ESSAYS IN THE ECONOMICS OF KNOWLEDGE

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To Heli

PREFACE AND ACKNOWLEDGEMENTS

Many many millions of years ago a race of hyper-intelligent pan-dimensional beings (whose physical manifestation in their own pan-dimensional universe is not dissimilar to our own) got so fed up with the constant bickering about the meaning of life which used to interrupt their favourite pastime of Brockian Ultra-Cricket (a curious game which involved suddenly hitting people for no readily apparent reason and then running away) that they decided to sit down and solve their problems once and for all.

And to this end they built themselves a stupendous super computer which was so amazingly intelligent that even before its data banks had been connected up it had started from *I think therefore I am* and got as far as deducing the existence of rice pudding and income tax before anyone managed to turn it off.

On the day of the Great On-Turning two soberly dressed programmers with briefcases arrived and were shown discreetly into the office. They were aware that this day they would represent their entire race in its greatest moment, but they conducted themselves calmly and quietly as they seated themselves deferentially before the desk, opened their briefcases and took out their leather-bound notebooks.

‘O Deep Thought Computer,’ said one of them, the task we have designed you to perform is this. We want you to tell us …’ he paused, ‘…the Answer!’

‘The Answer?’, said Deep Thought. ‘The Answer to what?’

‘Life!’ urged one.

‘The Universe!’ said the other.

‘Everything!’ they said in chorus.

Deep Thought paused for a moment’s reflection.

‘Tricky,’ he said finally.

‘But you can do it?’

Again, a significant pause.

‘Yes,’ said Deep Thought, ‘I can do it.’

‘There is an answer?’ said one with breathless excitement.

‘A simple answer?’ added the other.

‘Yes,’ said Deep Thought, ‘Life, the Universe, and Everything. There is an answer. But,’ he added, ‘I’ll have to think about it.’

One of the programmers glanced impatiently at his watch.

‘How long?’ he said.

‘Seven and a half million years,’ said Deep Thought.

For seven and a half million years, Deep Thought computed and calculated, and in the end announced that the answer was in fact Fourty-two.

'Fourty-two!' yelled a programmer. 'Is that all you've got to show for seven and a half million years' work?'

'I checked it very thoroughly,' said the computer, 'and that quite definitely is the answer. I think the problem, to be quite honest with you, is that you've never actually known what the question is.'

The story above is from Douglas Adams' *The Hitchhiker's Guide to the Galaxy*. (A second computer was built to find out the Ultimate Question, the answer to which was fourty-two, but those of us who have read the book know what happened to that computer.)

It tells us something about the peculiar nature of knowledge, at least in as much as it is relevant to understanding the connection between knowledge and the economy, but it is not why I share it here. Rather, it is because I felt for a long time that it was quite descriptive of my own intellectual journey.

I became interested in the economics of knowledge early on in my doctoral studies. "Knowledge, the Economy, and Everything" certainly seemed like the ultimate question in Economics and something definitely worth answering. However, after some trial and error, I came to realize that I had not even completely grasped what the question was.

As such, it became necessary to start with smaller and more tracktable questions as a first step towards understanding the bigger picture. This dissertation addresses a series of less ambitious problems that might nonetheless prove useful pieces in solving the bigger puzzle of what Kenneth Boulding calls "the role of knowledge in social systems".

In this day and age, science is more than ever a collective enterprise. As my name alone appears on the cover of this book, it is my responsibility to acknowledge to the best of my recollection all the numerous individuals who contributed in various ways to this project. First is my institutional home. As such, I would like to give my sincere thanks to the faculty, staff and doctoral students at the Department of Economics, as well as many others in the Turku School of Economics at large, for creating an inspiring, welcoming and cozy work environment.

I have been fortunate during the course of my doctoral studies to receive encouragement and advice from many senior faculty members, while having all the freedom to pursue my peculiar research interests. In particular, I would like to acknowledge Martti Vihanto for showing that critical thinking is a scholarly virtue, Paavo Okko for demonstrating daily of the importance of one's commitment to his home department and university, late Mika Widgrén for radiating aspiration and ambition into all those who came in contact with him, and Hannu Vartiainen and Heikki Kauppi for helping me overcome the final obstacles in completing my dissertation.

Researching what can only be described as a fringe topic is always an uncertain proposition, but fortunately we live in a time when one can more than ever tap into the brainpower of kindred spirits elsewhere. I would like to thank the faculty and students at the Erasmus Institute for Philosophy and Economics in Erasmus University Rotterdam and at the Center for the History of Political Economy in Duke University for their support and hospitality, which made my time spent there both enjoyable and productive. Numerous discussants and participants at conferences and seminars at home and abroad also provided valuable feedback on my research, without which the end result would have been much poorer. None of these visits or conference travels would have been possible without the generous and critical support of the Department of Economics and of Yrjö Jahnsson Foundation, TOP Foundation, Turku School of Economics Support Foundation, Alfred Kordelin Foundation, Turun Kauppaseuran Säätiö, KAUTE Foundation, and Finnish Cultural Foundation.

