Innovation Value Network in Emerging Technology

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Abstract--**The paper develops a contemporary innovation value network model in emerging technology, particularly in the case of micro and nano-manufacturing technology (MNT), based on primary and secondary data analysis and a survey conducted on European research and development projects. A mixed-methods approach was adopted in this research which investigated the business and technical challenges to the commercialization of technology. The research was motivated by a systematic literature review. A notable finding is that the emergent MNT often does not have a direct link with market demand. An intermediary role between the emergent advanced technology and market demand should be included to act as co-ordinator for the complex design issues inherent when developing such technology.**

I. INTRODUCTION

Nowadays, manufacturing is recognized as an important driver for a nation to generate wealth. In the European Union for example, it accounts for 20% of the Gross Domestic Product [1]. There is a strong emphasis on getting more innovation out of research, and cooperating between the worlds of science and the world of business within the EU [2], which support the need to investigate the typical 'technology push' nature of science, and 'need-pull' nature of business, to explore a revised framework.

To some extent technology can be seen as a means by which manufacturing firms can strive to ensure economic sustainability and competitiveness in this difficult and uncertain environment. On the other hand the rapid rates of technological change and the associated shorter product life cycles are themselves part of the challenge [3]. The economics of technological innovation have been one of the central issues in the technology management area. The literature within this field commonly talks about sustaining technologies and disruptive technologies [4, 5, 6], with particular emphasis upon end consumer products [7, 8, 9].

Emerging micro- and nano-manufacturing technologies (MNTs) are one such example of potentially disruptive technologies. In the case of small scale technologies, function and performance characteristics are clearly and tightly linked to structures and the structures are tightly linked to the processes [10]. Studies highlighting MNTs as disruptive technologies and the importance of developing MNT innovation models have been carried out by e.g. Kautt et al. [11], Romig Jr et al. [12] and all the references therein. This paper focuses more specifically on micro and nano manufacturing technologies, which simply refer to technologies used to fabricate structures at the micro and nano scale.

Technologies for micro and nano multi-material processing, including specifically 3D structuring technologies, is getting more and more important for innovative applications since they enable flexible and cost-efficient manufacturing of multifunctional products made of different materials in practically all manufacturing sectors, like biotechnology (e.g. biosensors, micro fluidics), ICT (e.g. optoelectronics) [13]. Therefore development of MNT process technology is closely linked with the advances and management of micro- and nano-manufacturing technologies. The gap in understanding of how such emergent technologies can be commercialised by either a technology-push or a need-pull approach has been introduced. An understanding of current literature on technology-push and market-pull was essential in order to understand how the area of MNTs relates to technology-push and market-pull. A systematic literature review process was used for this. The review provides some key classifications as to how the technology-push and market-pull theory has been used to analyse and examine the technological innovation processes. The results of the review clearly suggest that the traditional framework is too simplistic and leads to a tendency to treat the concepts of technology-push and market-pull as two extreme elements, supporting our motivation to extend the framework. Based on primary and secondary data analysis and the responses to a survey performed on 88 European research and development projects of the Multi-Material Micro Manufacture (4M) community in Europe, an extended push-pull model is introduced as to how these activities within the emerging MNTs management can be integrated.

The most important addition in the proposed model is the intermediary role between the technology-push and market-pull inherent in the traditional framework. The existence of the 'Valley of Death' in MNTs development is confirmed in our survey which supports our proposition to include the intermediary role in the market-pull and technology-push dynamic, suggesting that the intermediary role is crucial to escape from this 'Valley of Death', turning the technologies to their full innovative potential. To support our argument on the importance of the intermediary role, an innovation value network model in the context of MNTs is also introduced.

II. LITERATURE REVIEW

In order to facilitate a consistent approach to reviewing the literature in the area of technology-push and market-pull, we were introduced to the structured systematic review method. Such reviews were developed by Cochrane in the late 1970s [14]. They differ from standard literature reviews because they adopt a structured approach to the comparison of studies, instead of simple narratives which can be biased. A key advantage of systematic reviews is that research work is pooled from a number of sources, and as such is more powerful than single data sets. To begin with the key electronic databases for the subject area were identified using Metalib™ (Metalib™ is a meta-search engine that searches across a wide range of electronic databases simultaneously). This search highlighted databases with the largest datasets which referenced peer-reviewed Journal articles. Those selected were: ABI/INFORM (Proquest), Business Source Premier (EBSCO), Scopus and Emerald Library. These electronic references were all accessed via Metalib™. Initial pilot searches were conducted using each database and a number of initial search terms. Furthermore, the temporal range began at 1995 to the present, reflecting the newness of this area and a wish to keep the work up-to-date.

