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There's plenty of room at the bottom but is there room at the top? Nanotechnology in the Czech Republic: policy and barriers to innnovation

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Abstract: Due to the possibility of nanotechnology becoming the next general purpose technology, generating considerable socio-economic benefits, it has become popular with policy-makers and academics around the world, and led to massive investments in national R&D programmes. While in some cases nanotechnology is still in its early stages of research, in many others it has already resulted in innovations within many disparate sectors. This is important because in today's knowledge-based economy, innovation is a dominant factor, quite radically influencing economic performance of firms, regions, and states alike emphasizing a growing need for a strong, coherent, and up-to-date policy support. From an innovation systems perspective this thesis looks at the rapidly growing field of nanotechnology in the Czech Republic, exploring the innovation policy of the Czech Republic, barriers to innovation, and the extent to which policy addresses these barriers. An innovation survey within Czech nano-companies has been carried out in order to zoom in on some of the strengths and weaknesses of the policy support.

Key words: nanotechnology, Czech Republic, innovation systems, innovation policy, barriers to innovation,

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Introduction[1]

Since the turn of the millennium, nanotechnology has become somewhat of a buzzword in policy circles as well as universities and research councils around the world. Combining various scientific disciplines – physics, chemistry, biology, materials science, and engineering – nanotechnology can be viewed as an enabling tool with widespread applications. Due to the unique features that occur in ordinary materials at the nano-scale, far beyond recognition of the human eye, nanotechnology is expected to bring a radical change to industries ranging from electronics, engineering, chemicals, and textiles to healthcare, pharmaceuticals, construction and energy. In a knowledge-based economy, where the ability to learn and adapt to new technologies and changing paradigms is as important as ever, nanotechnology promises considerable socio-economic benefits, while addressing some of the world's most acute problems from climate change, to affordable healthcare and access to clean water (Palmberg et al., 2009). This interdisciplinary aspect of nanotechnology, or nanotechnologies as we are talking about many different subcategories, have led many to assert that it could become the next General Purpose Technology (GPT) with significant effects on productivity and economic growth.

According to Lux Research (2006), an advisory firm focusing on emerging technologies, nanotechnologies could grow to a market size of $3.1 trillion by 2015, creating 2 million jobs globally. Despite it being a rather optimistic forecast, especially due to the global economic crisis, which has taken a toll, more than 60 countries around the world have decided to invest in national R&D programs, recognizing the far-reaching prospects of nanotechnology (Shapira and Youtie, 2011). According to Michaelson (2008) "there is a growing realization that nanotechnology will have an impact on countries both in the developed and developing world by transforming the commodities market, global production, value chains, and the nature of scientific collaboration itself."

From an innovation systems perspective, the thesis looks at this rapidly growing field in the Czech Republic. According to a recent article by the New York Times (2012), "to Czech industry, everything is nano" with companies working with nanotechnologies becoming "a rapidly growing niche in the economy, which, although small, is widely respected for its technical prowess." Considering that ten years ago there hasn't been a single registered nanotechnology-related patent in the Czech Republic, this presents quite a drastic development, worthy of enquiry. According to the *The Czech Society for New Materials and Technologies* (2012) there has been a significant increase in the number of nano-companies over the past several years, growing from 25

[1] Parts of the introduction, and chapters 3.1, 3.2 and 4 and 4.2 have been adapted from Bärtl (2013), unpublished Research Design and *Innovation in the Czech Republic: Multi-Level Perspective* by Bärtl et al. (2012), unpublished.

in 2005 to 142 in 2011. Additionally the number of actors involved in R&D (both public and private) has nearly doubled from 72 in 2005 to 130 in 2011.

With this in mind, the thesis aims to explore the innovation policy of the Czech Republic, with a focus on the support of nanotechnology, barriers to innovation, and the extent to which the policy addresses these barriers. By carrying out a mini-survey of the firms involved, the thesis aims at distinguishing the challenges for nanotechnologies in the Czech Republic and considering whether they can become more than just a niche in the economy. The thesis thus aims to answer the following research question: What are the obstacles to innovation hindering further development of nanotechnology in the Czech Republic?

There are several benefits and limitations resulting from this being a rather exploratory study. The limitations include the lack of previous research on the topic, which could provide a solid base and a starting point for the thesis. Additionally focusing only on firms and policy provides only a very narrow understanding of the innovation system as a whole, especially since only nanotechnology is targeted. Patent and bibliometric analyses could shed further light on the level of R&D and innovation, while a comparison with other countries would be informative in establishing where the Czech Republic stands. On the other hand, providing a direct feedback from the nano-companies through an innovation survey can carry various policy implications. Whether it is the adoption of policies, which would ease access to finance, improve cooperation with other firms or R&D institutions, increase the amount of skilled personnel or reduce the regulatory burden, the obstacles to innovation perceived by companies can assist policy-makers in making appropriate changes.

The rest of the paper is organized as follows: first chapter introduces and defines nanotechnology as well some of the actors in the Czech Republic. Then, the concept of innovation is presented from a systemic perspective, followed by an overview of the data and methods used. Furthermore, the fourth chapter includes an overview of the Czech Innovation policy and its main weaknesses, the fifth chapter presents the results of a mini-survey of nano-companies, followed by a discussion. The thesis is rounded off by several conclusions and policy implications.

1. What is nanotechnology?

In reality there is nothing new or innovative about nanotechnology, it is present in the nature around us and has been for millions of years. Picture a gecko, for example, running effortlessly across walls and ceilings. This is enabled by tiny nano-scaled hairs that cover the surface of its feet enabling it to stick to anything through the millions of adhesion points. Or imagine a lotus leaf, covered with a “self-cleaning” surface enabled by a special coating, which causes water droplets to disperse at high speeds, taking any particles of dirt with them (European Commission, 2004). Both of these are examples of nanotechnology in nature, clearly independent of any human interference. However, humans too were able to exploit the unique features of these tiny particles very early on, beginning with the potters of Mesopotamia, who used nanoparticles of silver and gold to make their pots glitter, as did artists during the Renaissance (Sciau, 2012).

While there is nothing new about the presence of nanotechnology in the world, what is new and innovative, however, is the ability to exploit its special features at an industrial scale. The modern development of nanotechnology is usually traced back to a lecture given by quantum physicist Richard Feynman in 1959 labeled “There is plenty of room at the bottom,“ where he acknowledged the possibility of maneuvering materials “atom by atom“. (Feynman, 1959) Despite many scientists‘ skepticism this concept was later popularized by Eric Drexler, whose “science-fiction-esque” vision of nanobots has, since then, gained much traction. Only in the 1980s, however, has science caught up and nanotechnology became a reality, with the development of the Scanning Tunnel Microscope (STM), which is able to not only visualize, but also manipulate particles at the atomic level. (European Commission, 2004)

According to a definition by Poole & Owens (2003) “nanotechnology deals with various structures of matter having dimensions of the order of a billionth of a meter.“ It is essentially engineering at the level of individual atoms in the range of 1-100 nanometers. To put this into perspective – the size of one nanoparticle compared to a soccer ball is roughly the same as of a soccer ball to the entire earth. Or in another way yet, one human hair is roughly 100 000 nanometers wide. The crucial thing about the size of the particles is, however, that at this range commonly known elements behave and present properties radically different than those observed at a larger scale. (Auplat, 2012) At nano-level materials can be much stronger, insulators can become conductors, opaque substances can become transparent, solids can become liquids at room temperature, and these options are numerous. (Responsible Nano Forum, 2012) Unsurprisingly, it has in the recent years grabbed the attention of academics and policy-makers as well as investors and the general public, which eagerly attempt to assess just how big nanotechnology will turn out to be. According to Businessweek (2005) “some see nano simply as a new material revolution, akin to the dawn of plastics (…) others herald a transition as dramatic as mankind's advance from stone to metal tools.”

Consequently these special properties can be studied both from a basic science and applied research perspective. Whereas nanoscience studies the special phenomena at the miniature level, nanotechnology, or rather nanotechnologies since we are talking about a set of widely differing technologies, tries to develop applications that exploit the specific phenomena that appear at this level. (Van Der Most, 2009) Another possible classification of nanotechnology could be based on *top-down* or *bottom-up* approaches in the construction of objects. While the former has been dominant in the early stages and describes the construction of nano-objects using larger entities with the goal of miniaturization, with microelectronics being the obvious example, the latter refers to the process where materials and devices are built from the bottom up using chemically assembled molecules (Ott et al., 2008).

While nanotechnologies have already contributed to many innovations by enhancing the properties of existing products – from most electronic devices containing microchips to self-cleaning glass, stain-resistant textiles and antibacterial paints – many other possible uses are still at a very early level of research. For this reason one should be wary of talking about a “nanotechnology market” or “nanotechnology products” but rather about a value chain ranging from unprocessed nanomaterials to finalized nano-enabled products. (Holman, 2007) A particular example of the nanotechnology value chain in practice could be the use of nanomaterials (like carbon nanotubes or titanium dioxide nanoparticles) in intermediates, such as coatings, that enhance the properties of finishes (make them self-cleaning or pollution-absorbing, for example), which could in turn be integrated into a whole range of existing products from cars and airplanes to electronic devices or clothes (Youtie et al., 2008).

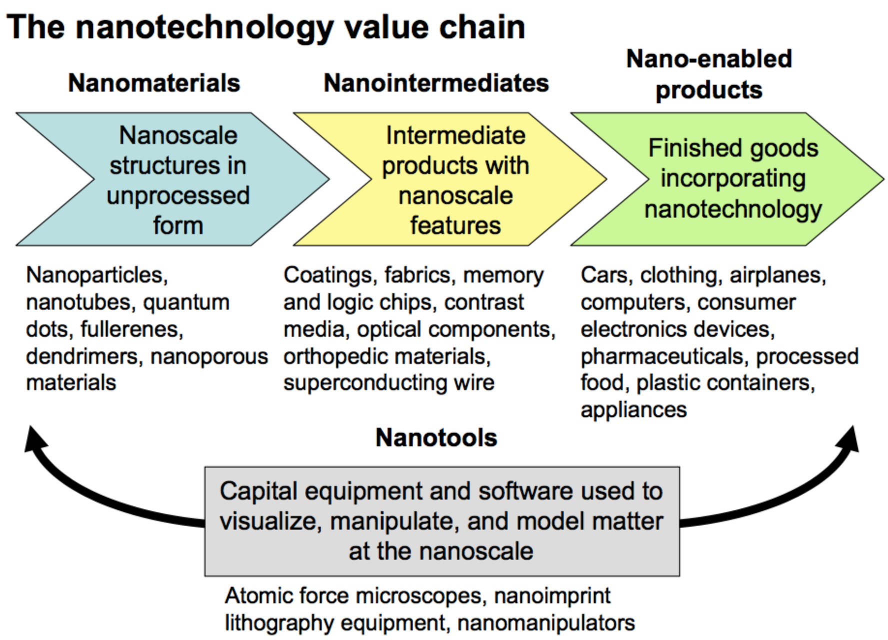

Figure 1. The nanotechnology value chain (data source Lux Research, 2007)

This variety in type of nanotechnology as well as its value-added is important to keep in mind when assessing the dynamic of innovation in different countries in the world. For example, innovations in the United States, clearly the leader in the field (based on the number of patents), are spread fairly evenly across the value chain. On the contrary, Japan's focus is on developments in the lower two parts of the value chain, while Germany seeks greater value-added, by targeting nano-products at the end of the chain (Alencar et al., 2007). This thesis uses a categorization of nanotechnologies based on the Austrian NANO Catalogue and modified by Shrbená and Šperlink (2012), see box below for full details.

1. Nanomaterials

- Nanopowders, nanoparticles, quantum dots, nanofibres
- Composite materials containing nanoparticles
- Materials with carbon nanotubes or fullerenes
- Thin layers, nanolayers, and nano–coatings
- Nanostructural metals and alloys
- Nano ceramics
- Polymer nanocomposites, polymer nanomaterials

5. Nanotechnology for (electro) chemical processing technologies

- Filtration, membranes, molecular sieves, and zeolites
- Catalysis or electrodes with nanostructural surfaces
- Chemical synthesis, supramolecular chemistry

2. Nanotechnology for information storage and transfer, micro– and nanoelectronics

- Nanoelectronics, materials, and equipment
- Photonics
- Optical materials, structures, and equipment
- Magnetic materials and equipment, spintronics
- Organic photonics, bioelectronics
- MEMS, NEMS

6. Long–term research with a wide range of applications

- Self–assembly
- Quantum physics, quantum phenomena in nanosizes, nanophysics
- Nano– and mesoscopic systems
- Chemical materials and processes – nanochemistry
- Ultra–precision engineering

3. Nanobiotechnology, nanomedicine

- Encapsulation of drugs
- Targeted drug delivery
- Tissue engineering
- Biocompatible and bioanalogical materials and layers
- Molecular analysis, DNA analysis

7. Instruments and equipment, research and application of technologies

- Analytical instruments, methods, techniques, and research
- Manufacture (preparation) of nanopowders (nanoparticles) and their processing
- Equipment and methods for the creation of layers and coatings
- Equipment and methods for the creation of objects (patterning, ECAP, fibre fabrication
- etc.)
- Ultra–precision machining and nanometrology

4. Nanotechnology for application in sensors	8. The health, environmental, ethical, social and other aspects of nanotechnologies
• Sensors utilising nanomaterials • Biomolecular sensors	• Toxicity of nanoparticles • Environmental aspects • Social and ethical aspects • Standardisation • Patenting • Prognoses, foresight • Popularisation of nanotechnology • Trade in nanoproducts

Box 1. Nanotechnology subcategories (data source Shrbená and Šperlink, 2012)

Lastly it is vital to point out that the future development of nanotechnology and the possibility of it becoming a GPT is also largely dependent on various social, ethical, and health issues that stem from the nature of the technology itself. Operating at the atomic level, it is extremely hard to measure and assess how nanoparticles react with the environment, check for possible toxicity and other potentially harmful effects. (Auplat, 2012) Since it is an emerging field, there is a lack of protocols and standardization, with "the possible impact of certain "nanomaterials" and "nanoproducts" on human health and the environment (…) still not fully known" (Shrbená and Šperlink, 2012). Because of their specific characteristics, namely that nanotechnologies are trans-sectorial, trans-national, and high potential high risk, they pose considerable challenges for international governance (Auplat, 2012). There is also the so-called "dual-use dilemma" where the same technology that holds great promises in the fields of medical diagnosis and treatment, for example, can be misused for other purposes. To illustrate, some nanoparticles are designed to enter the body in order to deliver medicine in a controlled manner. At the same time, this method could possibly be militarized and used in combat or abused in other manners, for example through an aerosol delivery of a harmful nano-agent, which could potentially endanger large populations at once (Eggleson, 2013). While it is beyond the scope of this study to analyze the environment, health, and safety concerns, when it comes to nanotechnology, it nevertheless must be noted that regulation and standardization, or lack thereof, as well as public opinion towards its possible negative effects can still play a significant role in accelerating or hampering the development of nanotechnology.

1.1 Nanotechnology in the Czech Republic

Compared to such industrial giants as the United States and Japan, or even its next-door neighbor Germany, Czech Republic's nanotechnology sector fills little more than a niche in its current economy. However, the number of public and private actors involved in nanotechnologies has been increasing rapidly over the past several years, up to 230 in 2012, a hundred more than four years earlier. This growth is especially considerable within the number of firms getting to one extent or another involved in nanotechnology. (Shrbená, 2012)

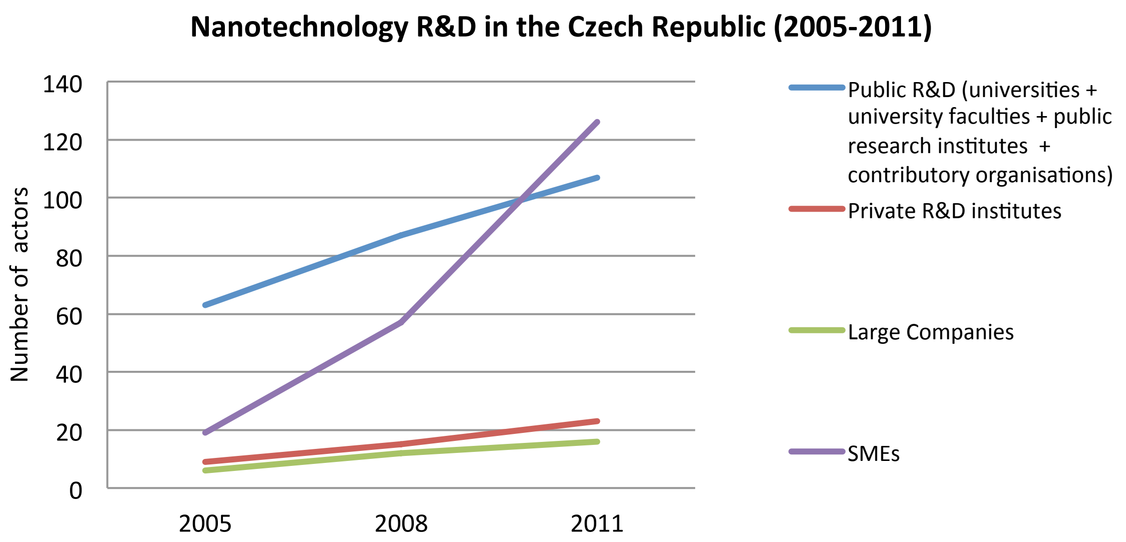

Figure 2. Nanotechnology R&D in the Czech Republic (data source CSNMT, 2012, graph by author)

Czech companies can be found all along the nanotechnology value chain. While a great deal of these is to be found in the lower two tiers, namely the manufacture of nanomaterials and intermediates, there is a growing presence of nano-enabled products, a trend which can be expected to continue. Additionally there are several firms, which are successful in the manufacture of tools and instruments to visualize, manipulate and model matter at the nanoscale.

