innovation tool. Doing so will benefit both the agencies and the market place.
- Customers should include innovation requirements in early phases of their engagements with industry. Though not always easy, it is a timing that needs to be appreciated, instead of allowing the logical innovation shyness of later phases to permeate the early phases in which innovation should be explicitly pursued.

List of Acronyms

Acronym	Explanation
A	
ACT	ESA Advanced Concepts Team
AOCS	Attitude and Orbital Control Systems
AOI	Announcement of Opportunity Instruments
ARPANET	Advanced Research projects Agency Network
B	
BDA	Bayh–Dole Act or Patent and Trademark Law Amendments Act (U.S.)
C	
CDF	Concurrent Design Facility (ESA)
CDI	Challenge Driven Innovation
CEO	Chief Executive Officer
D	
DARPA	U.S. Denfence Advanced Research Project Agency
DFRC	Dryden Flight Research Center
E	
EADS	The European Aeronautic Defence and Space Company N.V.
EO	Earth Observation
ESA	European Space Agency
ESTEC	The European Space Research and Technology Centre
ESTER	European Space Technology Requirements
ETP	European Technology Platform
EU	European Union
G	
GE	General Electrics
GM	General Motors
GMAT	General Mission Analysis Tool
GMES	Global Monitoring for Environment and Security
GNSS	Global Navigation Satellite System
GRC	Glenn Research Center
GSFC	Goddard Space Flight Center
GSTP	General Support Technology Programme
GSTP	General Support Technology Programme
H	
HQ	Headquarters

Acronym	Explanation
I	
IAS	Institute for Advanced Study
IBM	International Business Machines Corporation
IP	Intellectual Property
IPR	Intellectual Property Rights
IT	Information Technology
ITI	Innovation Triangle Initiative
iTMS	iTunes Music Store
J	
JPL	Jet Propulsion Laboratory
JSC	Johnson Space Center
K	
KET	Key Enabling Technologies
KSC	Kennedy Space Center
L	
LRC	Langley Research Center
M	
MIT	Massachusetts Institute of Technology
N	
NASA	The National Aeronautics and Space Administration
NIAC	NASA Innovative Advanced Concepts
NPI	Networking/Partnering Initiative
NRC	National Research Council (U.S.)
NYT	The New York Times
O	
OECD	Organisation for Economic Co-operation and Development
OHB	OHB System AG
OI	Open Innovation
OLT	Office of Technology Licensing (Stanford University)
OSS	Open Source Software
P	
PC	Personal Computer
PDC	Project Design Centre (JPL – NASA)
R	
R&D	Research & Development
RTTC	Regional Technology Transfer Center
S	
SaaS	Software as a Service
SBIR	Small Business Innovation Research Program
SDSS	Sloan Digital Sky Survey
SME	Small and Medium Enterprise

Acronym	Explanation
SSTL	Surrey Satellite Technology Ltd
STTR	Small Business Technology Transfer
T	
TLR	Technology Readiness Level
TRP	Basic Technology Research Programme
U	
U.S.	United States
W	
WIPO	World Intellectual Property Organisation

Annex

A.1 ESA Innovation Programmes and Initiatives

In order to enable researcher to explore new ideas from the very earliest stages, ESA has established the Basic Technology Research Programme (TRP). The programme is intended to stimulate blue-sky thinking, allowing tentative ideas to be confronted with reality through proof-of-concept testing. As a result, this demonstration of workability reduces the degree of risk of a given technology long before a mission is based around it. All ESA Member States contribute to the TRP on a mandatory basis. Running on a three-year based work plan, the TRP is organised according to technology themes based in turn on application areas, such as Earth Observation, Space Science and Human Spaceflight.[238]

Notable initiatives within the TRP include the StarTiger scheme, which was previously discussed as an example of a skunk works, and the Innovation Triangle Initiative or ITI. The latter is in line with the idea of technology leverage; its aim is to foster the introduction of breakthrough innovations and technologies in the space environment. Moreover, this initiative's goal is to explore technologies and services for space applications that are not currently being used or exploited in the context of space, and have therefore the biggest potential of seeding innovation.[239] The ITI approach is based on the 'Innovation Triangle' concept, which implies that a rapid and successful introduction of disruptive innovations in industry requires three different entities to cooperate: customer, developer and, inventor.