The concepts of technology-push and market-pull were introduced by Schoen in 1967 [15] as the underlying motivation and driving forces behind the innovation of a new technology. In the first stage of the Marquis model [16], called ‘idea recognition’, the source of innovation is deemed to come either from the recognition of technological feasibility, that is a ‘technology-push’, or from the recognition of potential demand, known as ‘market-pull’. Another view comes from Abernathy and Utterback [17], stating that radical product and process innovation (technology-push) is subsequently followed by incremental innovations (market-pull). This is in accordance with Pavitt [18], who states that technology is particularly relevant for the early stages of the product life cycle, and market factors especially for their further diffusion. Technology-push can be described as creative and/or destructive, with new or major improvements; while market-pull is a replacement or substitute [19, 20].

It has already been recognized that demand side factors and technology side factors jointly determine a company’s R&D success [21], and therefore, successful products and services rely on the targeted combination of market-pull and technology-push activities [22], since the integration of push-pull factors generally contributes to more innovativeness of the company [22]. In fact, it is claimed that the technology-push and the market-pull factors are the primary drivers of technological innovation [23, 24, 25, 26]. The technology-push concept argues that the users’ needs have a relatively minor role in determining the pace and direction of technological innovation. On the other hand, the market-pull concept is based on the view that users’ needs are the key drivers of innovation, thereby suggesting that companies should pay more attention to needs of users [23].

Although there have been extensive studies in the literature discussing such concepts, our systematic literature review highlighted a gap in the literature suggesting that there is still a need to enhance the concept, predominantly when the primary concern is the better understanding of the factors enabling the successful take up and exploitation of micro- and nano-manufacturing technologies. An important observation from the literature – highlighting another gap - indicates that most studies consider the technology-push and market-pull theory as the primary drivers of innovation without making a clear distinction between the types of innovation involved, which Walsh *et al.* [19] addresses by talking about continuous and discontinuous technological innovation.

The systems of innovation approach describe how companies do not normally innovate in isolation, but in collaboration and interdependence with other organisations [27]. Organisations may be firms such as suppliers, customers and competitors; they may also be organizations in the public sectors such as universities, school, and government ministries [28]. The interactions which take place between organizations in a system of innovation are bound at certain levels. For example, when they are in the borders of the nation state, then they are termed ‘national systems of innovation’ (NSI). This subsystem of the national economy brings together various organizations and institutions which interact and influence each other during the process of innovative activity [29]. This is an important level to focus research on as most public policies influencing innovation processes or the economy as a whole are still designed and implemented at the national level [28]. Furthermore where advanced technologies such as MNTs are concerned, then technological policy interventions are developed at the national level. This research identified a number of technological NSI and interviewed their key stakeholders to understand how they contribute to the technology-push and market-pull models. Authors such as Fri [30] describe how the notion of demand creation is the only strategy that actually drives new technology into commercial use while providing public good.

In summary, a systematic review of recent technology-push and market-pull literature highlighted the following.

1) It appears that there are strong interdependencies between technology-push and market-pull models. At the same time, there appears to be a research gap to understand how these approaches used to manage the product and process life cycle for the emerging MNTs and to develop a tailored framework for MNTs.
2) Uncertainty is a common factor referred to when managing the development of new technology paradigms [24, 31] since adoption depends on its successful diffusion.
3) A simple overall push-pull approach appears inadequate. Our literature review highlighted a gap for a contemporary integrated push-pull model. Such a model would be used to understand the adoption of emerging and disruptive micro- and nano-manufacturing technologies.

III. RESEARCH DESIGN

The research began with the aforementioned systematic review. This review highlighted a need for a contemporary integrated technology-push and market-pull model. A mixed-methods research approach was adopted for this investigation, harnessing the diverse range of research approaches, and providing a more holistic view of the area under investigation. The research process is outlined in Figure 1.