Perhaps the most well-known nano-company, serving as somewhat of a poster child for the emerging technology in the Czech Republic, is *Elmarco* located in the northern part of the country. Together with the *Technical University of Liberec*, it developed the Nanospider™ technology, and became the industry's first and leading supplier of industrial scale nanofiber production equipment. This enables a wide array of applications from air and liquid filtration products, to waterproof and breathable garments, as well as providing various solutions in healthcare. (Elmarco, 2012) One of the companies that utilizes Elmarco's electrospining machine is *Nanovia,* a manufacturer of anti-allergic and anti-bacterial textiles, which can be used in surgical masks, air and vacuum filters, among others. (Ihned.cz, 7.6.2012). Further along the value chain, *NanoSpace* is an example of a company that utilizes Elmarco's instrument and Nanovia's intermediates in order to create anti-allergic nano-enabled bed sheets.

Another company worth mentioning when it comes to the expansion of nanotechnologies in the Czech Republic is *Contipro Biotech*, which is also a prime example of converging technologies in practice. It is involved in research, development, and production of the active ingredients in cosmetics and pharmaceuticals, specifically hyaluronic acid, of which it is one of the world's largest producers. (Shrbená and Šperlink, 2012) Moreover, the company, which uses a large part of its profits to invest in R&D, recently introduced a machine called 4Spin capable of manufacturing nanofibers, that can dissolve in the human body, making it especially suitable for uses in medicine, especially in tissue engineering, wound healing, and targeted distribution of pharmaceuticals (Ihned.cz, 22.1.2013 and 10.4.2013).

A further example of a Czech nano-tool producer is *Tescan,* a company located in Brno, which manufactures scientific instruments for visualization at the nanoscale, specifically scanning electron microscopes and focused ion beam workstations. Most recently it gained a world primacy by introducing a "multi-nano" instrument with the capability to observe, analyze, manipulate and create structures at the nanoscale all in the same machine.

Not only instrument-building firms have found its place on the market, there are plenty of manufacturers of intermediates present. One example is *Advanced Materials-JTJ,* a company that developed a special coating utilizing nanoparticles of titanium dioxide, which when in contact with light purifies the surrounding air, getting it rid of viruses, bacteria and unpleasant odors. Over the course of one year, one square meter of a façade painted with this coating can decontaminate three million cubic meters of air, helping reduce pollution (The New York Times, 2012). The person behind the company, chemical engineer Jan Procházka, is also the same person that co-developed the NanoSafe™ battery, which due to use of nanoparticles minimizes the wear and tear of the battery enabling longer lifetime as well as faster recharge. (Ihned.cz, 31.5.2012)

Furthermore several clusters have emerged in the past years, bringing together firms and institutions that are to various degrees involved in the R&D, production and commercialization of nanotechnologies. One of these, the *Nanomedic* cluster, as the name would suggest, specializes in wound healing, tissue substitution, devices for specific drug delivery, and gene therapy. Similarly *Nanoprogres* is a cluster focusing at coaxial nanofibres, which also find use in biomedical applications (CzechInvest, 2013). Of particular interest when it comes to technology transfer and bridging the world of R&D and industry is *Nafigate*, a global portal and a nanofiber development firm, which focuses on exploiting the unique features of nanotechnology in areas as diverse as liquid filtration, energy, environment, health and personal care, food packaging and advanced materials (Nafigate, 2013)

2. Theoretical framework

2.1 Systems of innovation

It is an almost universally accepted notion that technological change and innovations in all its various forms are important for productivity growth, which in turn translates positively into increasing material welfare (Edquist, 1997) How to achieve innovation, however, is a different matter altogether and one that does not present such clear and straightforward path. Until the 1990s a linear model of innovation, seen as a series of steps from basic R&D to commercialization, has been at the core of innovation policies in most developed countries, emphasizing the supply of innovation inputs, while neglecting some other important aspects of innovation, such as the (lack of) absorption capacities of firms. (Tödtling and Trippl, 2005)

Increasingly, it has been recognized, by scholars and policy-makers alike, that innovation very rarely occurs in isolation, and that the linear model, running from invention to innovation to diffussion, presents only a very oversimplified image. On the contrary, innovation has been acknowledged to be a highly interactive, multifaceted process which involves the collaboration of a diverse network of stakeholders. (OECD, 2010) Ranging from other firms, such as suppliers, customers, and competitors, to organizations, including universities, research institutes, vocational training schools, banks and various governmental entities, the landscape of innovation is complex and systemic in nature. Additionally, institutions, which can be seen as the "the rules of the game in a society, or more formally, the humanly devised constraints that shape human interaction" (North, 1990: 3), can provide incentives as well as obstacles to innovation. (Edquist, 2005)

Together these components interact together in "systems of innovation" as was first articulated by Freeman (1987), who defined it as "the network of institutions in the public and private sectors whose activities and interactions initiate, import, and diffuse new technologies." The systems of innovation (SI) approach was later developed by Lundvall (1992) and Nelson (1993). While the former focused on SI from a rather theory-building perspective, the latter, on the contrary, analyzed the empirical side of things with specific case studies. According to the Edquist (2005) the following activities can be expected from most SIs:

(1) Provision of Research and Development (R&D), creating new knowledge, primarily in engineering, medicine, and the natural sciences.
(2) Competence building (provision of education and training, creation of human capital, production and reproduction of skills, individual learning) in the labor force to be used in innovation and R&D activities.
(3) Formation of new product markets.
(4) Articulation of quality requirements emanating from the demand side with regard to new products

(5) Creating and changing organizations needed for the development of new fields of innovation, e.g. enhancing entrepreneurship to create new firms and intrapreneurship to diversify existing firms, creating new research organizations, policy agencies, etc.
(6) Networking through markets and other mechanisms, including interactive learning between different organizations (potentially) involved in the innovation processes. This implies integrating new knowledge elements developed in different spheres of the SI and coming from outside with elements already available in the innovating firms.
(7) Incubating activities, e.g. providing access to facilities, administrative support, etc. for new innovative efforts.
(8) Financing of innovation processes and other activities that can facilitate commercialization of knowledge and its adoption.
(9) Provision of consultancy services of relevance for innovation processes, e.g. technology transfer, commercial information, and legal advice.

While the SI research has originally centered around the national arena, it has since then been complemented by sectoral and regional dimensions. From one point of view, Sectoral Innovation Systems (SIS) take the perspective of various technology fields and product areas, whose innovation processes are viewed as unique, and include other concepts such as product and industry life cycles. (see Carlsson, 1995, or Breschi and Malerba, 1997) Additionally, despite the notions that globalization has made the world flat, giving an equal business opportunities to all (Friedman, 2005), it is clear that national, and more importantly sub-national units play an important, and arguably a growing role in the creation and diffusion of knowledge. Regional Innovation System (RIS) thus takes a geographical approach to analyzing innovation processes within parts of countries, as well as across national borders. (see for example Cooke 1992 and 2001; Malmberg and Maksell, 2002; Asheim and Coenen, 2005; Lundquist and Trippl, 2013)

Due to this rather abstract web of complementing and sometimes overlapping concepts, one should be wary of viewing the innovation systems approach as a comprehensive theory as such, but as more of a conceptual framework that includes “all important economic, social, political, organizational, institutional and other factors that influence the development, diffusion and use of innovations.” (Edquist, 2005) According to Lundvall (2007), by essentially accumulating empirical studies at different levels of aggregation, showing that innovation is an interactive process, one can see that the SI concept reflects principles of grounded theory. It is, however, frequently criticized for being “undertheorized”, lacking more specific statements about the relations between variables as well as knowing too little about the determinants of innovation. (Edquist, 2001). This can be seen as a weakness of the SI concept.

On the other hand, in relation to the focus on of my thesis, there is a clear advantage to using the SI approach, specifically the original NIS perspective. As opposed to other theories, such as Porter’s Diamond that focuses on competitiveness in industrial clusters, NIS captures the importance of policymaking and its influence on innovation. Quite possibly it is the looseness and openness of the SI framework, which bridges the worlds of academia and policy-making, that has made it so appealing and contributed to its impressive diffusion and adoption in academic and public policy circles around the world (Lundvall, 2008).

Based on the fact that this study's research topic is nanotechnology one might deem appropriate to use SIS as lens for analysis. Unfortunately, this can also be seen as problematic, mainly due to the generic nature of nanotechnology that spreads far beyond a single industry and thus has to be looked at from a broader perspective. And while it is possible to observe certain regional features when it comes to nanotechnology in the Czech Republic, regions are still rather weak units in regards to creating and implementing innovation policy, making a RIS approach difficult to carry out. A NIS approach was thus chosen because, while other forces like the supranational EU are increasingly influential in policy-making, innovation policy still remains largely a domain of the national government. This of course has limitations of its own, such as the fact that many nanotechnology firms are "born-global" and defy geographical delineations from the very outset. Additionally, due to spatial constraints the study cannot focus on all aspects of the Czech NIS, so emphasis is given only to firms, which represent the knowledge application and exploitation subsystem and to policy, which reflects the "rules of the game" aspect of innovation. Despite being quite important in such a science-based "sector", this leaves the knowledge generation subsystem, including universities and other research institutions, rather unexplored and open for further research.

Furthermore, while the RIS approach may not be completely appropriate for this study, some of the policy recommendations stemming from systemic failures (organizational thinness, lock-in, or fragmentation) may prove useful on a national level too (see Tödtling and Trippl, 2005). Additionally, by identifying how innovation processes in nanotechnology occur, a more targeted policy support can be created. This relates to the concept of differentiated knowledge bases as developed by Asheim et al. (2011), with nanotechnology most closely resembling an analytical knowledge base where "scientific knowledge based on formal models and codification, (…) university– industry links and respective networks are important and more frequent (…) knowledge inputs and outputs in this type of knowledge base are more often codified than in the other types (…) [and] inventions may lead to patents and licensing activities. Knowledge application is in the form of new products or processes, and there are more radical innovations than in the other knowledge types."

2.2 Nanotechnology as a General Purpose Technology

To some academics, nanotechnologies, present disruptive innovations, which create “radical new combinations“ in the true Schumpeterian sense (Fogelberg and Glimell, 2003; Mangematin and Walsh, 2012). These disruptive technologies can be defined as scientific discoveries that break through the usual product and technology capabilities in order to provide a basis for a new competitive paradigm (Kostoff et al., 2004) According to Alencar et al. (2007) nanotechnology is both “enabling“ and “horizontal.“ It is “enabling“ in the sense that it can be seen as a prerequisite for a whole range of other technologies, products, and processes, and “horizontal“ by making it applicable a wide range of sectors.

This interdisciplinary feature of nanotechnology has led several academics to argue that it possesses the characteristics, which could classify it as a General Purpose Technology (see Huang et al., 2003, Shea, 2005, or Palmberg and Nikulainen, 2006). The defining aspects of the GPT concept, most commonly associated with steam engine, electricity and most recently ICT, relates to technologies that have (1) a substantial and pervasive effect on the functioning of the society, while enabling a whole range of (2) complementary technologies and downstream innovations, but also maintaining a (3) scope for improvement. (Helpman, and Trajtenberg, 1994, Bresnahan and Trajtenberg, 1995) Due to the great impact on growth and productivity levels that they have, this puts them in a constant spotlight, despite a considerable lag between the introduction of a technology and the time to reap the benefits of the wide range of complementary technologies. (Youtie et al., 2008). When it comes to nanotechnology Youtie et al. (2008) have demonstrated that nanotechnology may have characteristics of a GPT, especially when it comes to the levels of “pervasiveness”, which are similar to that of ICT, while not being conclusive on the other two attributes. They also question the ability to judge an emerging technology based on patent data, as many of the above mentioned studies have done, since this type of data can shed light on current and past developments but not necessarily foresee the future development of a GPT. More ambitiously, Ott et al. (2008) argue that aside from accomplishing the generic function of being able to arrange single atoms, nanotechnology has huge potentials for improvement as well as a multitude of possible uses, which *de facto* fulfills the necessary attributes of a GPT, albeit at a very early stage of development.

Others, such as Meyer (2006) fail to see it as a single “unit“, closely associated with the label of “converging industries“, rather arguing that only very few firms actually cross boundaries between different nano-scale technologies. Instead of becoming the next General Purpose Technology (GPT), innovative activity in nanotechnology, according to Meyer, “tends to be of incremental nature and is very likely to occur along established technological trajectories.” For example, while more than 1,000 nanotechnology-enabled products have been identified, many of them have been incremental improvements to established products rather than radical innovations. (Shapira and Youtie, 2011)

Furthermore, while earlier predictions suggested that by 2015 one-tenth of the world's manufacturing output would be associated with nanotechnology, the global financial crisis has significantly decreased the tempo of nanotechnology's growth. (Lux Research, 2009) If nanotechnology is to become the next GPT a whole range of complementary technologies, organizations and institutions are necessary. Previous experience shows that with new technologies, productivity gains and, connectedly, economic growth may come with a significant time-lag. (Palmberg et al., 2009) It was this way with ICT and the trajectory may be similar with nanotechnology. Paraphrasing Solow's paradox about computers, Mangematin and Walsh (2012) maintain nanotechnologies are "found everywhere except as a new industry or a new scientific field."

2.3 Innovation policies

In the past several decades, with the onset of globalization, it has been firmly established that we are moving towards an economy, where knowledge becomes a major factor in economic growth and thus an important asset for any country to have. With this shift of an economic paradigm, the importance of a coherent innovation policy has increasingly come to the forefront (Llerena and Matt, 2005). This comes as a result of an intensified competition where economic performance is more and more dependent on the ability of individuals, companies, as well as states to learn and adapt to a rapidly evolving market. Furthermore, since the liberalization of financial markets has severely limited the autonomy in trade, monetary and financial policies, states must compensate with labour market, social, education, and above all innovation policies, in order to capture economic growth within this new paradigm (Lundvall and Borrás, 1997).

As pointed out by Chaminade and Edquist (2006) innovation policy can be defined as "the public actions that influence innovation processes, i.e. the development and diffusion of (product and process) innovations", in order to pursue, mainly, economic objectives, such as economic and productivity growth, increased employment and competitiveness. Specifically, innovation policies are a diverse set of tools that incorporate and complement a wide range of individual policy areas from science and technology, research and development, education and workforce training, to immigration, tax, trade, and intellectual property rights. (Ezell and Atkinson, 2010) Additionally, since technological innovation and commercialization are key components of entrepreneurial activity (Schumpeter, 1934), innovation policies directly influence levels of entrepreneurship in a country (Woolley and Rottner, 2008).

Even though some of the actors and instruments may overlap, one must acknowledge a distinction between science, technology, and innovation (STI) policies, respectively. Historically, as shown by Lundvall and Borrás (2005) on a series of seminal papers by OECD, policy tended to evolve from a focus on basic science at the beginning of the Cold War, towards a more economy-oriented technology policy, only to recognize innovation as a crucial component in the late 1980s. However, as they point out, science policy, which used to fulfill economic objectives, as well as ones relating to national prestige and security, still ranks very high on the policy agenda, especially with the current developments in high-tech industries, like biotechnology, where trajectories from discovery to market have been cut rather short, especially when it comes to actors involved, with inventors and innovators often being one and the same.