By providing seed-money, technical support and networking opportunities, the ITI supports new ideas or concepts by combing the creativity, know-how and experience of industry, space customers and the research community. The seed-money can be 50k€, 150k€, or higher, depending on the type of activity. In terms of technical support, ESA offers contact with its experts to discuss proposal concepts and gives access to relevant follow-up documents and the European Space Technology Requirements (ESTER) database. The networking opportunities are intended to help submitters find potential partners for the further validation, development and utilisation of their innovative concept.

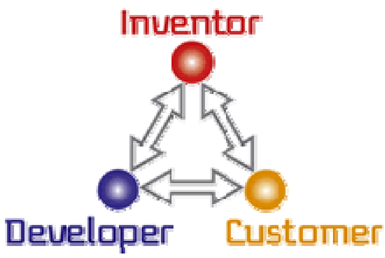

Figure 5: The Innovation Triangle Concept.[240]

ESA uses three types of contracts in the ITI, depending on the level of technological maturity of the proposal. Each of them is focused on one of the three elements in the "Innovation Triangle". The proof of concept contract is intended for inventors and conceived as a fast validation process of new ideas and demonstration of their advantages. Demonstration of feasibility and use is tailored for the needs of developers; mainly concerned with component and/or breadboard development up to validation in laboratories. Technology adoption contracts, meant for customers, offer support for technologies to be adopted by a European Space company with the final objective of including the developed technology in their services, products or processes.[241] The ITI call for ideas is opened on a continuous basis, with a standing Evaluation Board. This is done to ensure a fast authorisation of funding, even after a few weeks upon admission.

As opposed to the TRP, ESA's General Support Technology Programme (GSTP) is of much wider use. It exists to convert promis-

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[238] "About the Basic Technology Research Programme (TRP)" European Space Agency 23 Feb. 2012 <http://www.esa.int/esaMI/Technology/SEMNU5WPXPF_0.html>.

[239] "ESA Innovation Triangle Initiative" European Space Agency 24 Feb. 2012 <https://iti.esa.int/iti/index.jsp>.

[240] Ibid.

[241] "Innovation Triangle Initiative (ITI)" European Space Agency 27 Feb. 2012 <http://www.esa.int/SPECIALS/Technology_Business_Opportunities/SEMNA4M5NDF_0.html>.

ing engineering concepts into a broad spectrum of mature products for space sector. These can range from individual components to subsystems up to complete satellites. To do this, the design is developed into engineering models or 'breadboards' whose space-worthiness can be tested in both the lab and ESTEC's set of simulators to see the effects of exposure to acceleration, outgassing, temperature and radiation extremes. Besides this, the GSTP also includes work on product and process improvements, aiming for a flexible response to the needs of ESA programmes, Member States and European industry, including European-made space-qualified parts manufactured by commercial enterprises.[242]

According to ESA, the GSTP "functions to bridge the gap between having a technology proven in fundamental terms and making it ready for the agency and national programmes, the market and space itself". The GSTP is implemented as an optional ESA programme, open for ESA Member States to join and to choose their level of participation (incl. Canada as associate member). It has been operational for two decades and the current GSTP-5 operates on a five-year work plan, based around four programme elements: (1) General Activities, (2) Building Blocks and Components, (3) Security for Citizens, and (4) In Orbit Demonstration. Next to these elements, there is also a permanently open Announcement of Opportunity (AO), in which bidders can submit proposals for technology product development at any time.[243]

Thanks to the GSTP, European industry can count on the programme's technical support throughout its product development cycle, growing its capabilities and competitiveness, with companies able to issue proposals for research. By doing this, the GSTP ensures that the right technologies are at the right maturity at the right time. ESA states it is exactly this right balance of innovation & product development and maintenance that strengthens the competitiveness of European industry. Further, the combination of mechanisms such as the permanently open AO and the multi-year plans allows both fast response and advance planning[244]; giving shape to essential characteristics of a solid yet flexible business environment.

A.2 NASA Innovation Programmes and Initiatives

From a functional point of view, many similar innovation and technology development programmes exist within NASA. Compared to ESA's innovation processes and their formalisation, however, NASA's approach towards innovation seems to be more linear. Obviously, this difference in approach can be brought back to the path dependency in organisational structure of both space agencies. The internal NASA Space Technology Development Approach consists of three different divisions. In terms of innovation, the first, Early Innovation Division, is most relevant. It includes the forming of creative ideas regarding future NASA systems or solutions to national needs. Programs that are part of this division are the NASA Innovative Advanced Concepts (NIAC), Space Technology Research Grants (GRC), Small Business Innovative Research (SBIR) & Small Business Technology Transfer (STTR), the Center Innovation Fund and the Centennial Challenges. The consecutive phases, the Game Changing Technology Division and the Crosscutting Capability Demonstration Division are aimed at maturing and infusion of newly developed technologies. All NASA technology development divisions and their respective programmes are briefly described in the tables below.[245]

[242] "About the General Support Technology Programme (GSTP)" 28 Apr. 2009. European Space Agency 28 Feb. 2012 <http://www.esa.int/esaMI/Technology/SEMEU4WPXPF_0.html>.
[243] Ibid.
[244] Ibid.