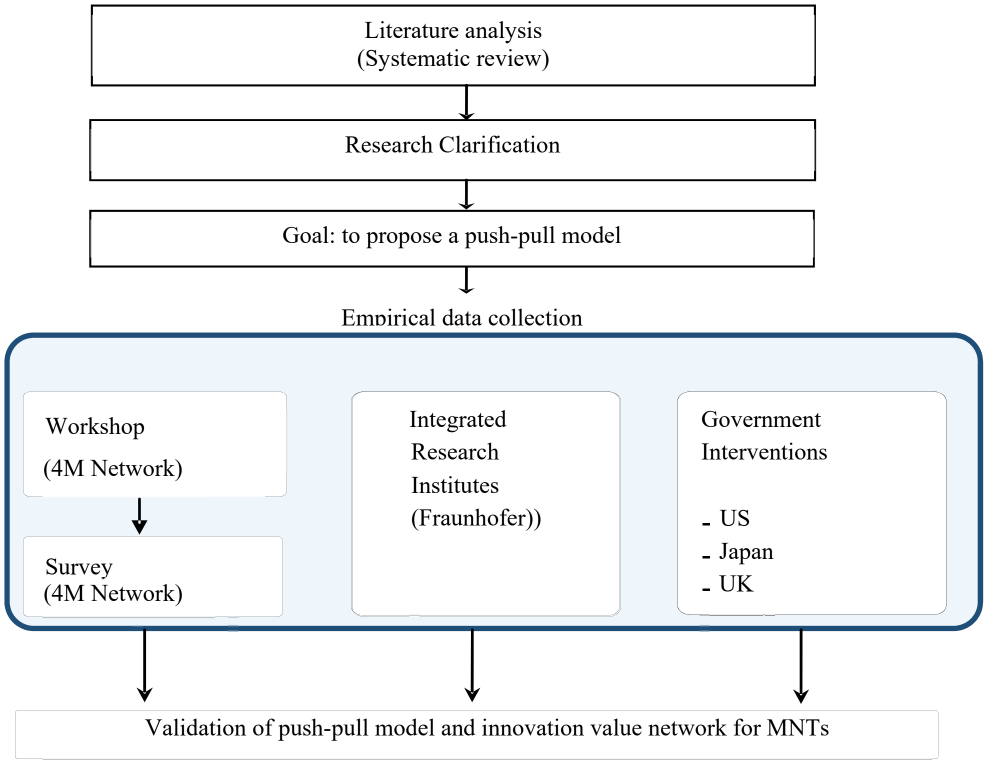

Figure 1: Research process

A literature analysis was built on the initial conceptions, leading to the research gaps, and requirement for a revised push-pull framework. The use of varied and complementary research approaches enabled us to triangulate data and develop a revised push-pull framework for MNTs, as shown in Figure 2. There is a tendency to treat the concepts of technology-push and market-pull as two extreme elements, with new technologies on one side and market demands on the other. Such a model is useful to discuss part of the life cycle of most technologies; however, having researched the area of MNTs, from a range of academic perspectives (e.g., engineering and business), we believe this is too simplistic. The proposed Push-Pull framework is being developed to represent the links between emerging micro and nano-manufacturing technologies and market demand.

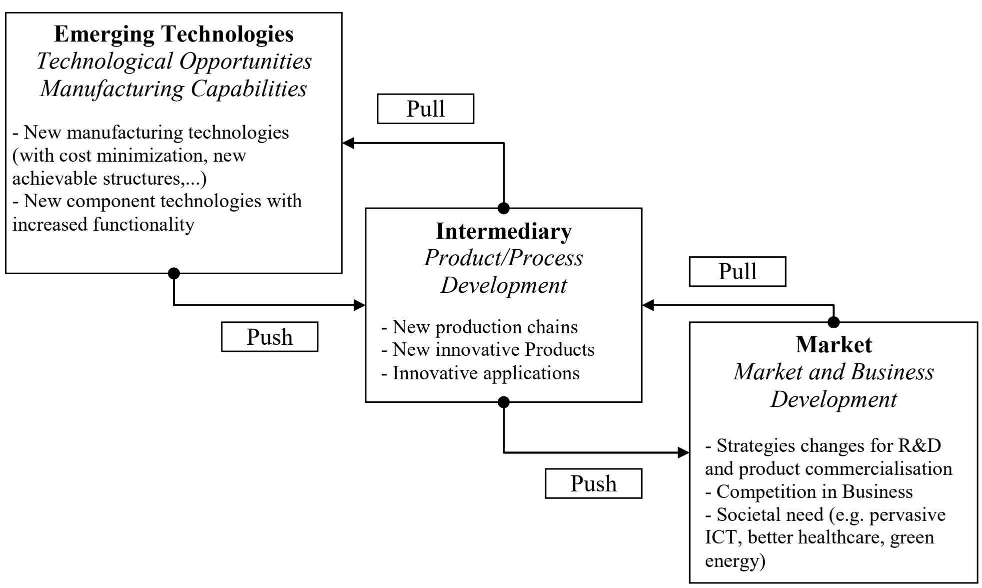

Figure 2: The proposed ‘push-pull’ model for the emergent MNTs

When considering emerging technologies such as MNTs, it would appear that a clear difference needs to be made between what are described as 'component technologies', and 'manufacturing technologies'. A 'component technology' can be an end-product which can be integrated into new innovative end-products; whereas a 'manufacturing technology' enables the development of new component technologies. This model introduces the idea that manufacturing technologies often do not have a direct link with market demand, particularly in the case of research institutions or university departments. It proposes that between them lies an intermediary body, acting as co-ordinator for the complex design issues inherent when developing such emerging technologies. It is implied that the role of this intermediary is to match market opportunities/needs with manufacturing capabilities. While traditionally, this role is taken either by a technology provider or an end-product producer, this intermediary can in fact take a number of other forms. In a number of cases, EU funding bodies and numerous Governments have deemed the problem to be of significant importance that they have intervened with funding programmes and/or interventions.