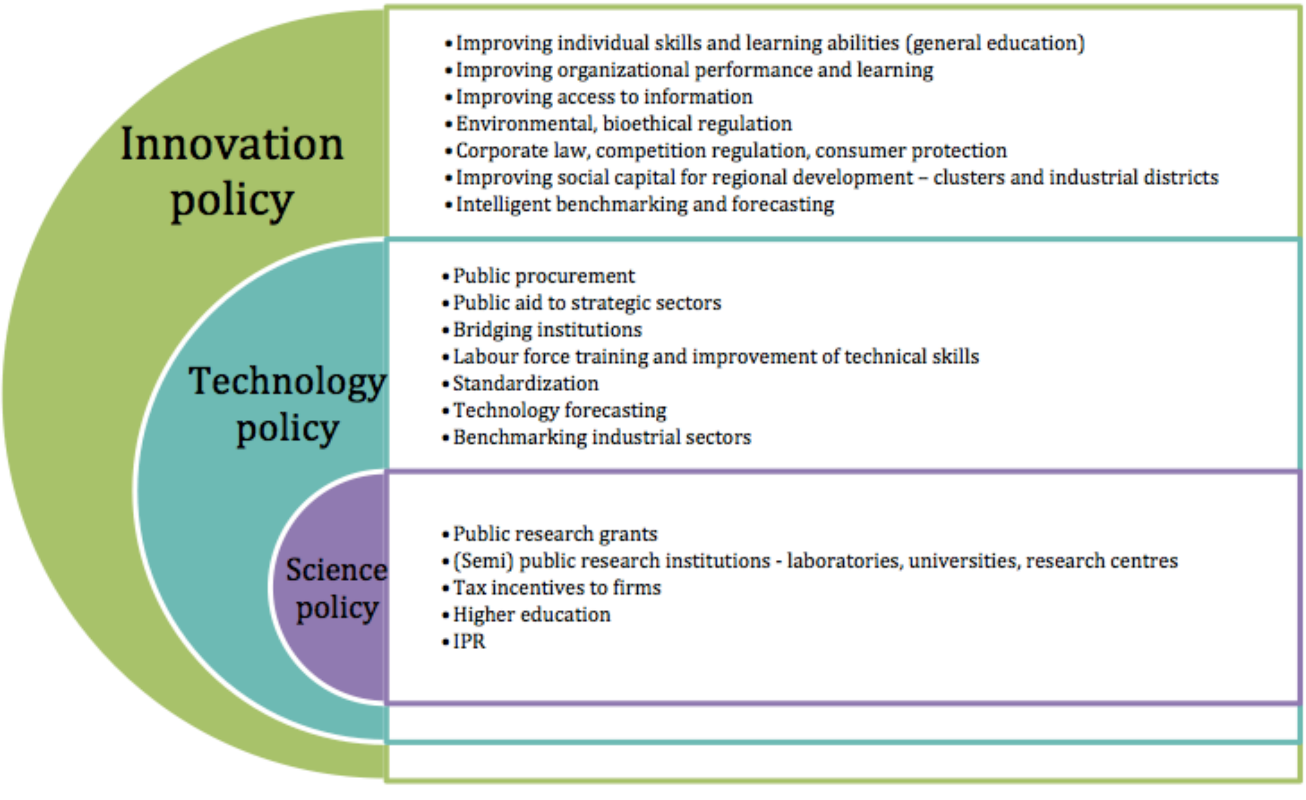

Figure 3. STI Policies (data by Lundvall and Borrás, 2005, chart by author)

One can see STI policies as each influencing a rather different part of the innovation system. On the one hand, there is the science policy, which focuses mainly on universities, research institutes and R&D laboratories, with basic science at its core. In recent times, especially due to budgetary constraints, this type of research has come under pressure from policymakers that want it to demonstrate social and economic usefulness. In a way this pushes basic science increasingly into the realm of technology policy, which is at core of economic growth by opening up commercial opportunities. As such, innovation policy involves an even broader set of policy issues and moves towards all parts of the economy that have an impact on innovation (Lundvall and Borrás, 2005).

The rationale for innovation policy can be viewed from two different perspectives – either through the "laissez faire" approach or by using a more systemic lens. Traditionally, the argument for public investment in R&D originated from a neoclassical "market failure" argument, where the specific characteristics of scientific knowledge (uncertainty, inappropriability, and indivisibility)[2] lead to under-investment in R&D by companies and less than optimal allocation of resources (Chaminade and Edquist, 2006). This occurs because innovative firms are unable to appropriate all the returns, while covering all of the costs. Public policy thus steps in either by creating a stronger IPR protection for the inventor or by direct support for R&D in the form of subsidies or tax relief. (Lipsey and Carlaw, 1998)

In comparison, the innovation systems rationale is based on systemic failures or problems rather than on market failures. The policy thus targets everything from physical and scientific infrastructure (IT, transport, universities), but also tackles transition and capability problems that stem from changing technological paradigms, as well as lock-in problems, that hamper the emergence of more efficient technologies, and network problems addressing inefficient linkages within the system. In addition, the policy targets institutional problems, both formal, such as regulations and laws, but also more tacit, like the social and political culture (Chaminade and Edquist, 2005).

The inherent uncertainty of innovation is even more visible in new technological fields, such as nanotechnology, where markets have not yet been established and demand is yet to be determined. Public support in such an early phase can thus have a tremendous impact on the future development of a technology or an industry. In the USA, public procurement has been used on a large scale, in order to provide markets for new products.[3] The initial support also presumes a forecasting role of the state, which should be able to choose priority areas of R&D&I. (Chaminade and Edquist, 2006) This is not to say that innovation policy is the same as industrial policy, which can in its ugliest form manifest itself in "picking-the-winner" strategies occurring within narrow technologies or even specific firms, but rather that the government can create supporting factor conditions for several broad technologies and industries. (Ezell and Atkinson, 2010) Furthermore, due to the uncertainty of innovation, where new technologies and industries are often the result of spontaneous activities, states must be wary of trying to simply adapt a "one-size-fits-all" model

[2] Chaminade and Edquist (2006) explain the findings of Nelson (1959) and Arrow (1962) in the following way: "*Uncertainty* refers to the impossibility to fully know the outcomes of the research process and the risk associated to it. *Inappropriability*, means that firms cannot fully appropriate the benefits which derive from the invention. There will always be externalities emanating from the research process. As knowledge is considered to be information and this is assumed to be costlessly accessible to all economic agents, this means that the incentive for research activity by firms is limited, i.e. smaller than it would be if it was possible for firms to appropriate all the benefits. *Indivisibility* implies that there is a minimum investment in knowledge before any new knowledge can be created."

[3] An example of this can be the development of the most recent general purpose technology – ICT – and the way it was aided by the US government.

from elsewhere. As tempting as it may be for policymakers to try to “grow“ their own Silicon Valley, effective policy-making requires the consideration of local conditions, such as institutional history and specific knowledge bases present (Asheim et al., 2011)

To sum up, while the actors and instruments of STI policies are often one and the same, each focuses on rather different part of the innovation system. An effective innovation policy thus analyzes the system based on general insights about what is good practice in a global context when it comes to technology and competition, but also takes into account the specialization and institutional set-up of the NIS, as well as its place in the global economy (Lundvall and Borrás, 2005).

3. Data and Methods

As a fairly recent phenomenon, at least in the Czech Republic, there is a clear lack of studies that would analyze nanotechnology from management and business research, not to mention innovation, perspective. For this reason my thesis balances between an exploratory and descriptive study. Accordingly, as a rather pilot study, this thesis relies on a combination of primary and secondary data. On the one hand, secondary literature such as books, academic and trade journal articles, among others, are used to introduce the basics of nanotechnology as well as the nature of innovation within this rather disparate “field”. These sources are further used in a discussion on innovation policies with an emphasis on high-tech, knowledge intensive and science-driven innovations. Additionally, government documents and working papers are used to support the secondary literature to explain the policy aspects of the Czech NIS, relating it back to nanotechnology. This part of the thesis, which can be labeled as rather descriptive, is followed by a more exploratory section, which uses a survey to collect primary data and thus ensure a direct feedback from nano-companies about the levels of state support and perceived factors hampering innovation in their firm. Do companies feel that government policy and strategy is helping them as much as it could and should? What obstacles to innovations in the field of nanotechnology in the Czech Republic do they identify?

3.1 Data

Due to the broad scope of nanotechnology, which encompasses everything from electronics to water purification, identifying a homogenous group of nano-companies is generally quite tricky.

In the Czech Republic it is no different, partially due to the lack of commonly agreed definitions and frameworks, as well as because many firms dabble in nanotechnology only partially while their core business lies elsewhere. These innovations are often of an incremental character in already existing products and industries.

As could be expected, there is no official list of nano-companies in the Czech Republic - the Register of Companies in which all Czech firms must be included by law doesn't provide a sectoral classification, which in any case would be difficult with nanotechnologies. Similarly, even though the Czech Statistical Office keeps a Register of Economic Subjects by industries, it doesn't include nanotechnology as a single category in the Classification of Economic Activities (CZ-NACE). For this reason I have turned to a database developed by *The Czech Society for New Materials and Technologies* (CSNMT) that tracks both public and private actors involved in nanotechnology R&D and commercialization. An overview of these has been included in a publication called Nanotechnology in the Czech Republic (originally created in 2005 but updated in 2008 and 2012), which was made available to me by the CSNMT and which was used in order to put together a list of firms that are directly or indirectly involved in nanotechnologies. This includes companies along the entire nanotechnology value chain, from the production of nanomaterials to the manufacture of nano-enabled products, or simply carrying out nano-related R&D. Due to a relatively low number of nano-companies in the Czech Republic, around 130, I have decided against making a smaller sample. Instead the intention was to collect data from all of the nano-companies that are directly or indirectly involved in R&D of nanotechnologies in the Czech Republic.

3.2 Measuring innovation

Unlike other, more straight-forward indicators, innovation involves multidimensional novelty that is intrinsically difficult to measure and compare. This relates to the problem of how we define the novelty of an innovation – does it have to be new to the world? What if it is new only to the firm – is that innovation or just imitation? And how radical does the change have to be? That is to say innovation isn't impossible to measure, however, it has its problems and until recently these were reinforced by the lack of economy-wide indicators, which would allow for international comparisons. (Smith, 2005)

Despite this, one of the common ways to asses levels of innovation has been the use of public and private R&D expenditure or the number of R&D workers employed. This has the obvious limitation of only measuring inputs to innovation, rather than actual outputs, while at the same time discriminating against smaller businesses, where R&D tends to be spread out across the enterprise and not be confined in a dedicated R&D department (Storey and Greene, 2010). Even though this indicator tells little about actual innovation it is quite popular with governments, due to the long periods of time over which data has been collected and the possibility for comparability between countries.[4]

Another possible measure of innovation is through "intermediate output measures" such as publications and patent data, which, however, also provide only a limited picture of the nature of technological change and innovation. (Palmberg et al., 2009) First of all, bibliometrics relates primarily to the dynamics of science rather than innovation. (Smith, 2005) Secondly, while the main advantage of using patents to examine innovation is the fact that it is a measure of output, it does not cover the whole array of innovations. And even though one can assume that in the current pro-patent era and by the nature of "science-driven" innovations patent analysis can be a solid way of identifying actors involved in nanotechnology, it is not uncommon for some companies to rely on other ways of protecting their technology, based on tacit knowledge and secrecy. (Libaers et al., 2006) Additionally, other forms of intellectual property are not included, like design, copyright and trademark rights. Furthermore, due to the considerable costs of patenting, leaving SMEs with a range of other options, again large company bias is present. In any case, patents are an indicator of invention rather than innovation, and very few inventions actually make it to the market (Storey and Greene, 2010).

Finally, innovation surveys have been the latest in an attempt to create indicators that would focus directly on innovation outputs. This process started in the early 1990s when OECD came up with the Oslo Manual (OECD, 1992), in order to create a common toolkit and standardize the practice of carrying out innovation surveys, which, most importantly, resulted in the creation of EU's Community Innovation Survey (CIS). This series of surveys, which includes EU countries, Norway and Iceland, has been carried out seven times since 1992 and helped map not only R&D expenditures in companies but also non-R&D inputs, sources of information, technological collaboration and perceived obstacles to innovation. (Smith, 2005) The main advantage of this approach is the recognition of cooperation and collaboration in research and development, which effectively espouses the systemic nature of innovation. Furthermore through questions about innovation barriers the national government is recognized as an important part of these processes, in regards to not only strengthening science and technology infrastructure but also improving the regulatory framework and institutional conditions that affect innovation (UNU-INTECH, 2004). Another interesting aspect of innovation surveys is the fact that they manage fairly well to avoid a company size bias as well as categorize innovation according to stages of novelty. On the other hand, this method has limitations of its own, most importantly rooted in the subjectivity where the

[4] To illustrate, one of European Union's key goals in the innovation arena is to increase the ratio of gross expenditure on R&D (GERD) to GDP to 3% from the current 2% EU average – in 2010 Czech Republic trailed behind with 1.56% (Eurostat, 2012)

respondents are businesses themselves and not independent observers. In practice this mean that companies can be more prone to list their successes than failures. Furthermore, innovators are more likely to respond than non-innovators creating a possible bias (Storey and Greene, 2010). Additionally, as this indicator deals more with the perception of innovation, the responses can be skewed as a result of different business cultures where respondents over- or under- rate their achievements. While these limitations are considerable, an innovation survey is still the best-suited tool for the purpose of my thesis. To minimize the limitations of each of the indicators and for a more balanced result, future research should combine all of the afore-mentioned methods.

3.3 Questionnaire

As a model questionnaire I have adopted the Czech version of the CIS 2010, as produced by the Czech Statistical Office, which is a word-for-word translation of the official EU questionnaire.[5] This was complemented by several questions used in the Malaysian National Survey of Innovation for topics regarding government assistance for innovation, which were not present in the CIS questionnaire, and are crucial for the aim of my study.[6] Several other questions were added to clarify various issues. Since the main focus of my mini-survey was not primarily on the nature of innovation itself but on the level of governmental support, but also for the sake of keeping the questionnaire as short as possible in order to ensure a better response rate, some topics from the CIS were omitted.

First a series of general questions was posed, like the founding year of the company and number of employees, to find out more about the type of firms that deal with nanotechnology, as well as questions to establish whether nanotechnology is their core business. This was followed by question about the specific subfield of nanotechnology the companies operate in. Subsequently a series of queries investigates product and process innovations in the company, whether they were carried out alone or with partners, and their level of novelty.

Next, a key set of questions deals with factors hampering innovation activity. In addition to the ones posed by the CIS two other factors were included – excessive regulation, which could be related to the social, ethical and health aspects of nanotechnology, and the current macroeconomic climate, because the growth of nanotechnology has received a severe blow following the global financial crisis (Lux Research, 2009). Pursuing this further, an open question on other perceived bottlenecks to innovation is given so the firms may get a chance to elaborate. Another section of the

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[5] English version of the entire CIS 2010 is available online: http://innovacion.ricyt.org/files/CIS%202010.pdf (accessed 13 May, 2013), the modified version used by me to carry out the mini-survey can be found in the Appendix.

[6] For the Malaysian National Innovation Survey visit the official website of the Malaysian Science and Technology Information Centre (MASTIC) - http://www.mastic.gov.my/web/guest/home

questionnaire is dedicated to financing of innovation from public sources – local and national government and EU – as well as private financing through venture capital. Furthermore the type of state support is identified and again an open question is posed on suggestions for other ways that the state could support innovation activities, giving a chance to expand on the previous answers. Finally the questionnaire looks at information sources for innovation activities to establish the presence of partnerships between actors in innovation activities, as well as the geographical location of these partners.

These questions can point to several possible conclusions. For example, information about whether firms receive governmental support for innovation, as well as identifying the sources of financing their R&D (grants, venture capital, parent company) can be an indicator of whether there is need for more funds to be dedicated to the development of nanotechnology. Other obstacles might also be identified such as a lack of skilled personnel or a knowledge gap when it comes to acquiring information on new technology. This would point to an insufficient support for the knowledge generation subsystem and lack of cooperation between universities and firms. Governmental support for companies can range from direct assistance by providing funding for subsidies and grants for R&D, commercialization of R&D results, and various tax incentives to various "softer" approaches like helping manage technology transfer through consultancy services and technical support services, such as helping with patent registration. In order to ensure a better response rate, the research was carried out under the patronage of the Economic Section of the Czech Ministry of Foreign Affairs, which has also provided an official Letter of Endorsement.

4. Czech Innovation Policy

As many other countries in the European Union, Czech Republic has a very centralized, top-down approach to innovation with policymaking on the national level being rather dominant. Regions have nonetheless in the recent years become an ever more important unit of analysis when dealing with innovation, along with the financial support from supranational bodies, namely the EU, which provides a large portion of the funds for building innovation infrastructure.[7] As noted by Klusáček et al. (2008a) "the Czech Republic has been advancing towards a knowledge based economy since 2004, when the basic conceptual documents were formed for the research and innovation policy. (…) [Furthermore] resources from the EU Structural Funds for the period 2007 – 2013 provide an opportunity for a further shift in the transformation of the Czech Republic from a

[7] The volume as well as the scope of EU support is extensive. Within the 2004-06 funding period, 2.6 Billion Euros were allocated to the Czech Republic and withing the current period (2007-13) the Czech Republic is in the process of receiving 26.7 billion Euros in total (European Commission, 2009).

labour intensive to a knowledge intensive economy, which could further stimulate research and innovation activity in the Czech Republic." So far the transition rate of the type of economy in the Czech Republic has been rather slow, largely due to a strong base and a tradition of technical and engineering fields (Hebakova et al., 2011). However, even though the economic growth has been achieved through a combination of investments into production capacity broadening, and simultaneously adopting modern technology developed in advanced countries elsewhere, innovation has been recognized as a key growth engine for maintaining competitiveness in the future (Klusáček et al., 2008b) .

In regard to innovation performance, the Czech Republic ranks in the category of *modest innovators* (along with Greece, Hungary, Italy, Lithuania, Malta, Portugal, Slovakia and Spain).[8] This means that the country ranks below EU average in most innovation indicators, performing weakest when it comes to the excellence and attractiveness of the research system (having a high rate of scientific co-publication but rather low citation impact). Furthermore there is a well-known problem with a lack of collaboration between public and private sectors, a low number of patent applications, inadequate amount of venture capital (VC) investments and rather low employment as well as export rate in knowledge-intensive industries. On the other hand Czech Republic has been improving in the majority of these indicators, most notably in the increase of population with tertiary degrees, which shows highest growth in the entire EU (European Commission, 2013). A more detailed discussion of some of the weaknesses that innovation policy needs to address is presented in the next chapter.

In the Czech Republic there is no single legally defined institution, which would be responsible for the entire innovation policy. Rather the agenda is divided between a plethora of separate institutions, sometimes without clearly delineated responsibilities, which causes severe coordination problems. Currently, two different ministries responsible for carrying the National Innovation Policy – the *Ministry of Industry and Trade*, which is in charge of industrial innovation, while *Ministry of Education, Youth and Sports* administers public R&D and universities.