[245] "Office of the Chief Technologist" NASA 20 Dec. 2011 <http://www.nasa.gov/offices/oct/about_us/index.html>.

Name of the program	Mission
NASA Innovative Advanced Concepts (NIAC)	Fund early studies of visionary, long term concepts - aerospace architectures, systems, or missions (not focused technologies). The intended scope is very early concepts: Technology Readiness Level 1-2 or early 3; 10+ years out.
Space Technology Research Grants (GRC)	Focus on innovative research in advanced space technology and fellowships for graduate student research in space technology.
Small Business Innovative Research (SBIR) and Small Business Technology Transfer (STTR)	Engage small businesses in aerospace research and development for infusion into NASA missions and the nation's economy.
Center Innovation Fund	Stimulate and encourage creativity and innovation within the NASA Centres in addressing the technology needs of NASA and the nation. Funds will be distributed to each NASA Centre to support emerging technologies and creative initiatives that leverage Centre talent and capabilities. NASA scientists and engineers will lead projects but partnerships among Centres and with other agencies, research laboratories, academia and private industry are encouraged. The individual Centres will have full discretion on the use of the funds and the Center Chief Technologists will coordinate a competitive process at their Centre for the selection of projects. Centres will report on progress periodically and the programme office at NASA Headquarters will evaluate the Centre's efforts on an annual basis.
Centennial Challenges (6):	Incentive prizes to stimulate innovative solutions by citizen inventors and independent teams outside of the traditional aerospace community. Over time, some topics have been closed and others have been introduced. Currently there are six different challenges being addressed.
Green Flight	Bring forth aircraft that maximise fuel efficiency, reduce noise and improve safety--features that can be applied in the full range of private, commercial and military aircraft of the future.
Strong Tether	Driving material science technologies to create long, very strong cables (known as tethers) with the exceptionally high strength-to-weight ratio. Such tethers will enable advances in aerospace capabilities including reduction in rocket mass, habitable space structures, tether-based propulsion systems, solar sails, and even space elevators.
Power Beaming	Practical demonstration of wireless power transmission. Practical systems employing power beaming would have a wide range of applications from lunar rovers and space propulsion systems to airships above the Earth. Another future application of power beaming would be the space elevator concept.
Sample Return Robot	An autonomous capability to locate and retrieve specific sample types from various locations over a wide and varied terrain and return those samples to a designated zone in a reasonable amount of time with limited mapping data.
Nanosatellite Launch	Aims: Safe, low-cost, small payload delivery system for frequent access to Earth orbit. Innovations in propulsion and other technologies as well as operations and management for broader applications in future launch systems. A commercial capability for dedicated launches of small satellites at a cost comparable to secondary payload launches--a potential new market with Government, commercial, and academic customers.

Night Rover	Foster the development of mobile systems to collect solar energy, store that energy, and later use it productively. Innovations in energy storage technology for space operations and, in particular, to meet the demands imposed by the daylight/darkness cycle on the Moon. Energy system innovations to benefit terrestrial applications, including vehicles and renewable energy generation systems.

Table 4: Early Innovation Division (5 Programmes).[246]

Name of the program	Mission
Game Changing Development Program	The Game Changing Development Program seeks to identify and rapidly mature innovative/high impact capabilities and technologies for infusion in a broad array of future NASA missions. Multiple performing teams using varied approaches will attempt to achieve selected high impact challenge goals. Performing teams are held accountable for ensuring that discoveries move rapidly from the laboratory to application. The Game Changing Development Program portfolio will produce both subsystem/system level multidisciplinary innovations and component/discipline innovations. While advances in discipline and core knowledge are by-products of the Game Changing development Program, the objective is to mature transformational innovations for future space systems in preparation for flight demonstration.
Franklin Small Satellite Subsystem Technology Program	Technologies that enable small satellites to provide game changing capabilities for the government and commercial sectors will be supported under a competed Small Satellite Subsystem Technologies Program. In this program, ground testing of promising transformational small satellite capabilities are sought. The selected small satellite subsystem technology development projects may provide subsystem advances for the Edison Small Satellite Demonstration Program and other small satellite demonstration opportunities.