To illustrate the addition of the 'intermediary' box in the typical push-pull model, in the next section we begin by describing the 4M Network, as one such EU funded MNT program. Secondly, examples of Government interventions from the US and Japan is provided; and to finish with, an example of a UK Government MNT intervention program is given.

IV. INTERMEDIARY ACTORS

A. Network of research organizations

A good example of networked research organization is the 4M Network which seeks to integrate fragmented European R&D capacity in non-silicon micro technologies into a European Centre of Excellence. It is designed to help European companies engage with the growing demand for micro- and nano-technology, by supporting their developments for the batch-manufacture of micro-components and devices in a range of materials. In itself the 4M network acts as an intermediary as defined in Figure 2. It should be noted that the vast majority of the partners were research institutions. Due to the complexity of the manufacturing processes considered and the fact that these institutions are recognized as leaders in their respective fields in Europe, we believe that their involvement in the technology-push and market-pull balance should be representative. Out of 88 European projects, 81 research projects gave sufficient budget information on both total budget, building up to a total budget of 242 million Euros, and industrial contribution to allow us to draw an interesting picture of the types of 'intermediary' stimulating MNTs' R&D in Europe. Five types of such 'intermediary' or funders were identified, namely the Industry, the R&D Institutions (Institutional), Regional funding bodies, National funding bodies, and European Funding bodies (EU).

Figure 3 shows the distribution of project per intermediary, the biggest contributor appears to be National Funders, followed by the EU. However, looking at the budget distribution per intermediary (Figure 4), the EU appears to be the most significant funder followed by National bodies, leaving other types almost negligible. In particular, in this portfolio of project, the total industry led budget reaches less than 1% and industrial financial contribution appears significant only within public led budgets.