Another crucial institution for my development was the Institute for Humane Studies. I would like to thank Nigel Ashford and the IHS staff for their tremendous support of scholars interested in classical liberalism. Among the connections initiated by the IHS, the most important was getting in touch with Pierre Desrochers. Obviously, Pierre and I became co-authors in several papers, two of which are in this dissertation, but that is far from all. Pierre took a great chance at inviting this young and inexperienced scholar to Toronto in 2006. During the following years, Pierre became my mentor, collaborator and friend, and helped me to grow up as a scholar in more ways that I can tell. Thank you for everything, Pierre! My sincere gratitude also goes to my doctoral thesis pre-examiners, Panu Kalmi and Tuomas Takalo, who provided invaluable feedback on my manuscript. Thanks also to Pekka Matomäki for his continuous supply of mathematical support and fresh fruit! The usual caveat naturally applies. Lastly, it is a great honor that Professor Suzanne Scotchmer accepted the invitation to be the official opponent of my thesis.

There is of course more to life than plain work, although to me they have always appeared as complements. As such, I would like to thank my family and relatives, both past and present, as well as my friends for making this journey bearable and worthwhile. Above anyone else, my gratitude belongs to my beloved wife, Heli, to whom this book is dedicated. Only Heli truly knows what a roller-coaster ride this has been as during the whole ride she has been there besides me, in the front car, holding hands up high. There is so much to be grateful for, but fortunately I have a life time to pay back.

As for all the others that deserved acknowledgement but whom I forgot to mention, touch base with me the next time you're around and I will buy you a drink.

Cheers,

Samuli

P.S.

Lastly to you who ever you may be, by paraphrasing Leonard Cohen (adapted from the "Introduction to the Chinese edition of *Beautiful Losers*"):

Dear Reader, Thank you for coming to this book. It is an honor, and a surprise, to have the frenzied thoughts of my journey expressed in this book. I sincerely appreciate the efforts of the Publication Board and the printing press in bringing this curious work to your attention. I hope you will find it useful or amusing.

This is a difficult book, even the parts written in plain English, if it is taken too seriously. May I suggest that you skip over the parts you don't like? Dip into it here and there. Perhaps there will be a passage, or even a page, that resonates with your curiosity. After a while, if you are sufficiently bored or unemployed, you may want to read it from cover to cover. In any case, I thank you for your interest in this odd collection of thoughts, an interest that indicates, to my thinking, a rather reckless, though very touching, generosity on your part. Dear Reader, please forgive me if I have wasted your time.

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INTRODUCTION TO ESSAYS IN THE ECONOMICS OF KNOWLEDGE

1 THE ECONOMICS OF KNOWLEDGE AS AN ORIGINAL DISCIPLINE

The economics of knowledge studies the “role of knowledge in social systems, both as a product of the past and as a determinant of the future”, wrote Kenneth Boulding (1966, 1), who was apparently the first to use the name of this sub-discipline of economics. After that the term appeared rather irregularly in the economic literature, but in the early 21st century two books bearing the term in their title were published (Foray 2004; Andersson & Beckmann 2009) and it also reappeared in academic journal articles (e.g. Ancori et al. 2000; Antonelli 2003b; Lundvall 2004). Closely related to the discipline, while from different perspectives, were the recent books by Warsh (2007) and Hardin (2009).

Indeed, it seems to be a regular trend that economic questions concerning knowledge, its production, sharing and use, disappear from sight for a while only to surface again later. A reason, perhaps, is that these are perceived in economics as such grand questions and themes with no clear or established way to approach them. By now, however, Foray (2004) argues that the economics of knowledge has been finally established as an original discipline. Let us next concentrate, then, on what he and others see as the defining characteristics of the discipline.

Foray writes that the economists’ and other social scientists’ interest in knowledge grew with the emergence of so-called knowledge-based economies. While the causes and consequences of technological change, for example, had received the attention of several early economists, by the late 20th century these issues had become increasingly important. Foray and others (e.g. Antonelli 2003b; Lamberton 1971; Lundvall 2004; Machlup 1980; Stiglitz 2000) use interchangeable concepts to describe the central themes in the economics of knowledge, but three themes emerge among them: the generation, dissemination, and use of knowledge. Our later discussion will revolve around this taxonomy.