Table 5: Game Changing Technology Division (2 Programmes).[247]

Name of the program	Mission
Technology Demonstration Missions Program	Matures, through flight demonstrations, a small number of Agency crosscutting technologies in partnerships with the Mission Directorates, industry, and other government agencies
Edison Small Satellite Demonstration Missions Program	Develops and operates a series of NASA-focused small satellite demonstration missions in collaboration with academia and small business
Flight Opportunities Program.	Provides flight opportunities of reduced-gravity environments, brief periods of weightlessness, and high-altitude atmospheric research

Table 6: Crosscutting Capability Demonstrations Division (3 Programmes).[248]

[246] Ibid.
[247] Ibid.
[248] Ibid.

A.3 Key Enabling Technology Platforms

Science Parks per Country	Nanotechnology	Micro- and nanoelectronics	Photonics	Advanced materials	Biotechnology	Relevant European Technology Platform(s)
Belgium						
Brussels Technopole			✓			NEM, Photonics21
Parc Scientifique University Catholique de Louvain			✓	✓	✓	ESTP, Photonics21, EuMat, ENIAC, Nanomedice, SusChem, Food, PLANTS, EPoSS
EBN						*HUB: relate to all relevant ETPs*
Parc Scientifique d´Université de Liège	✓	✓	✓	✓	✓	ESTP, ISI, Photonics21, EuMat, ENIAC, Nanomedice, Food, PLANTS, SusChem
Fsagx Creqlys Science Park			✓		✓	Food, PLANTS
Denmark						
Danish Science Park SCION DTU	✓	✓	✓	✓	✓	all ETPs
International Science Park Odense					✓	*Function: Linking and supporting*
INCUBA Science Park			✓		✓	Nanomedice, eMobility, Photonics21, PLANTS
Symbion Science Park			✓		✓	Photonics21, Nanomedice, NEM, eMobility
Finland						
Agropolis Oy					✓	Food, PLANTS
Culminatum	✓		✓		✓	PLANTS, Food, Nanomedice, ENIAC, Photonics21, EPoSS
Finn-Medi Tampare					✓	Nanomedice
Foodwest					✓	Food
Helsinki Science Park Ltd.					✓	PLANTS, Food, Nanomedice
Carelian Science Park			✓	✓	✓	Photonics21, EuMat, Food, EPoSS, eMobility
Jyväskylä Science Park	✓		✓	✓	✓	EuMat, ENIAC, PLANTS, Nanomedice
Kajaani Science Park		✓	✓			Photonics21, ENIAC
Medipolis	✓				✓	Nanomedice, EPoSS, eMobility, Photonics21
Oulu Technopolis					✓	Nanomedice
Otaniemi Science Park	✓	✓	✓	✓		ENIAC, Nanomedice, Photonics21, NEM, EuMat
Prizztech Ltd.	✓	✓	✓		✓	ENIAC, Nanomedice, Photonics21
Tampere Technology Centre Hermia		✓	✓			ENIAC, ARTEMIS, eMobility, EPoSS
Technology Centre Kareltek			✓			eMobility, EPoSS, NEM, Photnics21
Kuopio Science Park		✓	✓	✓	✓	Photonics21, EuMat, Food, PLANTS, Nanomedice, ARTEMIS
Technology Centre Merinova		✓				ENIAC
Turku Science Park			✓	✓	✓	EuMat, Food, Nanomedice, Photonics21
Vaasa Science Park		✓				ENIAC
Viikki Science Park					✓	Food, PLANTS
France						
Agroparc		✓	✓		✓	Food, Photonics21, ENIAC
Agropole					✓	Food