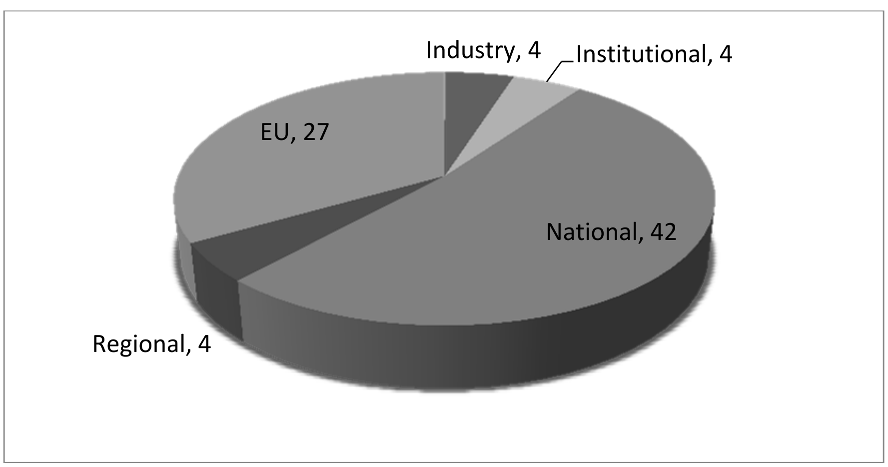

Figure 3: Distribution of project per intermediary

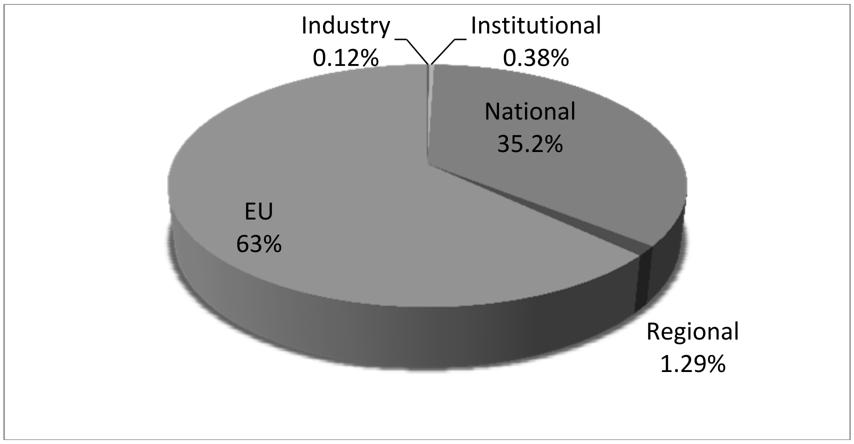

Figure 4: Budget Distribution per intermediary

More specifically, as depicted in Figure 5 and 6, it is important to distinguish between the projects that focused on the development of new products only (without research in manufacturing processes), the projects that focused on the development of new manufacturing processes (without specific product in mind) and those that focused on both. With this in mind, with almost 34 million Euros, the industry contribution to this portfolio of research projects reaches 14%. 59% of which were for research projects focusing on the development of new products together with new manufacturing processes. 30% of this contribution was for projects focusing on the development of novel manufacturing process without particular a product to be developed and only 11% for projects focusing only on the development of new functional products. This could be interpreted as an interesting direct market-pull dynamic, where manufacturing technologies are developed concurrently with the design of new products. However, as mentioned previously, less than 1% of the projects budget (Figure 4) was for projects solely funded by industry. The industry contribution mentioned above mostly took part of a wider funding scheme organised by another so called Intermediary, generally the EU, where 50-60% of industry contributions (Figure 6) and the total budgets (Figure 5) were dedicated to concurrent research for both processes and products development. These figures demonstrated that the development of these MNT technologies strongly benefit from intermediaries to bring together manufacturing capabilities and marketable products. There are only a few industrially led projects, to which the surveyed institution took part, and this could be explained by the high risk linked with the use of such emerging micro and nano-manufacturing technologies and an intermediary helps minimising such risk.