Foray makes the case that the economics of knowledge deserves to be identified as an original discipline, distinct from others such as the economics of research, the economics of innovation, or the economics of information. This is because it does not exclusively confine itself to the study of formal production of technological knowledge (i.e. the economics of research, or invention) or its underlying conditions or consequences (i.e. the economics of innovation). Nor does it study exclusively decision-making under imperfect or asymmetric information, which is the domain of the economics of information. In its broadest sense, the economics of knowledge includes all these and more. But does that make the discipline too broad to be considered as a uniform body of economic research? Indeed, the apparent fragmentation is the basis of Mirowski's (2009) diagonally opposite thesis that "there is (as yet) no such thing as an economics of knowledge." To answer that question we perhaps should first look at the set of themes that this broad view encompasses.

Boulding (1966) names F.A. Hayek, Fritz Machlup, T.E. Schultz and Fred Harbison as the members of the small club of economists who took the importance of knowledge seriously. Foray sees Adam Smith, Karl Marx and Joseph Schumpeter as the historical figures behind the discipline, whereas the unquestionable latter-day pioneers are, in addition to Hayek and Machlup, Herbert Simon and Kenneth Arrow. As the works of these authors suggest, the early foundations of the discipline are in diverse paths of research. To specify the scope of the discipline, Foray lays out two views.

The narrow view of the scope of the economics of knowledge includes research, education, impacts on growth, learning and competences. In addition to these, the broad view also includes the economics of information, which studies change, ignorance, uncertainty, and risk; the role of expectations, the role of prices, and decision theory in general. Now, it is not clear whether the economics of information should be included, as it is well-recognized discipline on its own. To be sure, however, the topics of the narrow view and those of economics of information are largely intertwined and in the past not much distinction was drawn between the two areas. An example is the book edited by D. M. Lamberton (1971), titled *Economics of Information and Knowledge,* which contains seminal writings of the time dealing with a range of topics from search for information and information networks to research activities and the patent system.

Foray notes that Machlup's work, in particular, covers a vast domain, from knowledge creation and transfer to knowledge sectors and industries, to the theory of choice and expectations under uncertainty and incomplete information. Unlike Foray, Andersson and Beckmann (2009) do not give a detailed account of the scope of the economics of knowledge. Judging by the contents of their book, however, the economics of knowledge includes, at the very least, the production of knowledge (both research and education), its use and diffusion, as well as the macroeconomic consequences of growth and social sharing of knowledge. They do note that before Machlup, knowledge surfaced in many discussions, many times disguised by terms such as human capital, technology and innovation, but that only he had a broader and more concrete view of the discipline. Boulding's (1966) view of the scope of the economics of knowledge is similarly broad. He remarks that three areas of economic thought where knowledge has been neglected and where there is henceforth demand for such a work are the theory of the market, the theory of development, and the theory of decision making (both public and private). As such, we proceed forward with this broader view of the economics of knowledge while keeping the discussed reservations of its scope in mind.

While most aspects of the generation, dissemination and use of knowledge are microeconomic by their nature, the macroeconomic dimension of knowledge is present in both Foray (2004) and Andersson and Beckmann (2009). Indeed, Lamberton (1971) in his introduction to the edited volume saw the discipline bridging the gap between micro- and macroeconomics. On one hand, the microeconomics of knowledge can provide part of an explanation for the economic fluctuations that we observe in the macro economy. On the other hand, creation and diffusion of new technologies, in particular, results in economic growth, a view which is the fundamental building block of endogenous growth theory (e.g. Romer 1990). Hence, while the discussion in this introductory chapter mostly concerns the microeconomics of knowledge in its various forms, it is good to keep in mind that these are not interesting and relevant questions for their own sake only, but ultimately have implications for macroeconomic questions as well (see, David & Foray 2002; Braman 2006).

Another important aspect of the economics of knowledge is that it is different from most of the other subfields of economics. Unlike labor economics, for example, it does not solely study any particular market. While many studies have been done on so-called knowledge industries, information and knowledge are an integral part of the whole economic analysis itself (Lamberton 1971; Stiglitz 1985). Therefore, the economics of knowledge offers a perspective that can, and has been, applied to labor economics, finance and many other fields. However, the economics of knowledge is neither a tool nor a method like game theory, for example. In fact, game theory has proven useful in many questions that the economics of knowledge is concerned with. Perhaps the best way to describe the economics of knowledge is, then, as an "approach". It is an approach that analyses any given economic phenomenon from the point of view of knowledge. Behavioral economics is perhaps similar, since it comes with insights and approaches that can be applied to many different economic phenomena.

As Boulding (1966) noted, a fundamental difficulty in defining the economics of knowledge is that neither of these concepts have a simple, commonly agreed definition. Since ancient Greek philosophers, epistemology has tried to address what constitutes knowledge and, not surprisingly, there is no agreed definition among economists. We will come back to this issue later in this introductory chapter. As a working definition we use the standard epistemological definition of "justified true belief". Without going into the particularities at this point, it means that by studying knowledge we are interested in the contents of the human mind regarding the facts about the world outside. This approach lets us define our scope further: we leave aside skills or know-how, to the extent they are not about beliefs of the world outside, and information embedded goods, such as computer software, since that does not refer to the contents of the mind per se. We use information, for now, as shorthand for communicated knowledge.