Additionally other institutions are involved in preparing and carrying out the innovation policy, such as the *Research, Development and Innovation Council (RDIC)*, an advisory body to the government, the *Academy of Sciences of the Czech Republic (ASCR)*, which serves as a sort of a quasi-ministry of science, the *Czech Science Foundation*[9], in charge of grant allocation, and the *Technology Agency*, a new institution in charge of applied research and development. Furthermore, while regional and local governments are mainly in charge of implementing the national policy, they provide inputs and draft initiatives of their own, which until recently caused a total of 22

[8] Interestingly, on a desegregated level, the region of Prague belongs to the highest category of innovation leaders whereas the rest of the regions are fall either into the innovation follower or moderate innovator category.
[9] Known also as the Grant Agency of the Czech Republic

different authorities with R&D and innovation responsibilities (Goglio, 2006). After a reform of R&D&I carried out in 2009 this has been simplified to 12, however a budgetary fragmentation still prevails (Hebakova et al., 2011). This lack of transparency when it comes to funding can lead to other problems, as can be seen on the example of innovation infrastructure financing from EU's Structural Funds, which has been halted in all but one region in the Czech Republic on the basis of corruption, incompetence and hemorrhaging money (Respekt, 28.4. 2013).

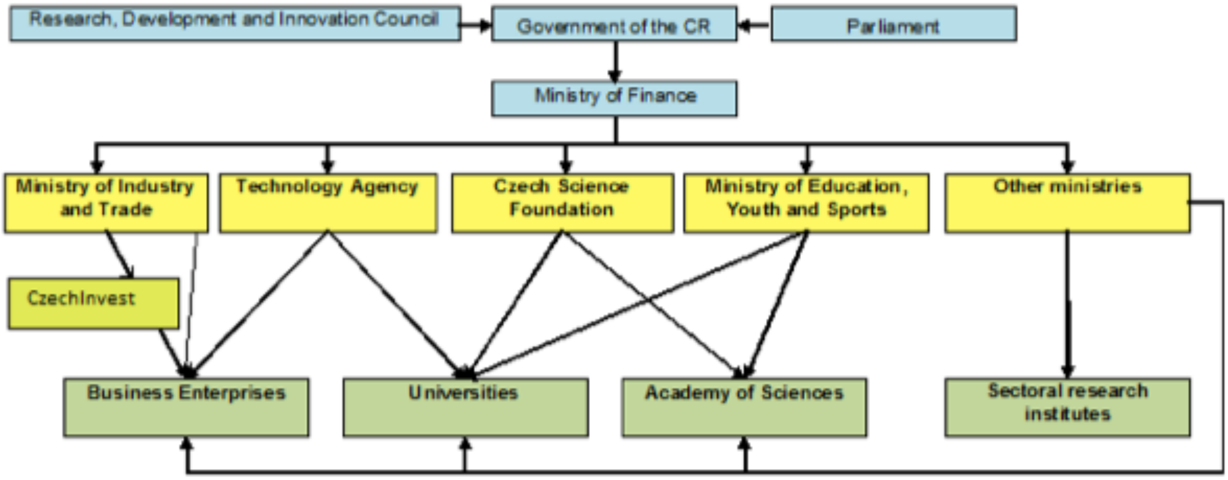


Figure 4. Organizatinal chart of innovation governance in the Czech Republic (data source: Klusáček et al., 2008a)

Nonetheless, despite the progress being far from ideal, main innovation policy objectives have been laid out by several strategic documents, the most important of which is the *National Innovation Strategy*, which creates a broad framework for *The National Research, Development and Innovation Policy of the Czech Republic 2009–2015*. Additionally, these documents are part of an even broader *International Competitiveness Strategy for the Czech Republic 2012 – 2020.* As the document states "while in many countries innovation and competitiveness strategies have become more or less synonymous, (…) Czech Republic still has many problems in regard to its basic preconditions for growth (e.g., its public administration efficiency, corruption, etc.) (…) therefore its innovation strategy must constitute only one of the main pillars of a complex international competitiveness strategy" (MPO, 2011). This corresponds with the notion of Lundvall and Borras (2005) in regards to developing countries, where ordinary STI policies are not sufficient to overcome the obstacles for economic development and a broader social mobilization is necessary. Rather than simple financial support to R&D, the overall competitiveness strategy aims at improving the institutional environment (including infrastructure, healthcare, education, labour market, financial market, etc.) that influences innovation (Hebakova et al., 2011).

The above mentioned documents all recognize the fact that Czech Republic must move away from simple efficiency gains through Foreign Direct Investment (FDI) to an innovation-led growth.

This is to be achieved by:

(1) stimulating the so far very limited demand for innovation in the domestic business sector;
(2) collaboration and in particular on the transfer of knowledge between the business and R&D sectors;
(3) modifying the existing system of R&D evaluating and funding, including additional conditions to support the excellence as a matter of priority;
(4) creating a "strong central authority", ready to define and coordinate policies and to implement instruments across the entire innovation ecosystem. (MPO, 2011)

Furthermore a reform of the research, development, and innovation system of the Czech Republic aims to:

(1) simplify R&D aid – to assist institutions on the basis of results and teams on the basis of their projects;
(2) make a significant reduction in the current 22 budget headings that channel aid into R&D in the Czech Republic; to simplify the paperwork;
(3) promote research excellence, to favour such excellence and to capitalize on the results for innovation;
(4) to make R&D programme assistance contingent on cooperation between public research and the users of R&D results, based on proportionate funding from public and private sources;
(5) install a more flexible public research organizational structure;
(6) secure the experts required for research, development and innovation;
(7) increase international cooperation in the field of research, development and innovation. (Council for R&D&I, 2009)

4.1 Strengths and weaknesses of the Czech innovation policy

Czech Republic has faced many challenges regarding innovation since entering the EU in 2004, including a widespread mistrust between business partners, a lack of development policies in place as well as innovation system that missed key components, such as tools for the transfer of technology (Blazek and Uhlir, 2007). While several of these have been addressed during the 2008 reform of R&D&I, many problems continue to persist. On the positive side there has been the recognition of innovation as an important growth factor, manifested by the existence and implementation of innovation strategies on both national and regional levels. Furthermore, a significant strength comes from the attractiveness of the country for foreign capital, openness of the Czech economy linked to growing export volume, an increasing impact of local research over the past several years as well as improving competitiveness in the high-tech sector. On the other hand, major weaknesses prevail, such as a lack of coordination of education, R&D, innovation, and industrial policies, as well as ineffective allocation of public finances to R&D, which doesn’t take into account the quality of research. Additionally, a weak innovation culture is reinforced by an unfavourable business environment, with complicated tax collection and procedural complications when closing a business, but also by the absence of tax incentives (and in fact double taxation) when it comes to venture capital (Klusáček et al., 2008a)

According to an international audit of the Czech National Innovation System (NIS) carried out by Arnold (2011), the main structure of the NIS still stems from the long period of communist rule and the subsequent transition during the 1990s. While R&D has recovered in traditionally strong sectors, like the automotive industry, the main growth is still led by FDI, which while appearing to give the country an edge in medium- and high- tech, in practice revolves around rather low-value production in these industries. In regards to innovation governance Arnold (2011) points out that some of the structures through which the Czech state supports R&D and innovation are "internationally unusual and problematic". This mainly points to the role of the Academy of Sciences, which he calls a quasi-Science ministry, due to having a line in the state budget as well as an authority to decide how to spend its money, together with the Research, Development and Innovation Council, a small advisory body to the government, which not only assumes the role of principal over the ASCR, and other institutions, but covers long-term strategy development, monitoring, evaluation and decision-making on budget allocations, thus taking responsibility for micro-management and assuming the role of an executive body. Furthermore, while lip-service to the concept of innovation systems is paid in most documents, it is possible to see that the public support to R&D&I still follows a rather linear perspective of innovation processes from basic research to market (see Figure 5). From this point of view, however innovation policy covers most of the individual phases of the innovation process with the exception for the transition from development to pilot operation, which is usually connected with considerable costs and high risk of failure (Klusáček et al., 2008a).

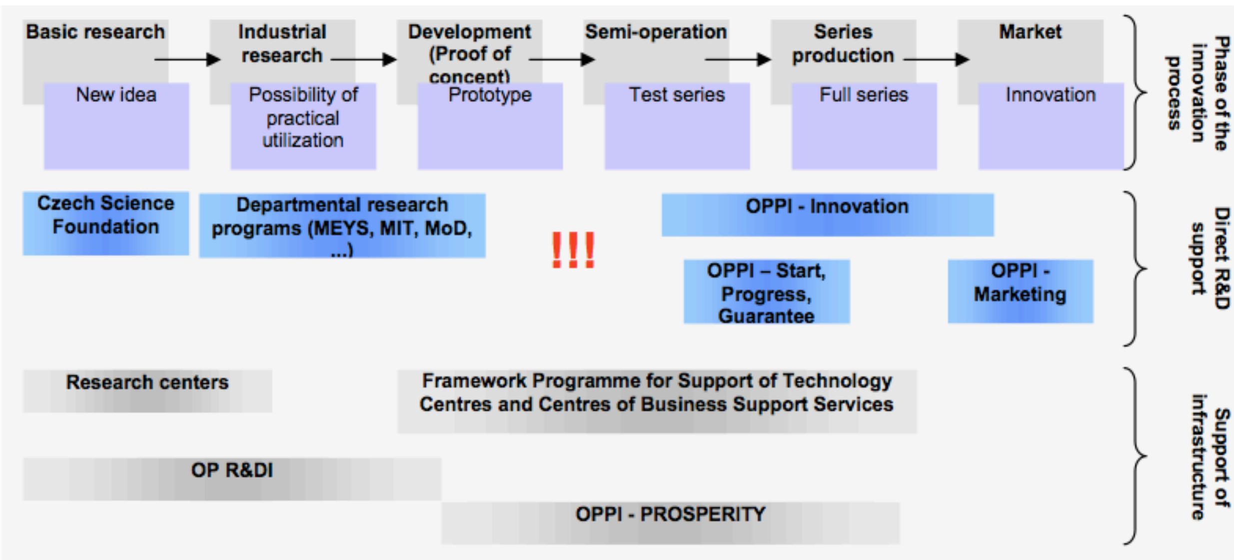


Figure 5. Public support instruments during the innovation process (data source Klusáček et al., 2008a)

One of the issues that illustrates an institutional path-dependence stemming from the country's communist past is the rather strict division between basic and applied research. Essentially, during the Cold War period, it was not expected that R&D institutions and universities would commercialize their research results and thus there was little exploitation of the results from the research. This split can still be felt between the Academy of Sciences, which was more or less the sole producer of basic research during the communist period, and between the university system. (Arnold, 2011) This is a common issue among EU members and is partially caused by an "absence of clear responsibility for delivering innovation policy and an absence of a mechanism coordinating interventions in the "grey zone" between research policy and business development" (Blazek and Uhlir, 2007). Even though this issue has been recognized as a problem already in the first national innovation policy, approved in 2004, it remains a key aspect limiting innovation.

Furthermore, Czech policy has yet to set up effective incentives for better public-private R&D cooperation. Research results, for example, are still evaluated based on citations, rather than granted and commercially exploited patents, licenses sold etc. Additionally, a majority of grants is allocated based on an institutional rather than project-specific bases (Goglio, 2006). While this is not unusual in an international comparison (few countries obtain as much as 50% of funding competitively, whereas Czech Republic aims at reaching 60%), it can, without proper evaluation lead to insufficient quality of research or a mismatch with national thematic priorities. Unfortunately, the evaluation methods have in this case been criticized for functioning badly. While the reliance on quantitative indicators are good at counteracting nepotism, corruption, and lobbying, at the same time addressing low productivity in some research institutes (by essentially saying "no output, no financing") it succumbs to reductionism and assesses immediate outputs rather than whether they produced the desired societal effect (Arnold, 2011). However, on a more positive note, while generally Czech innovation policy focused mainly on the supply side, increasingly there has been a shift towards the greater practical use of R&D. Together with an emphasis on greater collaboration with industry through conditioned support based on public and private co-financing or even requiring application of R&D results in practice, these can be seen as positive changes in the NIS (Hebakova et al., 2011) A good example of such a policy in practice is the use of innovation vouchers in the South-Moravian Region where companies (mainly SMEs) receive subsidies in the form of vouchers to purchase knowledge from research institutions in the region (MZV, 2010).

Aside from the above-mentioned weaknesses of the Czech NIS, policy has yet to sufficiently cover the issue of innovation in legislation. While main aspects of innovation have been included for example in the act on the support of R&D from public funds, other aspects, like spin-offs, have not been turned into law (Lengyel and Cadil, 2009). On the other hand, innovation policy has been supported indirectly by introducing a new tax regulation in 2005, which enabled businesses to deduct R&D expenditures twice, as expenses and as an amount to be deducted from the tax base before taxation. This was seen by the government as a more effective than direct innovation subsidies (MZV, 2010).

Since innovation is a costly process, alternative sources of financing can be greatly beneficial in picking up the slack, so to speak, where the public funds are lacking. Unfortunately, the levels of VC available, especially in the pre-seed phase are quite unsatisfactory, with the Czech Republic having one of the lowest VC investment rates in Europe. With a situation where pension funds and insurance companies are unable to invest into VC due to strict regulation, the Czech Republic actually ranks in last place when it comes to VC-related tax and regulatory environment (Toman and Kousalová, 2011). In this regard, the Czech government has recently proposed a seed fund, with a goal of improving access to finance for innovative startups. Co-financed by the EU and the government the fund is to be administered by CzechInvest, a development agency affiliated with the Ministry of Industry and Trade, and will distribute EUR 53 million. Moreover entrepreneurs can receive consulting and coaching services via the CzechEkoSystem programme in order to increase their chances of finding an outside investor. Providing budding entrepreneurs with the necessary soft skills they might be lacking, together with offering a fund as an alternative to the lack of VC available can be seen as a step in the right direction. However, these actions have been received with rather mixed feelings by the private sector, which expressed worries over the bureaucrat decision-making abilities and the looming threat of corruption (Startup.lupa.cz, 23.1.2012). And to their dismay, some of the fears have indeed been fulfilled as the development agency in charge was rocked by a corruption scandal in the summer of 2012 connected with the programme (ihned.cz, 22.10.2012).

While both of the above mentioned projects are back on track as of 2013, they relate to perhaps the most acute problem within the Czech NIS – the lack of trust, especially towards the government, impeding policymaking in regards to R&D, innovation as well as in other policy areas. This is related to a political instability which has plagued Czech Republic for years and which has resulted in politicizing of innovation and in giving preference to interest groups rather than strategic vision. Frequent changes in governments as well as personal reshuffling within ministries, exacerbated by failure to implement civil service reforms make long-term innovation strategies difficult to carry out (Arnold, 2011) These findings are corroborated by the Global Competitivenss Report carried out by the World Economic Forum, which despite considering Czech Republic as an innovation-based economy, points out several disturbing problems in the institutional arena, ranking the country 139^{th} in public trust in politicians, 119^{th} in wastefulness of governmental spending, 127^{th} in diversion of public funds, 123^{rd} in favoritism in governmental decisions and 98^{th} in transparency of government policymaking (Schwab, 2012). Even despite quality scientific base, which the Czech Republic arguably has, R&D will be to no avail in translating into economic success unless institutions can be trusted. This problem is all-embracing yet extremely difficult to eradicate.

4.2 Innovation Policy relating to nanotechnology

Nanotechnology has been recognized as an important area of support on multiple policy-making levels. In 2011 the government's National Economic Council has specifically mentioned nanotechnology as one of the key sectors of the 21st century and an integral part of future economic development strategies in developed countries, providing an enormous innovation potential and possible gains for the Czech economy (Mejstřík, 2011). Additionally, the Competitiveness Strategy for the years 2012-2020, quite broadly states the need for identifying key technological areas for the Czech Republic, towards which R&D support will be directed. While nanotechnology isn't directly mentioned in this document, one can assume that it is one of these prioritized areas (MPO, 2011). More specifically, nanomaterials have been highlighted as one of the priority areas by the Research, Development and Innovation Council. Likewise, the National Innovation Strategy (2011) recognized the need for giving special attention to innovations within "science-based" companies, while criticizing the lack of prioritization of applied R&D in the Czech Republic, which fails to emphasize the areas where domestic R&D has reached excellence. All of the documents above strongly advocate the establishment of a "central authority" which would be in charge of defining and coordinating policies within the entire innovation "ecosystem". Finally, CzechInvest has also labeled nanotechnology as a key sector for investment in the Czech Republic.

Nonetheless, despite the formal acknowledgment of nanotechnology's importance for Czech economy, as well as the increase in the number of research institutes and nano-companies in recent years, a national programme for nanotechnology development, which is present in most developed states in and outside the EU, has yet to be created. This programme would be useful for defining a development strategy as well as oversee the standardization process, and monitor possible social, health or environmental risks of nanotechnology. (Shrbená and Šperlink, 2012) The yardstick for nanotechnology innovation support comes from the United States where the federal government recognized the potential of nanotechnology already in 2000, creating the National Nanotechnology Initiative through which it guided the development of nanotechnology to the tune of USD 16.5 billion, maintaining a healthy lead over other countries.