Agropolis Science Park					✓	Food
Angers Technopole		✓	✓		✓	Food, PLANTS, ENIAC, NEM
Atlanpole		✓	✓	✓	✓	ESTP, ARTEMIS, Food, Nanomedice, ENIAC, EuMat, NEM
Bordeaux Technopolis	✓	✓	✓	✓	✓	ARTEMIS, ESTP, ISI
Centre de Transfert de Technologie du Mans		✓		✓	✓	ENIAC, EuMat, Nanomedice
Centre d´initiatives locales de Saint-Nazaire						Function: support, relate to all relevant ETPs
DigiPort Technopole Lille Metropole			✓			eMobility, EPoSS, NEM,NESSI, Photonics21
Europole Mediterraneen de l´Arbois		✓			✓	ENIAC, SusChem, PLANTS (incl. integration)
ESTER Limoges Technopole			✓	✓	✓	EuMat, ENIAC, Photonics21, eMobility, PLANTS, Nanomedice
Futuroscope Technopole	✓	✓	✓	✓		ESTP, ISI, ARTEMIS
Heliopark Pau-Pyrenee Technopole			✓		✓	ESTP, ISI, PLANTS, EPoSS
Laval Mayenne Technopole			✓		✓	Food, PLANTS, ARTEMIS
Parc Scientifique & Technologique de Marseille-Luminy					✓	Nanomedice
Sophia-Antipolis		✓	✓		✓	EPoSS, ARTEMIS, ENIAC, Nanomedice
Technopole Alimentech					✓	Food, PLANTS
Germany						
International University Bremen Science Park	✓	✓	✓	✓		Photonics21, ENIAC, Nanomedice, eMobility, ARTEMIS
Science City Ulm		✓	✓	✓	✓	EuMat, ENIAC, Nanomedice, eMobility, ISI, ARTEMIS, Photonics21, EPoSS
Science Park Saar			✓		✓	EPoSS, eMobility, Nanomedice, Photonics21
Technologiepark Braunschweig		✓	✓	✓		Photonics21, EuMat, ENIAC, eMobility, EPoSS, NEM, ARTEMIS
Greece						
Patras Science Park						Function: offer managerial support (relate to all relevant ETPs)
Science Technology Park Crete		✓	✓		✓	ESTP, ISI, ENIAC, PLANTS, Nanomedice, eMobility, EPoSS, NEM, ARTEMIS
Thessaloniki Technology Park		✓	✓	✓	✓	SusChem, EuMat, Photonics21, eMobility, ENIAC, Food
Ireland						
Kerry Technology Park			✓		✓	NEM, ENIAC, PLANTS, SusChem, Food, Nanomedice
National Technology Park			✓		✓	EPoSS, NEM, Photonics21, ENIAC, Nanomedice
Italy						
AREA Science Park	✓	✓	✓	✓	✓	EuMat, ENIAC, PLANTS, Nanomedice, eMobility, EPoSS, NEM
Bioindustry Park Canavese			✓		✓	SusChem, Nanomedice, Food, Photonics21
San Raffaele Biomedical Science Park					✓	Nanomedice
Technoparco del Lago Maggiore		✓		✓	✓	PLANTS, ENIAC, EuMat
Portugal						
Taguspark		✓	✓	✓	✓	eMobility, EPoSS, NEM, NESSI, Photonics21, EuMat, ENIAC, PLANTS, Nanomedice,