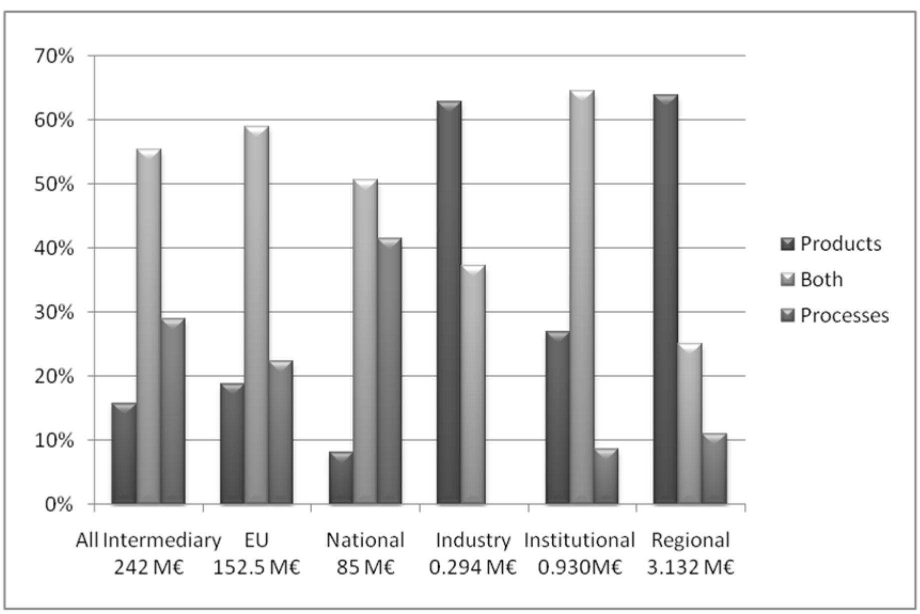

Figure 5: Project budgets distribution per intermediary

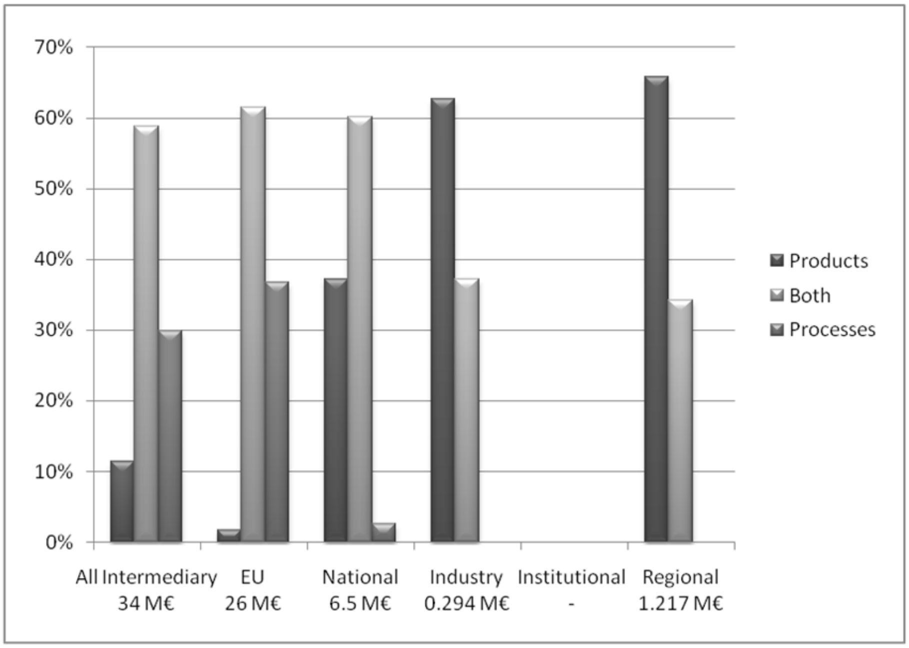

Figure 6: Industrial contribution distribution per intermediary

The interesting finding is that generally research budgets in ‘processes research’ are higher than in ‘product research’, which is to be expected for research institution. However, looking at the industrial contribution, this is still strongly the case for EU funded project, with 2% contribution for products research and 37% for processes research, but is totally the opposite for Nationally funded projects, with 3% contribution for ‘processes research’ and 37% for ‘products research’. This might reflect different funding priority depending on the intermediary.

B. Government interventions

From the current broad perspective of R&D in MNTs, countries are developing areas responding to their own expertise and needs and looking for niches in the international R&D mosaic [32]. The focus varies from a general science based strategy (for example, the US and France) to industry relevance driven strategy (for example, Korea and Taiwan); from broad spectrum of areas (for example, the US, Japan and Germany) to specific strengths (UK). The main difference among countries is the time scale and research area domains that are targeted. The purpose of analyzing the government interventions is to highlight the role of intermediary in the push-pull model.

In the US, MNTs are recognized as critical technologies for the 21st century and considered to be at the early stage of exploration and exploitation. Both federal and local government funding, as intermediary bodies, support interdisciplinary research teams including long term fundamental science and engineering research and grand challenge areas for the translation of research into useful applications. Research funds have been channeled into the creation of academic centers of excellence rather than university-industry collaborations [33]. Government funding is traditionally spent on fundamental or applied research and development infrastructure. The ‘centers of excellence’ or multi-year research center grants in developing and utilizing specific MNTs research tools and in promoting research partnerships was emerged since couple of years. R&D infrastructure including a nationwide network of shared use facilities called the National Nanotechnology Infrastructure Network (NNIN) were also established for transforming MNTs research. Outside the NNIN, various public and private funding agencies are involved such as large companies in chemical, materials, computer, semiconductors and other sectors. These intermediary organizations, which sit between businesses and the university sector, perform many functions including foresight and diagnostic analysis including various kinds of accreditation, validation and regulation, and finally, activities connected more directly with the commercialization process in the MNTs sector.

In Japan, the national effort consists of the involvement of both the public and the private sector, as opposed to the US effort, where industry makes most of the decisions in the later stages. Government organizations and very large corporations are the main source of funding for MNTs, while small and medium-size companies play a minor role. The role of intermediaries in the Japanese MNTs systems was strengthened through the science and technology basic plan during the last years in bridging public and private research and knowledge transfer. Internal intermediaries are, for example, technology licensing offices (TLO) have proliferated in Japan, after the Bayh-Dole Act (1980) granted US universities the right to appropriate and commercially exploit knowledge generated by or jointly with academic departments. After conducting a series of 25 face-to-face interviews with the actors both in public and private sectors, some suggestions have been made, for example, government needs to make continuous investments in research in a competitive mode among research groups in MNT field to remain competitive. In addition to support flagship-type projects aggressively, the industry leaders were also looking at other opportunities that will have an early return on investments especially for the electronic industry [34].

The UK Government drew up plans to address the technology gap in the UK market for MNTs. An intervention and innovation program followed, securing million pounds of funding [35], creating a regionally dispersed network of MNTs facilities. This network was created to provide UK businesses with access to the latest range of MNTs services and capabilities within key sectors; an example of a mechanism by which a public body has attempted to fill the void between technologies and application, and therefore fits in the 'intermediary' box of Figure 2. We have collected data from 28 key stakeholders from the intervention network. Stakeholders ranged from the 'architect' of the centres, through to Regional Development technology managers, MNT centre CEOs/Directors, and the Government auditors of the program. Overall interviewees consider that this Government intervention has been favourable, with a few exceptions. Examples were given where products where developed that could not have been without access to these MNTs centers; one particular example saw the development of a micro fluidic device used in a piece of analysis equipment for the pharmaceutical sector. The need for intermediaries to consider realistic developmental time-scales must also be considered, in order to meet the balance between technology-push and market pull. The complexity of the 'intermediary' in meeting the customers need emerged as an important theme. A number of centers described the situation where customers often don't understand what they need; or the difficulties of communicating what can be achieved with an emerging technology, and what is required. Most likely, this is a reflection of the complexity of developing emerging MNTs.