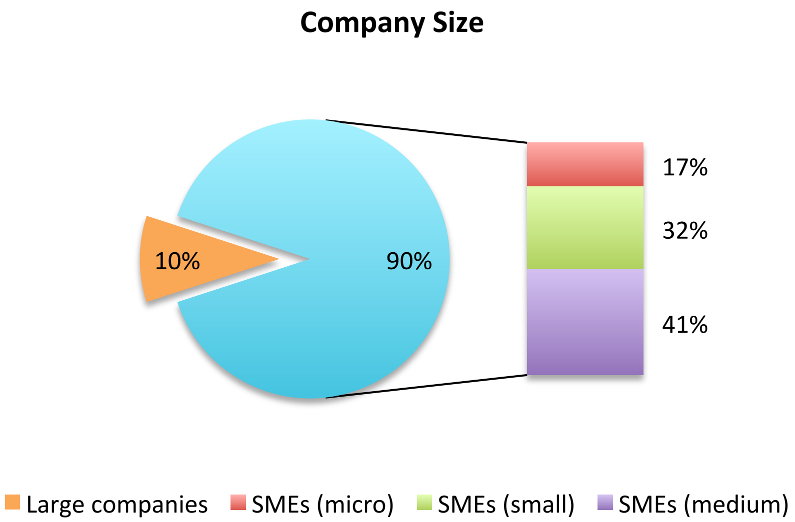
Understandably the levels of support are nowhere near this amount in the Czech Republic. There are, however, several avenues through which the development nanotechnology is encouraged. Unfortunately, due to the fragmentation of the R&D&I system in the Czech Republic as well as the nature of nanotechnologies, the annual amount of support can only be estimated, with roughly CZK

1.85 billion going towards R&D in 2008, 91% of which came from public sources (Shrbená et al., 2009). Nonetheless, the Czech government is actively supporting the development of nanotechnology. This process was significantly helped through a programme called "Nanotechnology for Society", which was administered by the Academy of Sciences and had during three public procurement rounds from 2005 to 2011 distributed CZK 1.75 billion in funds to 38 different projects. Furthermore, basic research has further been aided by the Czech Science Foundation which had by 2007 registered 51 nano projects worth EUR 5.7 million, by the Ministry of Industry and Trade which had through the Progress and Permanent Prosperity programmes registered 27 projects worth a total of EUR 10.5 million, and by the Ministry of Education, Youth and Sport which had supported 34 projects worth EUR 12.4 million (CzechInvest, 2008)

Furthermore, nanotechnology has been supported through the building of innovation infrastructure with the help of EU funds, such as the *Operational Programme Research and Development for Innovation, Operational Programme Enterprise and Innovation, and Operational Programme Education for Competitiveness*. Most interestingly, a new research centre – the Centre for Nanomaterials, Advanced Technology and Innovation – worth CZK 655 million and co-financed from the Structural Funds opened its doors in the fall of 2012, as part of the Technical University of Liberec, with the purpose of carrying out basic research but also "strengthening cooperation with industry, not only in the use of R&D results and services, but also for lifelong learning of employees". (CXI, 2011) This focus on commercialization of nano-R&D is an important example of a demand-led innovation policy, more of which is necessary in order to translate scientific discoveries into economic successes. According to Ladislav Mareš, former boss of Elmarco and current head of Nafigate, a company, which specifically aims at commercializing the results of nano research, the Czech Republic has built up a solid scientific environment as a result of a generous grant support from the state, which can help local companies stay at the top of the nanotechnology field (E15.cz, 6.11.2012). Similarly, Liliana Berezinková, a sales and marketing manager at Nanoprogres, a cluster focusing on medical applications of nanotechnologies, believes that the Czech Republic has "tradition, people and ideas (…), which are definitely at the very front [in developing new applications]", but wonders whether it can compete at the execution level (The New York Times, 2012). Technology transfer and commercialization thus might be the country's biggest challenge when it comes to the future development of nanotechnologies.

5. Survey results

To enquire further about the emerging sector of nanotechnology sector in the Czech Republic, and to find out about how barriers to innovation are perceived by actors involved, a mini-survey has been carried out by email in two consequent rounds during the second half of April, 2013. For this purpose 139 nano-firms have been identified based on whether they carry out research and development that in some way relates to nanotechnologies. Within the companies, personnel in charge R&D has been contacted – in larger firms this meant the heads or members of R&D departments, a Chief Technology Officer (CTO) or alternatively a member of the board of directors. More often than not, however, especially in smaller firms without a dedicated R&D department, the CEO or owner was queried. Out of the total number of nano-companies in the Czech Republic, 51 have responded to the survey, reaching an active response rate of 39.2%.[10]



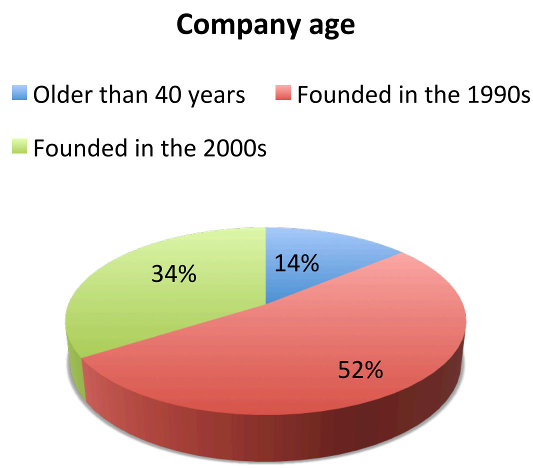


Figure 6 and 7. Pie charts reflecting the size and age of respondent nano-companies (data source and charts by author)

The prevailing majority of respondents (90%) came from small and medium enterprises (SMEs), most of which have been established in the 1990s, during and after the transformation of Czechoslovakia and subsequently the Czech Republic. Surprisingly only 15% of the firms identified themselves as pure nanotechnology companies while the overwhelming majority (85%) saw nanotechnologies only as a part of their core business, which lay elsewhere, in fields that varied considerably from biotechnology and pharmaceuticals, to textiles, ceramics, and filtration, among others (see box below).

[10] Out of the 139 firms, 5 have been marked as ineligible for various reasons (one was not a nano-company, for another it was too soon to tell, because the project was only in its beginning, one went bankrupt, and two, while providing interesting insights, responded by email and thus could not be counted in the response rate). Furthermore, 4 have been unreachable – email could not be delivered even after trying various email addresses.

Core areas of business (for respondents, who didn't identify themselves as pure nano-companies)		
air heating, cooling, filtration equipment	ecological services	production of active pharmaceutical substances
biotechnology	hydrogeology	production and sales of paints
car parts manufacture	machines for the manufacture of semiconductor components	production of ropes, polypropylene fibers, and artificial grass
ceramic wall and floor tiles	medical appliances	processing and removal of hazardous waste and remediation of contaminated areas
chemical, biological, radiological, and nuclear defense and camouflage	optical fiber sensors and fotonics	PVD (Physical Vapour Deposition) layers
chemical substance production	particle research	retail and R&D
coating and construction materials	piezoceramics	scientific and laboratory instruments
computer simulation of biological processes	pharmaceuticals and supplements	special tools
construction materials	plastic products, elastomers	special work clothing
environmental protection	pressure devices	textile production

Consequently, with such a large variety of business areas, R&D has been carried out within many different subcategories of nanotechnologies, the majority of which related to the production and use of nanomaterials (44%), such as nano-particles, fibres, powders, and coatings. These subcategories were based on a nomenclature used in the Austrian NANO Catalogue and modified by Shrbená and Šperlink (2012). (For a full list of nanotechnology subcategories see chapter 3, box 1)

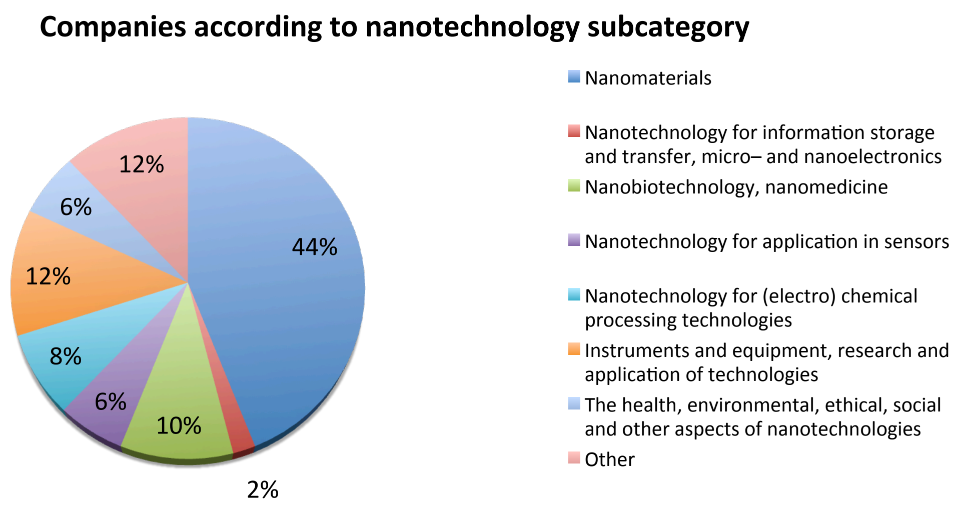


Figure 8. Pie chart dividing respondents into nanotechnology subcategories (data source and charts by author)

In the first set of questions the presence of product and process innovations in the respondents‘ firms was addressed. According to the latest Community Innovation Survey (CIS) for the years 2008 to 2010, 51.7% of Czech companies were innovative, down from 56% in 2006-2008 (CZSO, 2012). Out of these, 53.2% have introduced a new or significantly improved goods, and 19.50% new or significantly improved services. In both these categories the results for nano-companies were significantly higher with 81% and 51%, respectively (see Figure 9).

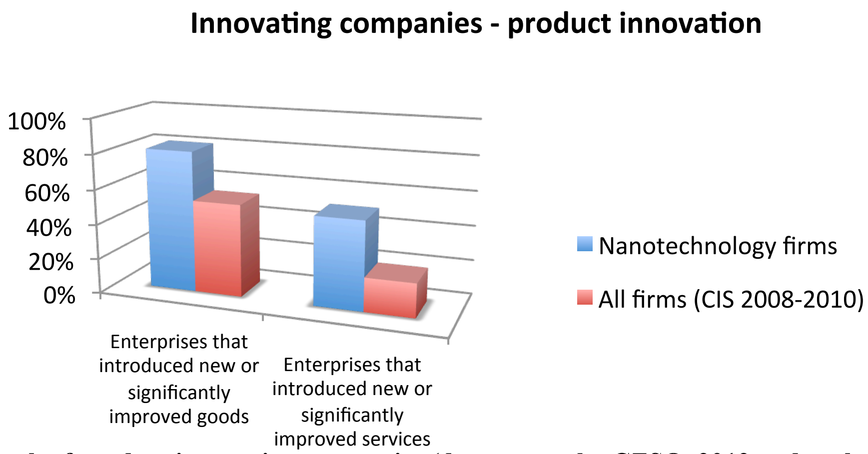


Figure 9. Bar graph of product innovation companies (data source by CZSO, 2012 and author, graph by author)

Interestingly, a stark contrast can be seen when looking at who developed the product innovations in nano-companies and other innovative businesses in the Czech Republic. While in most cases product innovations were carried out solely by the innovating enterprise (around 70%, see Figure 10), it appears to be different in nanotechnology, which highly depends on co-operation

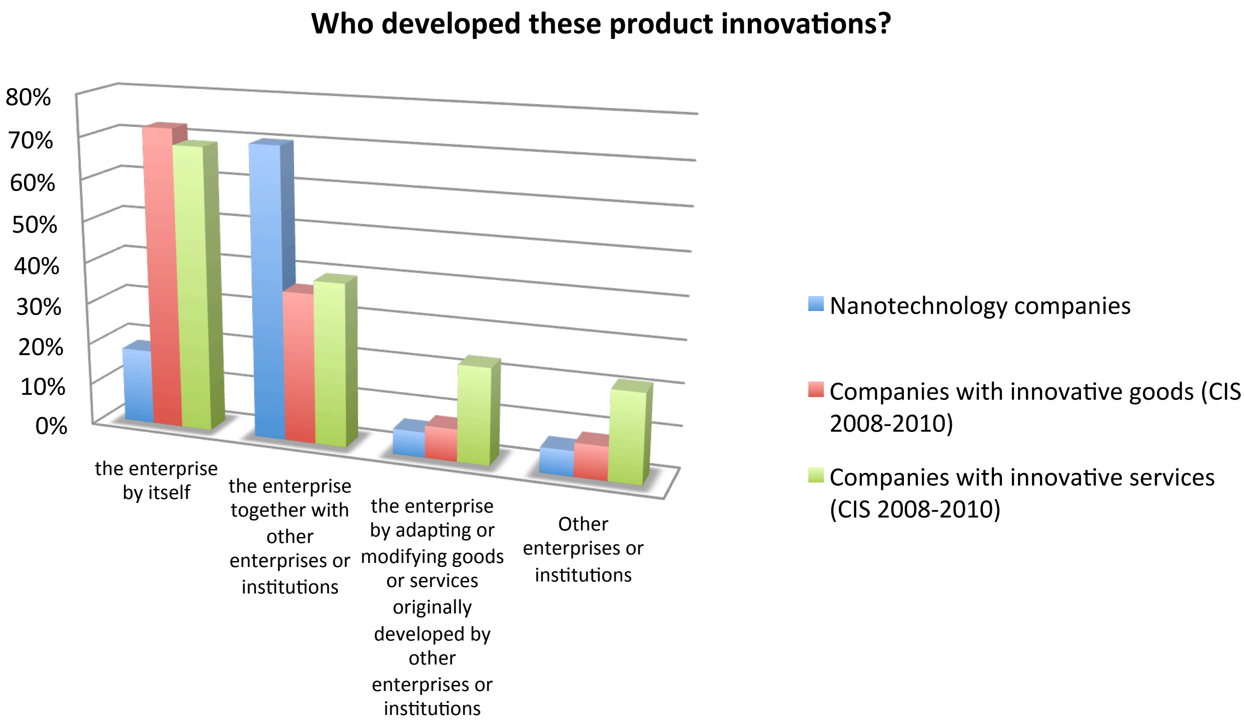


Figure 10. Bar graph of product innovation companies, arranged by the actors involved (data source by CZSO, 2012 and author, graph by author)

with other enterprises and institutions (also by 70%, out of which 55% is co-operation with universities or other public research institutes) and only a minority develops innovations on its own.

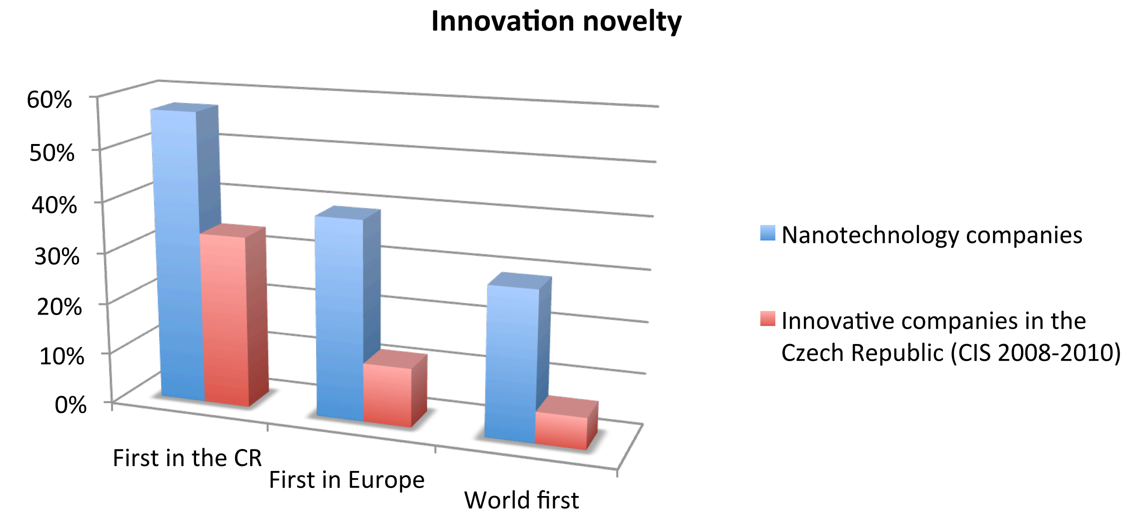


Figure 11. Bar graph showing innovation novelty of nano-companies and other innovative companies (data source by CZSO, 2012 and author, graph by author)

This corresponds with the findings on innovation information sources (see Figure 19) and innovation partners (see Figure 20). Similarly to the higher rate of product innovations in nano-companies compared to other industries, nanotechnology also ranks higher when it comes to innovation novelty, with the individual innovations often being introduced as the first in the Czech Republic, Europe, or the world (see Figure 11).

On the contrary, when shown side by side with the CIS, process innovations in nanotechnologies were only slightly more frequent compared to other industries when it comes to improved methods of manufacturing or producing good or services, while actually less so in the other two categories – improved logistics, delivery and distribution methods and supporting activities (see Figure 12).