						SusChem
Spain						
Barcelona Science Park	✓		✓	✓	✓	Photonics21, ENIAC, SusChem, Nanomedice
Technology Park of Basque Country		✓	✓	✓	✓	ESTP, ISI, Photonics21, EuMat, ENIAC, PLANTS, eMobility
Sweden						
Aurorum Science Park		✓	✓			Photonics21, EPoSS, ENIAC
Chalmers Science Park	✓	✓	✓	✓	✓	ENIAC, Photonics21, Nanomedice, EuMat
Kista Science City			✓			Photonics21, eMobility, EPoSS, NEM, NESSI
Karolinska Science Park					✓	Nanomedice, Food, PLANTS
Lindholmen Science Park		✓	✓			ARTEMIS, NEM, ENIAC, eMobility, Photonics21,
Novum Research Park					✓	Nanomedice
Mjardevi Science Park		✓	✓			Photonics21, eMobility, ENIAC, ARTEMIS, EPoSS
Uppsala Science Park			✓	✓	✓	Nanomedice, PLANTS, EuMat, EPoSS
Switzerland						
Berner Technopark						*
Technopark Winterthur		✓	✓		✓	ISI, ENIAC, SusChem, Nanomedice, EPoSS, NEM, ARTEMIS
The Netherlands						
Amsterdam Science Park			✓	✓	✓	Nanomedice, PLANTS, ISI, EuMat, Photonics21, EPoSS, NEM
High Tech Campus Eindhoven		✓	✓		✓	ENIAC, EPoSS, Photonics21, eMobility, NEM, Nanomedice
Bio Science Park					✓	Nanomedice
Mercator Technology & Science Park		✓			✓	ENIAC, eMobility, EPoSS, NEM, Nanomedice
United Kingdom						
Aberdeen Science & Technology and Science & Energy Parks		✓			✓	*
Aston Science Park		✓	✓			ENIAC, Photonics21
Begbroke Business and Science Park		✓		✓	✓	ENIAC, EuMat, Nanomedice
Brunel Science Park	✓		✓		✓	Nanomedice, Food, EPoSS, SusChem, Plants, ENIAC, ARTEMIS
Cambridge Science Park	✓	✓	✓	✓	✓	all ETPs
Chilworth Science Park	✓	✓	✓	✓	✓	ISI, Photonics21, EuMat, ENIAC, Nanomedice, SusChem, Food, Plants, eMobility, EPoSS, NEM, ARTEMIS
Coventry University Technology Park			✓	✓	✓	Photonics21, EuMat, FTC, eMobility, EPoSS, NEM
Durham University Science Park and Mountjoy Research Centre		✓	✓	✓	✓	Nanomedice, Food, SusChem, ENIAC, ARTEMIS, Photonics21, EuMat
Edinburgh Technopole		✓	✓		✓	Nanomedice, PLANTS, Food, ENIAC, eMobility, EPoSS, NEM, Photonics21
Elvingston Science Centre					✓	*
Granta Park		✓			✓	Nanomedice, ENIAC
Harwell Oxford		✓	✓	✓	✓	ESTP, ISI, Photonics21, EuMat, ENIAC, SusChem, eMobility, EPoSS
Heriot-Watt University Research Park			✓	✓	✓	Photonics21, PLANTS, Food, ARTEMIS, SusChem, eMobility, EPoSS

Hannah Research Park					✓	PLANTS, Food
Hillington Park Innovation Centre		✓	✓		✓	ENIAC, eMobility, NEM, Photonics21, Nanomedice
Keele Science Park		✓	✓	✓	✓	Nanomedice, EuMat, ENIAC, Photonics21, EPoSS, ISI
The London Science Park at Dartford		✓	✓	✓	✓	FTC, SusChem, ENIAC, NEM
Manchester Science Park		✓	✓		✓	Nanomedice, EPoSS, eMobility, Photonics21, ENIAC, PLANTS
Malvern Hills Science Park	✓	✓	✓	✓	✓	EuMat, ENIAC, Photonics21, ARTEMIS, EPoSS, eMobility, Nanomedice
Northern Ireland Science Park		✓	✓			eMobility, EPoSS, ENIAC
Norwich Research Park					✓	PLANTS, Nanomedice
Nottingham Science and Technology Park			✓		✓	Nanomedice, ARTEMIS, EPoSS, eMobility, Photonics21, SusChem
Oxford Science Park		✓	✓	✓	✓	practically all, except for FTC and Food
St John´s Innovation Park		✓	✓	✓	✓	Photonics21, EuMat, ENIAC, eMobility, SusChem, EPoSS, NEM
South Bank Technopark			✓		✓	EPoSS, eMobility, Nanomedice
University of Reading Science & Technology Centre			✓		✓	Food, EPoSS, Nanomedice, SusChem, NEM
University of Warwick Science Park		✓	✓	✓	✓	Nanomedice, SusChem, Photonics21, EPoSS, ENIAC, ARTEMIS, Food, EuMat
Wolverhampton Science Park		✓	✓		✓	ENIAC, PLANTS, SusChem, EPoSS, Nanomedice
Czech Republic						
Czech Technology Park Brno		✓	✓			eMobility, EPoSS, NEM, ENIAC
Estonia						
Tartu Teaduspark			✓	✓	✓	Photonics21, EuMat, Nanomedice, EPoSS
Poland						
Krakow Technology Park		✓	✓	✓	✓	Photonics21, EuMat, Nanomedice, eMobility, EPoSS, ENIAC
Note: In some cases, only the ETPs of major importance for a science park are listed to keep an overview. This is done in function of the relative importance of a sector within the given science park. * = Data incomplete or missing due to lack of availability.						

Table 7: Key Enabling Technology Platforms Identification Matrix for Science Parks.[249]

[249] Giannopapa, Christina. "Streamlining the Implementation of Open Innovation in the Space Sector through Key Enabling Technologies." ESPI Report P83, Vienna: European Space Policy Institute, 2011.

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