V. INNOVATION VALUE NETWORK FOR MNTS

The proposed push-pull model suggests that innovations in MNTs are complex and would necessitate involvements of different players performing different functions along the end market demand at one end, the advancement of technologies at the other end, and the intermediary functions between those two ends. A more formal framework that we believe quite relevant in analyzing such complex and multi-disciplinary innovation processes in MNTs is the so called 'innovation value network'. Adner [38] defines a value network as the collaborative arrangements through which firms or organizations combine their individual offerings into a coherent, customer-facing solution. The value network concept offers a comprehensive view of understanding how the innovation processes in MNTs can and should be broken down into different inter-related and inter-dependent processes and what values the different players could offer without which successful MNTs adoptions could never be realized.

In the case of MNTs, as also confirmed by the results of our interviews and survey, new manufacturing technologies or new market opportunities that have emerged quite often only send weak and ambiguous signals to the other end. This is particularly true when the expectedly successful innovation need to overcome many complex design issues. Using the value network concept, we argue that the intermediary roles carried out by actors who belong to the middle box are crucial in turning opportunities emerged either from a new technology or market demand into a successful innovation.

An example of a value network in the context of MNTs is used to support our argument on the importance of the intermediary role introduced in the push-pull model. The example is based on SEMOFS, a project funded by the European Commission through the Sixth Framework Program for Research and Technological Development involving five research partners, two industrial partners and an end user (hospital). Motivated by general trend towards more decentralized and immediate diagnostics for health, the project's main aim is to develop a next generation of polymer based label free biosensors achieved through the combination of innovative concepts of plasmonics, integrated optics (light source, detection) and micro-fluidics. This will be a real significant breakthrough since all functions will be totally integrated on a single polymer-based chip. When reaching the mass production capability, the chip will be extremely low cost and disposable while providing increased sensitivity and diagnosis possibilities.

The project can be seen as an innovation value network that consists of many inter-connected pieces and players. Figure 7 shows the value network representation of the project. The main contributing expertise or role and the associated partners as follows:

- Plasmonics: to enhance the surface-plasmon resonance (SPR) sensor enabling label-free optical detection system
- Active Micro Optics: to fully integrate active and passive optical components
- Fictionalization: to accommodate biotechnological fictionalization of sensor surface achieved through the creation of a chemical interface between the sensor surface and the antibody
- Active Micro Fluidics: to produce biocompatible microfluidics with fully integrated fluidic actuators
- Integration: to integrate all the functions into a polymer chip
- Industrial applications
- Proof of concept
- Main funder and facilitation: European Commission