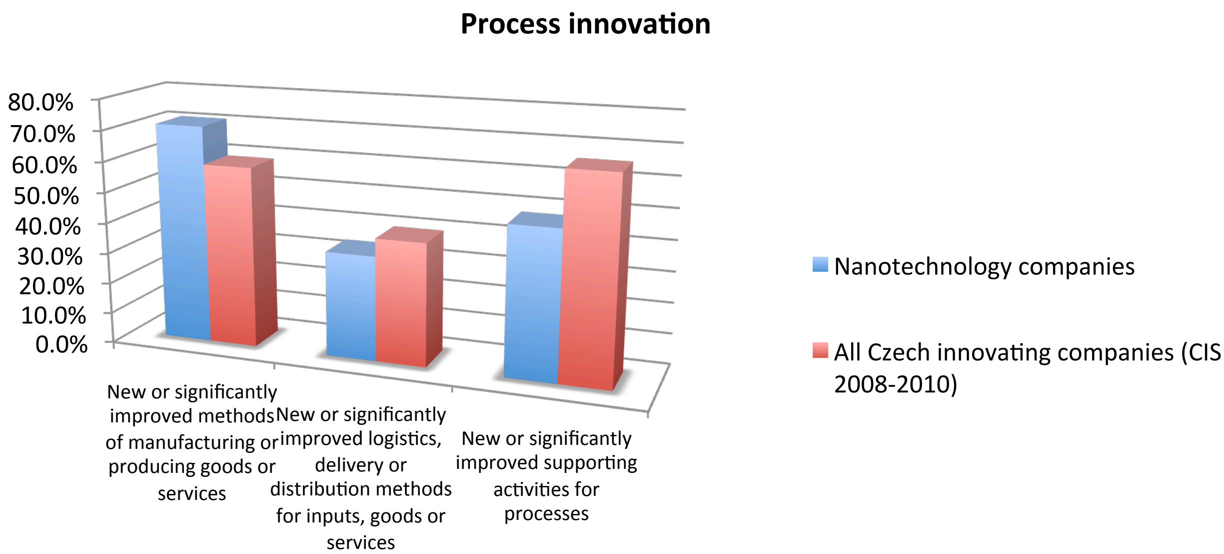


Figure 12. Bar graph process innovation of nano-companies and other innovative companies (data source by CZSO, 2012 and author, graph by author)

In order to identify some of the bottlenecks in the innovation support for nano-companies, the next set of questions focused on public sector financing of innovation activities. Respondents were asked, whether they have received funding from public sources, and if so, on which level of governance – regional, national, or European. Surprisingly, 72% of the respondents have received some sort of financial support from ministries and governmental agencies on a national level, while 54% have received funding from the European Union (see Figure 13). This is much more than the national average where only 13% of firms got funding for their innovation activities on a national level and 16% on a EU level.

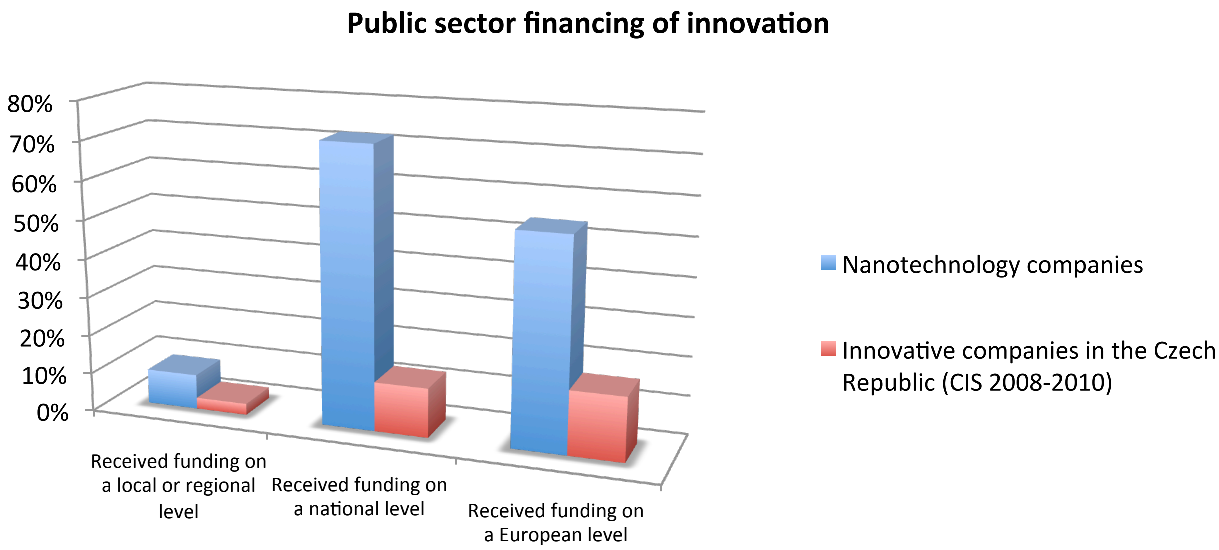


Figure 13. Bar graph showing public sector financing of innovation (data source by CZSO, 2012 and author, graph by author)

Additionally, the survey showed that most of the state support came in the form of subsidies for R&D (see Figure 14), being identified as highly important and important for 71% of the respondents, followed by funding for commercialization of R&D (46%) and technical consultancy services, such as assistance through technology transfer, productivity improvement, patent registration, etc. (35%). On the other hand tax incentives and duty free import of machinery or equipment proved rather unimportant.[11]

[11] For the sake of analysis, in this question and where necessary, "Highly important" and "Important" categories were grouped together as well as "rather unimportant" and "not used" as to be able to explain a majority sentiment.

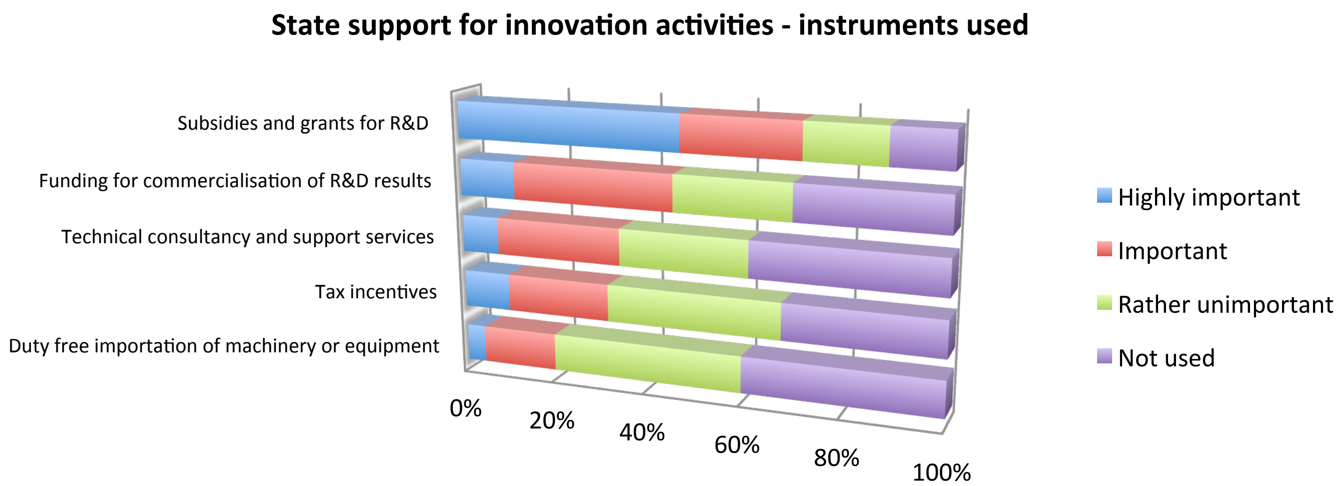


Figure 14. Bar graph showing public sector financing of innovation (data source by CZSO, 2012 and author, graph by author)

Next, a follow-up question was asked on what type of state support would have been helpful but was or is not available in the Czech Republic. In this case, the respondents' answers were split fairly evenly between the five options, most longing for tax incentives, followed by subsidies for R&D and commercialization (see Figure 15).

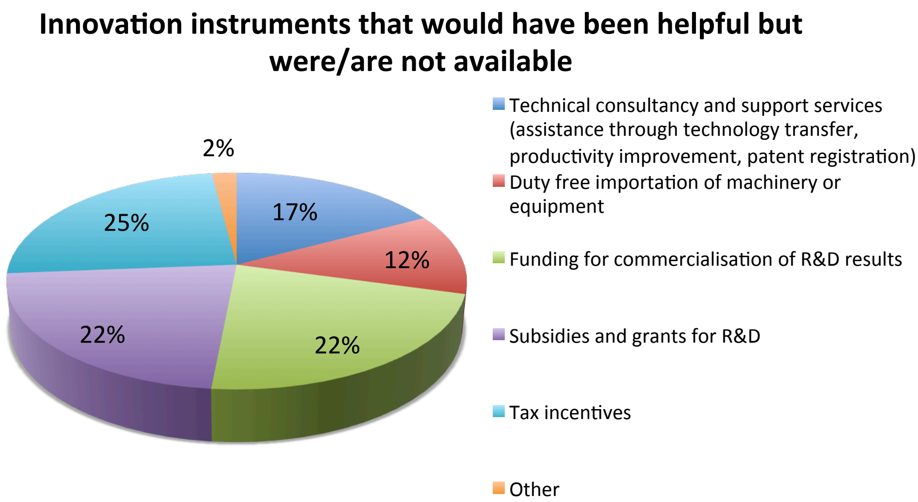


Figure 15. Pie chart showing innovation instruments that were/are not available (data source and chart by author)

Furthermore, the mini-survey showed that not a single company received funding for innovation activities in the form of venture capital. This is an interesting, although not surprising finding, due to the rather dire situation when it comes to VC in the Czech Republic. What came as a surprise, however, was that only 16% of respondents felt that this lack of VC available was actually hindering the innovation activities of their businesses. Additionally, an open question ensued, giving respondents the option to elaborate on their answer by suggesting other ways that the government could support innovation activities in the Czech Republic. Some of them included:

"(...) cutting unnecessary administrative red tape and changing the rules for selection of suppliers in subsidized projects. A company usually has long-term, reliable suppliers of components and services, but when developing a prototype of an innovated product, which received a subsidy, all of the parts must go through a public selection procedure, where absurd rules apply, increasing the amount of paper work, and delaying the time to actually carry out the project – to illustrate our typical product contains 5000 components."

"(...) incentivizing customers in the industry to use the services of established and newly founded innovation centers, when it comes to R&D, which would make [the carrying out of] analyses less costly and start the process of meaningful R&D outsourcing. At the moment, innovation centers have a hard time finding partners and customers, which would in turn guarantee them its financing. Support should be given to quality projects, which are based on cooperation [between firms and innovation centres]."

"[greater support for Czech companies] in their export efforts to expand to new markets (Asia, South America) through embassies. There should be a better participation and presentation of firms at international trade fairs."

"(...) ensuring better infrastructure for preclinical and clinical evaluations, approval processes in the field of healthcare and by providing sources for finalizing R&D outputs."

"Some sort of a bridge that would transfer a technology into practice [which is] completely lacking. You might have an invention, a quality product, then there is this valley of death that you must cross on your own at the end of which you are awaited by investors with limousines. There is no water available to help you out during the process, despite being all around. Unfortunately there is no tradition of picking a promising company or a product and helping it to market. For an innovative company this [lack of resources] means a delay of at least five years, which comes at the cost of the local economy, because many give up or choose to sell to someone abroad."

Next section of the survey, key to the research question posed in the introduction of this study, dealt with barriers to innovation. To compare between general innovation barriers and those specific to nanotechnologies, CIS (2008-2010) was used as a benchmark to compare the nano-companies (Figure 17) with other innovative enterprises in the Czech Republic (Figure 16). Like in previous sections, while some of factors ranked similarly on both lists, the comparison also showed some particular differences.

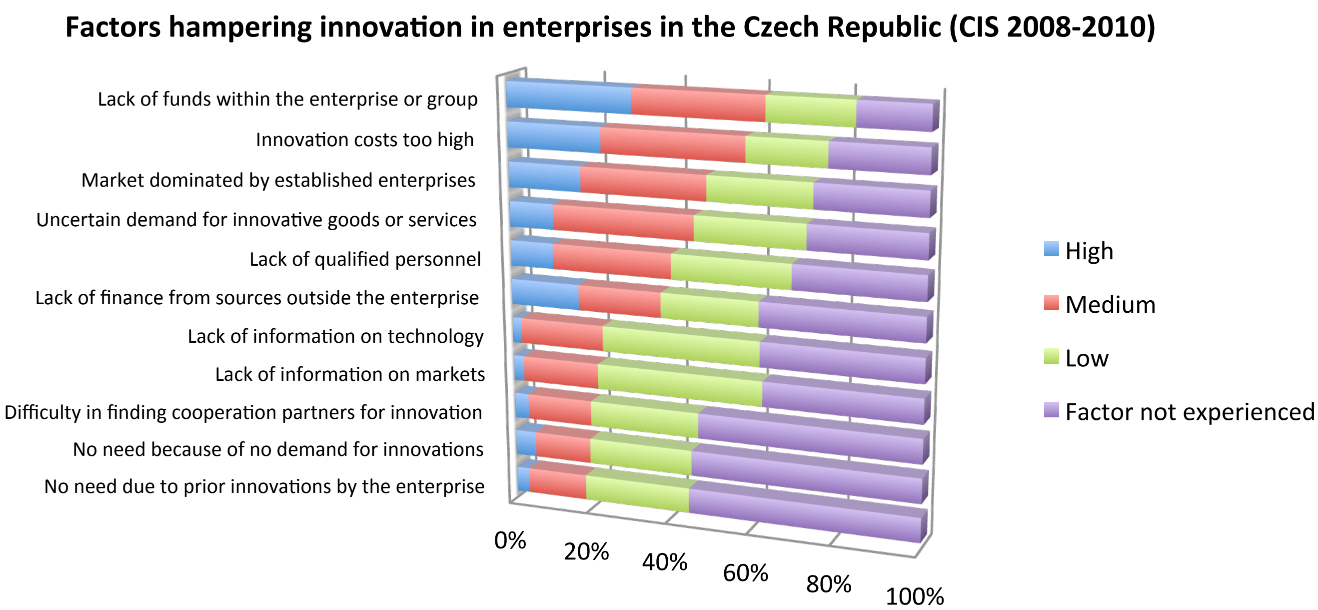


Figure 16. Graph showing factors hampering innovation in enterprises (data CZSO, 2012 and chart by author)

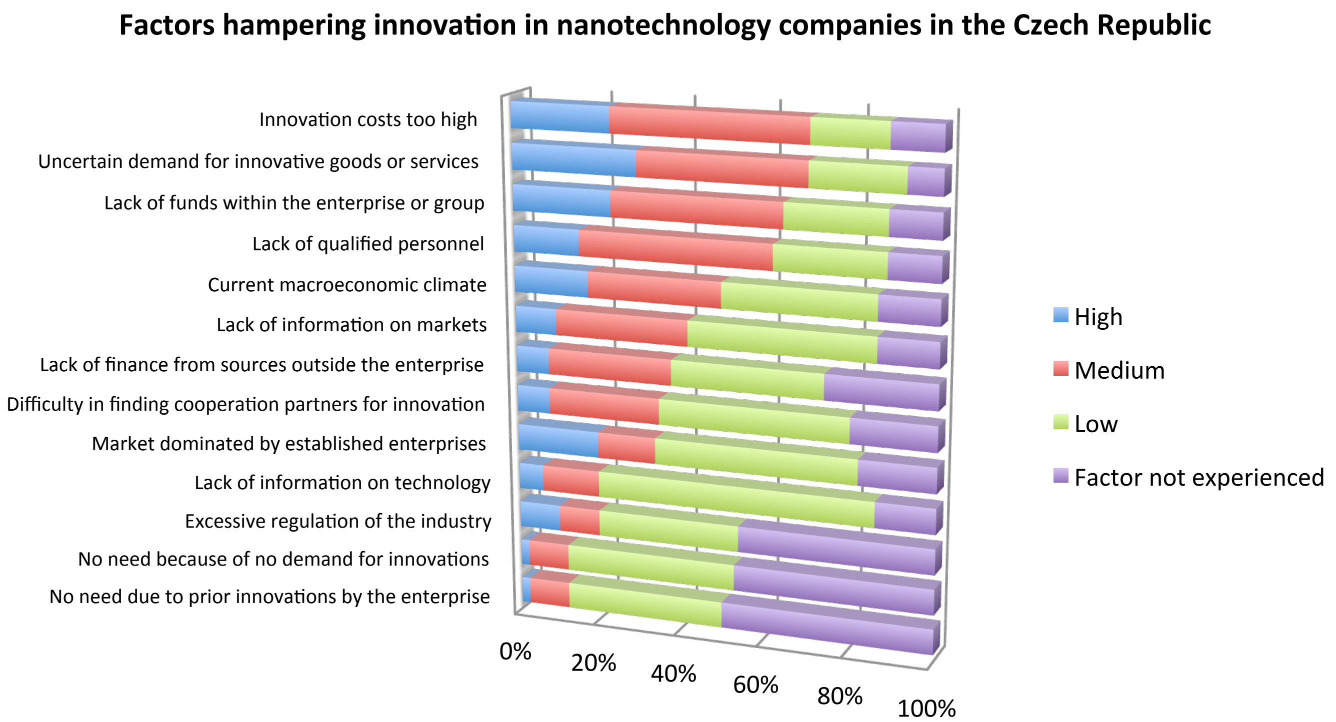


Figure 17. Graph showing factors hampering innovation in nano-companies (data and chart by author)

First of all, high innovation costs ranked at the top of the list for both nanotechnology firms and other firms (1st for nano-companies, 2nd for all companies), which can also be related to the issue of insufficient funds within the enterprise or group of enterprises (3rd for nano-companies, 1st for all companies). On the other hand, there is a difference when it comes the industry life cycles, with markets being dominated by established enterprises featuring prominently in the CIS survey of all companies, whereas ranking only 9th with the nano-companies. Uncertain demand for innovative goods and services, most likely stemming from the "emerging" nature of nanotechnologies, was in their case a much greater factor in hampering innovation activities (ranking 2nd in the list). Furthermore, one of the factors added for the nano-survey and not included in the CIS, the current macroeconomic climate, proved fairly important (5th place), while the other additional factor on excessive regulation of the industry did not. Moreover, both the lack of information on technology as well as a difficulty in finding co-operation partners did not prove to be that important to the nanotechnology companies as one might have expected.