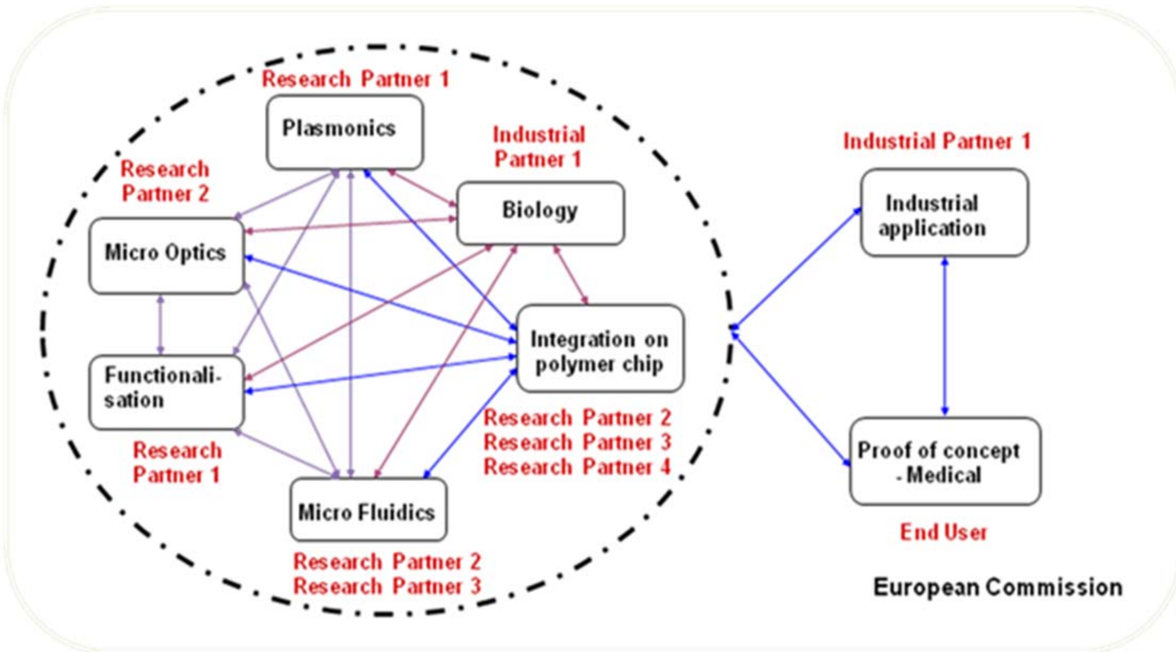

Figure 7: Innovation value network in MNTs

While Figure 7 depicts the project as an innovation value network, the actual interdependent relationships between different partners obviously are much more complex, which suggests that many issues exist in trying to optimally match the market demand requirements (medical application) with the technological capabilities available or should be developed further within the research centers. This example shows that such a promising innovation is only made possible by the intervention and facilitation carried out by the European Commission, which highlights the importance of the intermediary role in the innovation processes as we proposed in the framework. This supports our proposition in that the innovation model taking into account the dichotomy of push and pull-factors is too simplistic and incomplete. The same framework can also be used, in particular by technology policy makers, in identifying the gaps that may inhibit successful innovations. The concept of innovation value network is also relevant to revitalise the important roles that small firms can play in realizing successful MNTs adoption.

VI. DISCUSSION AND CONCLUSION

There is a great deal of research done in the area of MNTs innovation systems within the literature. However, there has not been any comprehensive theory developed yet of how to conceptualize technology-push and market-pull on an abstract level, combining the various research results. This paper attempts to address this gap, and can be used as a guideline or benchmark for community of micro and nano-technology practitioners and policy makers. In this paper, some important issues related to the understanding of the current implementation behaviour of micro and nano-manufacturing technologies were discussed. The need for a new pragmatic integrated technology-push and market-pull model was highlighted, in order to better represent the links between emerging micro and nano-manufacturing technologies and market demand. More often than not, whilst the market potential is clear, due to the emerging nature of such innovations they tend to be highly driven by R&D organizations rather than by the industry. The model proposes that an intermediary body lies between these two extremes. This body acts as co-ordinator, matching opportunities and needs with manufacturing capabilities. Traditionally, this role is taken either by a technology provider or an end-product producer. However other important intermediaries also exist – such as publicly-funded programs – which were discussed in this paper.

An interesting finding is that research budgets in ‘processes research’ are higher than in ‘product research’, which is to be expected for research institution. If we looked for industrial contribution, this is true for the EU funded project, but opposite for nationally funded projects. This might reflect different funding priority depending on the intermediary. In relation to this observation, it is worth consulting the study by Linton and Walsh [10] who suggest that process-based innovations such as MNTs require a new innovation model that is different from the models developed based on assembled products. For process-based products, product and process innovation are tightly coupled, i.e. a change in manufacturing process is expected to result in a significant change in the product, which then highlights the increasing importance of coordination between ‘processes-research’ and ‘product research’.

The paper has shown that new manufacturing technologies, for example, new component technologies with increased functionality do not have direct link with market demand rather needs an intermediary body for new product development and its commercialization. It is implied that the role of this intermediary is to match market opportunities/needs with manufacturing capabilities. In recent years, such an intermediary Fraunhofer Institute in Germany supports both technology-push and market-pull by undertaking contract research for MNTs for the public sector, government, and industry, including small and medium-sized enterprises (SMEs), which lack the critical mass to carry out their own R&D. In order to maximize their potential as an intermediary body, they have formed cooperative alliances that jointly offering their services on the market as well as advises the Executive Board on structural and business development within their emerging research field. As a result they were able to continuously transfer technologies and expertise into industry. To promote the transfer of research into industrial applications, the mechanisms were implemented by establishing Application Centers, Innovation Centers and Demonstration Centers. However, the complexity for the intermediaries in meeting customers' needs emerged, as highlighted in the UK case.

We have also demonstrated that our view on the complexity of the MNTs innovation processes and the importance of the intermediary role is well supported by the formal concept of value network. The concept really highlights the importance of system thinking; the MNT successful innovations would require collaboration between different players along the end market demand at one end, the advancement of technologies at the other end, and the intermediary functions between those two ends. Through the example case of a European Commission funded project, we have demonstrated the existence and the significance of such a network.

As our suggestion for further research, it would be worth mapping different players that belong to each of the three boxes and identifying the extant inter-relationships between them. The result of this process will help the technology policy makers in prioritizing the type of research projects and/or research organizations that should be funded. Furthermore, this mapping process will also help in identifying whether or not sustainable value networks have been created. As suggested by Adner and Kapoor [38], it is important to identify whether primary obstacles lie upstream or downstream of the intermediary box. Upstream obstacles act as barriers to production and in contrast downstream obstacles act as barriers to adoption. The policy makers can continuously play their strategic roles in serving as catalyst for overcoming such obstacles. Further work would include additional survey data from privately-funded projects to further validate the conceptual framework presented in this paper.

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