To get a better sense of the specific problems of nanotechnology firms, an open question followed, asking the respondents to identify barriers that hinder innovation activities in their firms. Some of the answers included:

"Research and development, product testing and introduction to market are all expensive endeavors. Despite having an extremely unique and useful product with high utility and value added, there is a rather low flexibility of investment firms in the Czech Republic, as well as an absence of institutions that have experience with innovative entrepreneurship and that understand its logic. In practice this means that a company must bear all of the expenses by itself (...) lead the product to market, expand the market, and only then do investors start appearing. (...) This is a serious barrier that, for example in the USA, is not present. Even though our products could reach the market much faster [if outside capital was available], we remain a family company, reinvesting every crown we make. (...) Another series innovation barrier is the bank system, rampant bureaucracy, and unnecessarily rigid tax laws."

"Apart from having a lack of time, limited intellectual capacities within the firm, as well as the unavailability of outside knowledge (or our limited ability to attain such capacities), we do not feel severely hindered in our innovation activities."

"Real-world application is missing."

"Insufficient capacity for development of new technologies – uniqueness of production processes."

"A general lack of awareness of the field within potential customers as well as an extremely long testing and optimalization time."

In the last section, the questionnaire was rounded off by a series of queries on sources of information for innovation activities, as well as geographical location of innovation partners. Again, CIS (2008-2010) was used as a benchmark to compare the nano-companies (Figure 19) with other innovative enterprises in the Czech Republic (Figure 18).

Based on the CIS, most valuable information for innovative enterprises in the Czech Republic came from the company itself or other affiliated enterprises (78%), followed by clients or customers (72%), and suppliers (68%). At the other end of the spectrum, government, public research institutes and universities ranked the lowest (9% and 16%), together with professional and industry associations (19%).

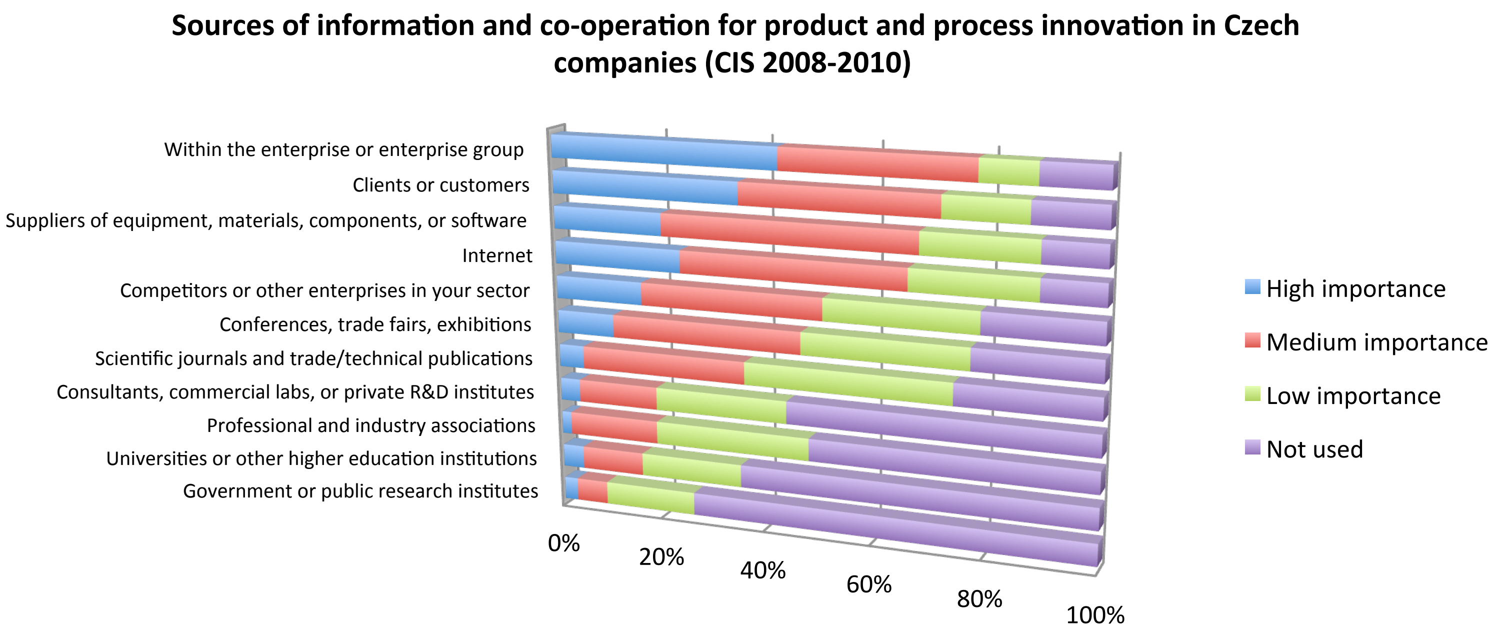


Figure 18. Graph showing sources of information and co-operation for product and process innovation (data CZSO, 2012, chart by author)

On the other hand, for nano-companies, aside from internet (90%, not mentioned in the CIS), scientific journals and trade/technical publications played a dominant role as an information source (83%), together with universities or other higher education institutions (74%). This is then followed by information sources within the firm itself and other affiliated enterprises, from competitors, and clients (74%, 70% and 67%, respectively). Interestingly government or public research institutes came in last place (33%), followed by professional and industry associations (33% as well), same as in the CIS, and then by suppliers of equipment, materials, components, or software (49%).

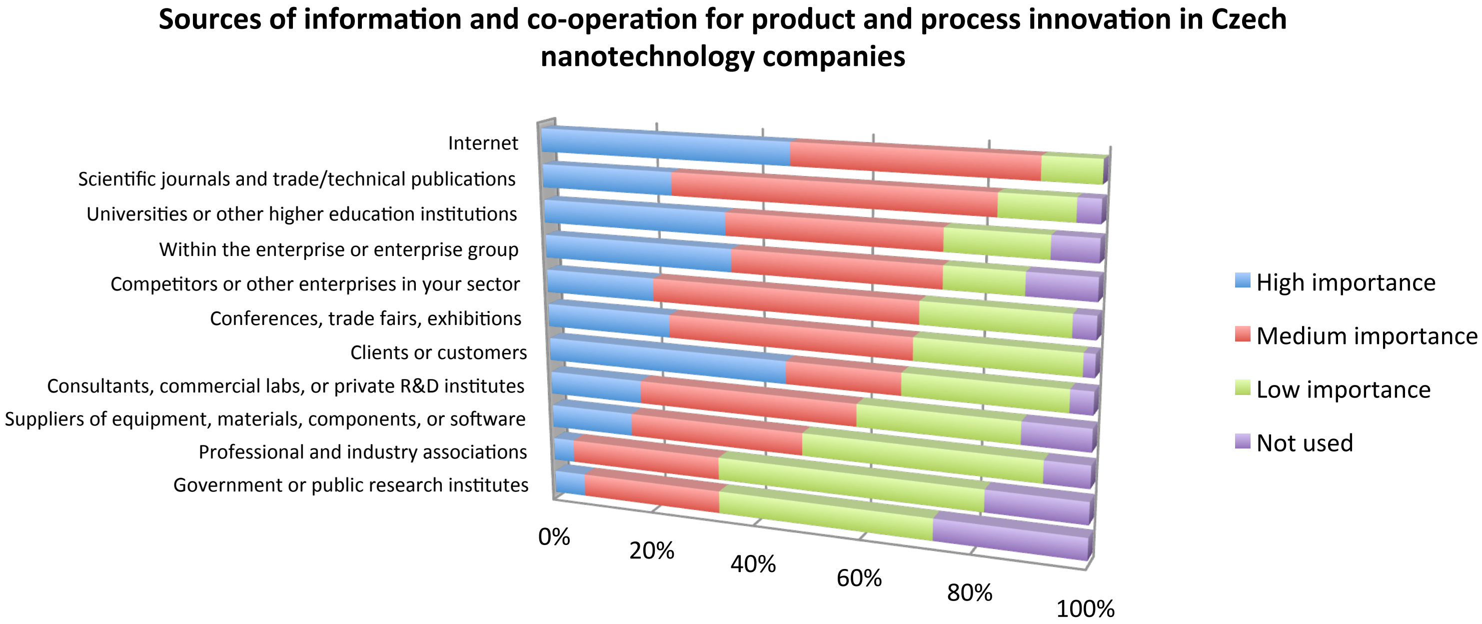


Figure 19. Graph showing sources of information and co-operation for product and process innovation in nano-companies (data and chart by author)

Finally, respondents were asked about whether they co-operate with other partners when carrying out innovation activities. Based on their answers, an overwhelming majority of the respondents, 88%, indeed co-operated with other partners on innovation activities. This is much higher than the national average in the Czech Republic based on the CIS, where only 34% co-operated with other partners. Understandably, these were mostly universities or other higher education institutions, which corroborates the earlier findings about who developed innovations (Figure 10) and which information sources were most valuable (Figure 19), where universities ranked highly on the list. On the other hand, while government or public research institutes were not deemed a very valuable source of innovation information, they are seen as important innovation partners, a puzzling result, which might be related to the role of the government as a partner in financing rather than in consultancy or R&D. Geographically, the partners are located predominately in the Czech Republic (for government, public research institutes, universities, other higher education institutions, consultants, commerical, and private R&D institutes, and other affiliated enterprises) and in Europe (mainly clients, customers, competitors, and suppliers). Only a tiny fraction of the nano-companies have co-operated with partners in the United States, China or India.

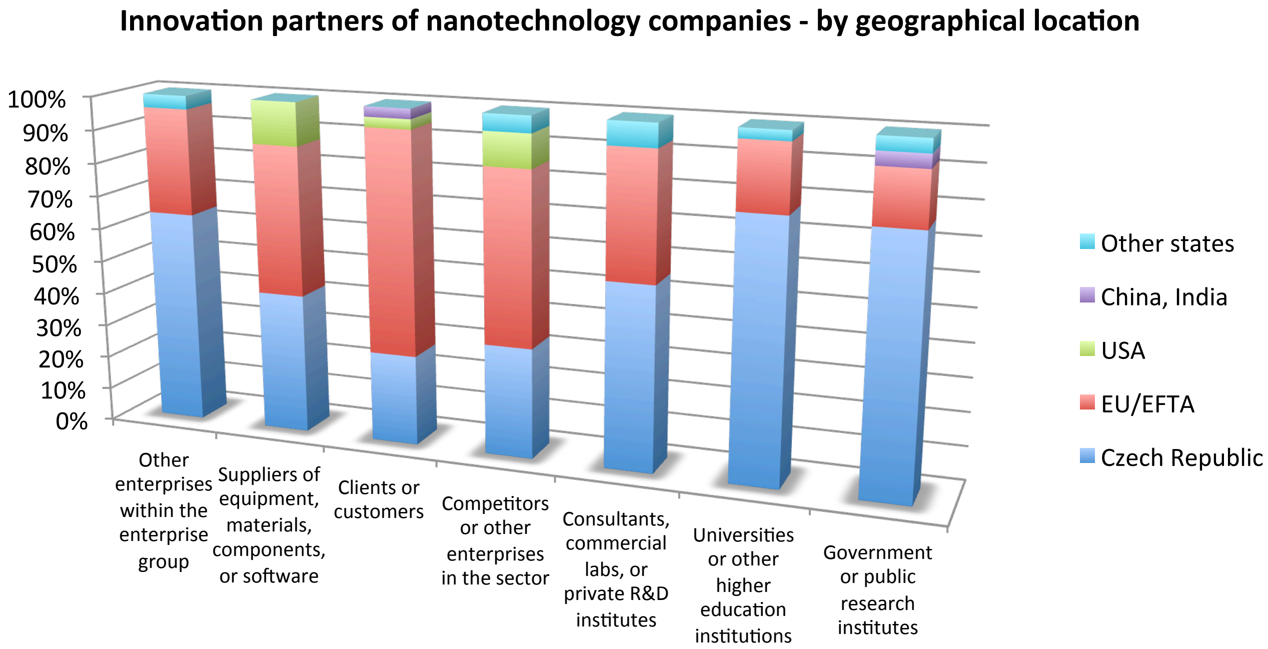


Figure 20. Graph showing innovation partners of nanotechnology companies by geographical location (data and chart by author)

6. Discussion

In the previous two chapters, an analysis of Czech innovation policies, focusing on weaknesses within the innovation system, has been carried out, together with a mini-survey of a group of nanotechnology-related firms, providing interesting insights into a promising, albeit understudied, field. While it may be too soon to assess whether this emerging technology can eventually become a cornerstone of the economy, several observations have been made about the knowledge application and exploitation subsystem in the national innovation system of the Czech Republic. Based on the nature of innovation processes and on the barriers to innovation that Czech nano-companies face, several suggestions follow.

First of all, the results of the survey clearly showed that nanotechnologies, are a rather multi-faceted field, which span a broad range of sciences and technologies, and thus cannot easily fit into the category of either an industry or a sector. While currently at a fairly early development phase, nanotechnology, however, most resembles a science-based sector, as described by Pavitt (1984), characterized by innovation activities that draw on institutionalized R&D, such as universities, laboratories, close interaction between science and technology, and a transfer of technology from universities to industry. Moreover, it was shown that co-operation with other partners is vital for nano-companies, as opposed to other innovative enterprises in the Czech

Republic, which usually rely on themselves (Figure 10). Together with receiving information for innovation activities from universities (Figure 19), scientific journals were also a key source of information, suggesting the importance of codified knowledge for the innovation processes in nano-companies. All of the above point to nanotechnology being highly related to an analytical knowledge base as defined by Asheim et al. (2011).

In some ways the nature of nanotechnology innovations can be compared to biotechnology especially in its science-based early development phase. On the other hand "many applications are more directly driven by market demand and customer (…) [resembling] ICT, where the main sources of innovation relates to markets, the development of services and standardization" (OECD, 2010). Consequently, while it is too early to tell, whether nanotechnology can fulfill its potential to become the next general purpose technology, the heterogeneity of its applications nonetheless points to a growing importance of the field, which is bound to continue. In this regard, the survey clearly showed that nano-companies innovate more than other companies (see Figure 9) and that their innovations present a greater degree of novelty (see Figure 11). This means the government of the Czech Republic should be instrumental in creating a conducive environment for the development of nanotechnology.

In order to stimulate innovation in an economy, various policy measures can be implemented – financial support being a typical instrument to achieve these means. In the Czech Republic, the need for financial support has been recognized by the national government, as is seen by the surprisingly high percentage of survey respondents, which have been the recipients of R&D funding (see Figure 13). Similarly, the European Union has been an important provider of investments into innovation infrastructure, which have together with the R&D subsidies on average benefited nano-companies more than other enterprises. This type of state support notwithstanding, lack of funds within enterprise still ranked prominently on the list of innovation barriers, together with innovation costs being too high. In this case, it is uncertain whether the problem pertains specifically to nanotechnologies or simply reflects the nature of science-based industries, which require long-term R&D, and take a considerable time to reach the market (OECD, 2010). As previous surveys on nanotechnology showed, companies in other countries have often faced similar problems, when it comes to innovation barriers. In a German survey carried out by Malanowski et al. (2006) shortage of financial support scored at the top of the list of barriers, while not enough necessary information to pursue the application, a lack of market potential and legislative issues were at the bottom. In Australia the lack of customer demand for nanotechnology products was the main issue (Dandolo partners, 2006) while in Finland major barriers included difficulties in achieving mass production, followed by shortages in funding and challenges in commercial application (OECD, 2010).

To a greater or lesser extent, all of these were important in the Czech Republic. Nonetheless, while the financial support for R&D is crucial (and should in the Czech Republic continue beyond the recently finished Nanotechnology for Society programme), other areas of the innovation system are just as important. And that is where Czech innovation policy falls short on several accounts. Most importantly, although not related just to nanotechnologies, a fragmentation of the innovation governance exists, which together with a rift between basic and applied research impede levels of innovation in the Czech Republic. Furthermore, as one of the respondents stated "some sort of a bridge that would transfer a technology into practice [is] completely lacking" leaving a "valley of death that you must cross on your own". While the Czech Republic has the knowledge base necessary for the development of nanotechnologies, it seems that the support for commercialization is not completely sufficient and should be improved. Not unique just to the Czech Republic, "the poor process scalability of R&D, i.e. challenges in the transition from R&D to pilot and industrial scale production, is among the most pervasive challenges identified" possibly due to the "the early phase of many nanotechnology sub-areas [that constitute] a barrier to entry into established value chains and to the commercialization of nanotechnology (OECD, 2010).

It is not uncommon, in the Nordics for example, that venture capital (VC) steps in to fill the gap, where governmental support falls short, especially in the early phase of commercialization. In the Czech Republic, this is unfortunately happening only on a very limited basis. Corroborating these findings, the survey results showed that none of the respondents' enterprises received financial support in the form of VC. Surprisingly, most of these did not feel like the lack of VC was limiting their innovation activities. This is a puzzling result, which could perhaps be explained by the fact that since this type of financing has not been firmly established in the Czech Republic, the actors involved could be less aware of its benefits. It could also be related to some innate feature of nanotechnology since other studies have also shown that VC, which often plays a strong role in emerging technologies, was not considered a particularly important source of funding in nanotechnology companies (OECD, 2010). Policy should in this case focus on fostering a VC market in the Czech Republic not only by establishing a seed fund, a process in the making, but also by easing regulation to make this type of financing more common and readily available.

Additionally, nano-companies talked about an uncertain demand for their innovative goods and services. While this issue could be just a matter of time before nanotechnology becomes more diffused within society, the government could, however, help in this regard, for example by targeting for support companies that stand higher on nanotechnology value chain, providing finalized nano-enabled products. Also, programmes for the popularization of nanotechnology aimed at potential customers (firms within various sectors) as well at the general public, could help with the diffusion, while downplaying environment, health and safety (EHS) concerns that could arise.

These, however, do not seem to play such an important role in the Czech Republic at least according to the survey where excessive regulation of the industry (based on EHS concerns) was seen as relatively irrelevant to the firms' innovation activities and was not specifically mentioned by any of the respondents.

Innovation policy, as such, addresses a much broader set of policy issues than the examples mentioned above and it goes far beyond the scope of this study to tackle them all. However, it seems that several policy aspects in the Czech Republic, despite paying lip-service to innovation systems theory, still struggle with viewing innovation as a rather straight-forward, linear process. This results in an innovation system, that while endowed with a relatively strong knowledge and innovation infrastructure ends up suffering from a fragmentation, lack of co-operation, networking, and knowledge transmission. Blazek and Uhlir (2007) argued that Prague is a prime example of fragmented metropolitan regional innovation system. By extension, I believe, this fragmentation can be applied to the Czech Republic as a whole. And quite possibly, borrowing from regional innovation systems (RIS) literature might help transpose some general policy implications to a national level. Since a fragmented innovation system lacks interactions and knowledge flows resulting in low levels of systemic innovation activities, one of the main policy aims should be to promote inter-firm networks and university-industry linkages. Furthermore, RIS literature suggests an explicit cluster strategy, which would support emerging clusters with a strong local knowledge base, developing specialization advantages to achieve synergies and international visibility, while attracting cluster-related FDI. (Tödtling and Trippl, 2005; Martin and Trippl, 2013). In several regions of the Czech Republic, nanotechnologies are a perfect candidate for such targeted support (see Appendix for a map of geographical clustering). Moreover, focus should be on nanotechnology start-ups and spin-offs and of course at achieving excellence in research at the university level, with highly specialized qualifications and skills (Ibid.). In regards to human capital development, it is also vital to boost support to academic entrepreneurs, who often do not possess the essential business and entrepreneurial skills, thus lacking the ability to commercialize the product on their own, but are also in certain case unable to explain the value of their products to potential investors or customers (OECD, 2010).

Another set of areas of improvement can be related to the analytical knowledge base that nanotechnologies represent. Interestingly, while it has been established that innovation support must take into account local conditions, general best practice models are not wrong when it comes to nanotechnology. This includes typical STI policy instruments, such as science and technology parks, technology brokers and transfer agencies, which in this case seem suitable enough, together with the promotion of a favorable business and innovation climate (through laws, regulations, tax incentives, etc.), which would help foster an entrepreneurial environment, while also attracting so-called star scientists (Martin and Trippl, 2013). Furthermore, stimulating cross-fertilization effects by strengthening the connectivity between analytical, synthetic and symbolic industries within an innovation system are also highly beneficial (Ibid.). In practice this means utilizing and building on the technical and engineering fields that in have a strong tradition in the Czech Republic.

Moreover, it is thought that innovations in industries that rely on codified knowledge, tend to defy geographical distance, occurring in "globally configured epistemic communities rather than in locally configured, trust based networks" (Martin et al., 2010). While this notion proved true in some aspects, with cooperation partners transcending national borders, the local arena still proved most important, followed by the EU (see Figure 20). On the one hand, with the USA as a nanotechnology hegemon and East Asia an increasingly important market, the government should help foster networks, which go beyond Europe. At the same time, regions, which currently play only a marginal role in the innovation policy of the Czech Republic, should become more involved through support of local networks, such as professional and industry associations, clusters, university-industry linkages etc. Furthermore, regional branding of areas where nanotechnology is strong could help attract VC, as well as nano-companies and star scientists from abroad.

As put forth by OECD (2010), due to the overarching nature of nanotechnologies, which offer a rather disparate range of applications, a general nanotechnology policy might not be appropriate. Instead, strategies and policy instruments should be tailored to the specific subcategories and applications. This, however, does not go in opposition with the creation of a national nanotechnology initiative, which is present in most developed countries in the world, and would be instrumental in defining a development strategy, prioritizing the areas of R&D in which the Czech Republic has reached excellence, while also monitoring possible EHS risks. This prioritization, however, relates to one of the most pressing issues burdening the Czech innovation system, one that unfortunately does not offer an quick-fix solution – the politicizing of innovation, resulting in a lack of strategic vision. Combined with a fundamental lack of trust towards institutions this problem seriously impedes policymaking (not only) in regards innovation. As noted by Arnold (2011) "R&D&I policy – like other parts of government and the state – will only work well when there is a degree of political stability and people feel they can trust the government."

Conclusion

In the past decade and a half, nanotechnology has become quite popular with policymakers and academics alike. Due to the possibility of nanotechnology becoming a general purpose technology and thus generating considerable socio-economic benefits, while helping alleviate some of the world's most worrying problems, many countries have invested heavily in national R&D programmes, investigating the peculiar features of materials at the nano-scale and applying them in practice. This is important because as we move towards a global economy where knowledge and, by extension innovation, become dominant factors, quite radically influencing the economic performance of firms, regions, and states alike, it is more important than ever to produce innovation policies that are coherent, comprehensive, and up-to-date.

This thesis has focused on the Czech Republic, a country, which while not at the very edge of the technology frontier, possesses a relatively strong knowledge base when it comes to nanotechnologies. While it may be too soon to tell, how big of a role Czech nano-companies will play in the future, there is definitely some truth to the label that to the Czech Republic "everything is nano" (The New York Times, 2012). If the current trajectory continues, nanotechnologies are bound to become increasingly important as more and more firms begin operating in the nano-scale. It was shown that nano-companies have received a considerable financial support from the national government and the EU. It was also shown that nano-companies tend to innovate more than other enterprises. It is thus not a stretch to assume that financial support for research and development had a positive effect on the development of nanotechnology in the Czech Republic.

Still, there are several obstacles to innovation that must be overcome. To answer the research question posed in the beginning of this study – "What are the obstacles to innovation hindering further development of nanotechnology in the Czech republic?" – the mini-survey showed that high innovation costs were a dominant reason for not innovating, despite the financial support for R&D offered by the state, together with uncertainty about demand, relating to the "emerging" nature of nanotechnology. Lack of qualified personnel and the current macroeconomic climate have also been identified as important obstacles.

In regards to innovation policy there are areas, which could and should be improved. Firstly, support is mostly focused on basic research, which is undoubtedly important, however more attention should be paid to the transfer of technology into practice and commercialization of research, which can, in turn, translate into increased economic performance. Additionally, there is a considerable gap between basic and applied research, and a bridge that would help cross this "valley of death" is far from ideal, whether in the form of venture capital or supporting infrastructure. Furthermore, this relates to the problem of fragmented innovation governance, where several institutions, sometimes without clearly delineated responsibilities, are in charge, leading to problems in the innovation system. Moreover, other institutional issues such as the inefficiencies within public administration, corruption and a lack of trust in the government can also have an adverse effect on the levels of innovation in the country.

In 1959, Richard Feynman famously proclaimed that "there's plenty of room at the bottom", marking the beginning of modern nanotechnology. But is there room for the Czech Republic at the top? Can nanotechnologies become more than a niche in the economy? To be able to respond in the affirmative, policy must embrace a more systemic view of innovation, which takes into account all of the various actors and networks involved. At the moment, innovation policy still embraces a rather linear model of innovation. In order to build an efficient, modern national innovation system, and give support to nanotechnology, among others, this paradigm has to evolve.

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List of figures and tables

Box 1. Nanotechnology subcategories (data source Shrbená and Šperlink, 2012) – p. 8-9.

Appendix

Appendix 1. Questions used for the innovation survey (in original language – Czech)

Nanotechnologie v ČR - Faktory omezující inovační aktivitu

Rok založení firmy:

Počet zaměstnanců:

Jsou nanotechnologie hlavním předmětem Vašeho podnikání?

a) ano
b) ne

Pokud ne, jaký je Váš hlavní předmět podnikání?:

V jakém odvětví nanotechnologií se angažuje Vaše firma?

a) Nanomateriály - např. nanočástice, nanovlákna, nanopovlaky, nanokeramika
b) Nanotechnologie pro ukládání a přenos informací - např. nanoelektronika, optické materiály atd.
c) Nanobiotechnologie, nanomedicína - např. zapouzdřování léků, tkáňové inženýrství, molekulární analýza, diagnostika
d) Nanotechnologie pro aplikaci v senzorech - např. senzory využívající nanomateriály, biomolekulární senzory
e) Nanotechnologie pro (elektro) chemické technologie - např. filtrace, membrány, chemická syntéza
f) Dlouhodobý výzkum s širokou oblastí aplikace - např. kvantová fyzika, nanofyzika, ultra-přesné inženýrství
g) Přístroje a zařízení, výzum a aplikace technologií - např. ultra-přesné obrábění, nanometrologie, zařízení pro vytváření vrstev a povlaků, objektů, či vláken
h) Zdravotní, ekologické, etické, sociální a jiné aspekty nanotechnologií - např. obchod s nanovýrobky, popularizace nanotechnologií, patentování, foresight

Produktová inovace

Zavedl váš podnik během let 2010–2012:

Nový nebo podstatně zlepšený výrobek (s výjimkou nového výrobku koupeného od jiného podniku za účelem dalšího prodeje a změny výhradně estetického charakteru)

a) ano
b) ne

Novou nebo podstatně zlepšenou službu

a) ano
b) ne

Kdo vyvíjel tyto produktové inovace?

a) Váš podnik ve vlastní režii
b) Váš podnik společně s jinými podniky včetně podniků ve vaší skupině
c) Váš podnik společně s vysokými školami nebo veřejnými výzkumnými institucemi
d) Váš podnik pomocí přijetí nebo úpravy výrobků či služeb původně vyvinutých jinými podniky, vysokými školami nebo veřejnými výzkumnými institucemi
e) Jiné podniky, vysoké školy nebo veřejné výzkumné instituce

Byla některá z vašich produktových inovací během let 2010–2012 uvedená jako první:

V rámci České republiky: ano/ne/nevím

V rámci Evropy: ano/ne/nevím

Celosvětově: ano/ne/nevím

Procesní inovace

Zavedl váš podnik během let 2010–2012:

Novou nebo podstatně zlepšenou metodu výroby nebo zpracování výrobků nebo služeb

a) ano
b) ne

Nové nebo podstatně zlepšené metody logistiky, dodávek nebo distribuce pro vaše vstupy, výrobky nebo služby

a) ano
b) ne

Nové nebo podstatně zlepšené podpůrné činnosti pro vaše procesy jako jsou systém údržby, nákupu, účetnictví nebo výpočetní techniky

a) ano
b) ne

Pokud ANO, kdo vyvíjel tyto procesní inovace?

a) Váš podnik ve vlastní režii
b) Váš podnik společně s jinými podniky včetně podniků ve vaší skupině
c) Váš podnik společně s vysokými školami nebo veřejnými výzkumnými institucemi
d) Váš podnik pomocí přijetí nebo úpravy výrobků či služeb původně vyvinutých jinými podniky, vysokými školami nebo veřejnými výzkumnými institucemi
e) Jiné podniky, vysoké školy nebo veřejné výzkumné instituce

Faktory omezující inovační aktivitu

Jaký význam měly následující faktory omezující vaše inovační aktivity nebo vaše rozhodnutí neinovovat v letech 2010–2012? (vysoký, střední, nízký, bez vlivu)

a) nedostatek finančních prostředků ve vašem podniku nebo skupině podniků
b) nedostatek financí ze zdrojů mimo podnik
c) příliš vysoké inovační náklady
d) nedostatek kvalifikovaných pracovníků
e) nedostatek informací o technologii
f) nedostatek informací o trzích
g) obtíže při hledání kooperačního partnera pro inovace
h) trh ovládaný zavedenými firmami
i) nejistá poptávka po inovovaném zboží nebo službách
j) nebylo třeba inovovat vzhledem k předchozím inovacím
k) inovace nebyly vyžadovány
l) příliš vysoká regulace odvětví
m) současný makroekonomický vývoj (ekonomická krize, atd.)

Jaké další faktory omezují inovační aktivitu Vaší firmy?

Financování inovací

Obdržel váš podnik na provádění inovačních aktivit v letech 2010–2012 finanční podporu z veřejných zdrojů následujících úrovní (včetně grantů a daňových odpočtů nákladů na výzkum a vývoj)?

Místní nebo regionální úřady: ano/ne

Ústřední vláda (včetně vládních agentur nebo ministerstev): ano/ne

Evropská unie: ano/ne

Realizoval váš podnik v letech 2010–2012 inovační aktivity spolufinancované ze Strukturálních fondů EU?

a) ano
b) ne

Obdržel váš podnik v letech 2010–2012 vnější financování v podobě rizikového kapitálu?

a) ano
b) ne

Pokud NE, vnímáte to jako faktor omezující Vaše inovační aktivity?

a) ano
b) ne

Státní podpora inovacím

Během let 2010 až 2012, jak důležitá byla pro Vaše inovační aktivity státní podpora v podobě:

a) technické konzultační služby (pomoc s transferem technologií, zvyšováním produktivity, registrací patentů, vyhledávání partnerů pro spolupráci): *vysoce důležitá/důležitá/spíše nedůležitá/ nevyužívá se*
b) daňové odpočty na import strojů a zařízení: *vysoce důležitá/důležitá/spíše nedůležitá/ nevyužívá se*
c) dotace na komercializaci výsledků výzkumu a vývoje (VaV) : *vysoce důležitá/důležitá/spíše nedůležitá/ nevyužívá se*
d) dotace a granty na VaV: *vysoce důležitá/důležitá/spíše nedůležitá/ nevyužívá se*
e) daňové stimuly: *vysoce důležitá/důležitá/spíše nedůležitá/ nevyužívá se*

Jaký druh výše zmiňované podpory by byl užitečný pro inovační aktivity Vaší firmy, ale nebyl/není k dispozici?

a) technické konzultační služby (pomoc s transferem technologií, zvyšováním produktivity, registrací patentů)
b) daňové odpočty na import strojů a zařízení
c) daňové odpočty na import strojů a zařízení
d) dotace na komercializaci výsledků VaV
e) dotace a granty na VaV
f) daňové stimuly

Jakým dalším způsobem by podle Vás mohl stát podporovat inovační aktivity v ČR?

Informační zdroje pro inovační aktivity

Kde jste získávali informace pro své inovační aktivity?

a) v rámci vašeho podniku nebo skupiny podniků
b) dodavatelé zařízení, materiálů, součástí nebo softwaru
c) klienti nebo zákazníci
d) konkurenční a jiné podniky v rámci vašeho odvětví
e) konzultanti, komerční laboratoře nebo soukromé VaV instituce
f) univerzity nebo jiné instituce vyššího vzdělávání
g) vláda nebo veřejné výzkumné instituce
h) konference, veletrhy, výstavy
i) vědecké časopisy a obchodní/technické publikace
j) profesní a průmyslová sdružení
k) internet

Spolupracoval váš podnik během let 2010–2012 na některé své inovační aktivitě s jinými podniky nebo institucemi?

a) ano
b) ne

Pokud ANO, označte odpovídající typ partnera a zemi působení spolupracujícího partnera

a) Ostatní podniky uvnitř skupiny podniků (ČR/EU/USA/Čína, Indie/ostatní státy)
b) Dodavatelé zařízení, materiálů, součástí nebo softwaru (ČR/EU/USA/Čína, Indie/ostatní státy)

c) Klienti nebo zákazníci (ČR/EU/USA/Čína, Indie/ostatní státy)
d) Konkurenční a jiné podniky ze stejného odvětví (ČR/EU/USA/Čína, Indie/ostatní státy)
e) Konzultanti, komerční laboratoře nebo soukromé VaV instituce (ČR/EU/USA/Čína, Indie/ostatní státy)
f) Univerzity nebo jiné instituce vyššího vzdělávání (ČR/EU/USA/Čína, Indie/ostatní státy)
g) Vláda nebo veřejné výzkumné instituce (ČR/EU/USA/Čína, Indie/ostatní státy)

Appendix 2. Map of the Czech Republic, showing geographical clustering of nano-companies

Interactive map can be viewed online at:
http://www.maptive.com/ver3/ee7d45a4a0a0bfe1516fa0a24c59f24e