Defining economics is equally difficult and various definitions have been offered, and later contested, throughout the history of economic thought; some sticking longer than the others. But for all its apparent crudeness, let us confine to the idea that economics studies production, exchange, distribution and consumption, and how incentives and institutions affect these activities. The economics of knowledge can, therefore, be defined as a study of incentives and institutions in the generation, dissemination and use of knowledge.

Regarding a further partition of knowledge, Machlup (1962) lists five different types: practical, intellectual, pastime, religious and unwanted knowledge. For our purposes, however, a category of two types of knowledge help us to frame the history of thought in the discipline: technological knowledge and market knowledge. The histories of these two types in economics are somewhat different, even if overlapping. This division was proposed by Richardson (1960), even though he used the concept of information instead of knowledge. Technical knowledge refers to production possibilities regarding the development of new products or services or more efficient production of the existing ones. Usually technology in economic analysis simply means the “unexplained constraint on human action in relation to production” (Metcalfe 2010, 155). Scientific knowledge, and its generation, dissemination and use, is a part of the same phenomenon, as its significance is usually seen, at least in economic literature, as the progenitor of technical knowledge. Most of the studies of the kind have been dubbed under the headings of the economics of invention and the economics of innovation. The first is usually confined to knowledge production, whereas the latter studies the issue more broadly, including the dissemination of new technologies and the economic impact of technological change.

Market knowledge is different in the sense that it concerns not only the available production technologies, but the decision-making environment in general. It includes knowledge about the available resources and the market in general, such as consumers’ preferences, rival products and the actions and beliefs of your competitors, from the point of view of a seller, and product quality and other issues, form the point of view of a consumer. Lachmann (1976, 55) concisely specifies market knowledge as the knowledge of tastes and resources.

These two types of knowledge are invoked in explaining different types of phenomena. Technical knowledge concerns technological development and subsequent economic growth. Market knowledge concerns decision-making and subsequent market coordination (or discoordination). Many of these latter issues are categorized as the economics of information. Therefore, while much research is confined to specific topics, it is good to keep in mind that there is a wider perspective of economic analysis of knowledge in the background.

2 ON THE HISTORY OF ECONOMIC ANALYSIS OF KNOWLEDGE

To write a complete bibliography of the economics of knowledge is next to impossible, since perhaps the majority of prolific economists have written something on the topic. At best, then, what can be offered here is a brief review of central ideas and approaches, and the authors behind them that stand out in the literature. We will first follow the developments in economics of technical knowledge and after that in economics of market knowledge, as these studies have, to some extent, followed their own paths (see, Hirshleifer 1973). Along the way, however, we will begin to see how these paths are often intertwined.

2.1 Invention, innovation and technological change

Most histories of economic thought begin with Adam Smith; so does this. While Smith (1776) did not extensively discuss technical knowledge, it was included in the benefits of the division of labor as he saw them: specialization made individuals to develop inventions, new ways to make their work even more efficient. Later in the 20th century, one can see a connection here to Kenneth Arrow's (1962a) idea of "learning-by-doing", i.e. how people accumulate (technical) knowledge as a by-product of their work and specialization.

However, it took a while before technical knowledge inspired further discussion among economists, which is perhaps surprising considering the ongoing process of industrialization during the 19th century. Mostly the issue came up in the discussions concerning whether technological change would be able to undo the effects of decreasing returns, which seemed inevitable for many economists (Warsh 2007). The Marginal Revolution was, of course, a major event in the history of economic thought, but Menger, Walras and Jevons had been more interested in the demand side of the economy and the connection between value and utility. The next to touch upon the topic of technical knowledge, and from a new perspective, was Alfred Marshall (1842–1924).

In his seminal work, *The Principles of Economics*, Marshall (1890) addressed the issue of why some industries co-locate in particular places (see, also, Ellison et al. 2010). Besides the advantages provided by the physical or economic conditions of a place, Marshall noted that new inventions tended to spread more easily in these locations. Knowledge spillovers, as they were dubbed by later economists and economic geographers, were a source of external economies and thus a cause of industrial agglomeration. What became important for Marshall was the dissemination of technical knowledge and, to a lesser extent, how this process generated new knowledge when "a new idea […] is taken up by others and combined with suggestions of their own; and thus it becomes the source of further new ideas" (ibid. IV.X.7).

A.C. Pigou (1920) took Marshall's idea of external economies further by developing the concepts of negative and positive externalities. Both were deemed as sources of market failure: when marginal private costs are less than marginal social cost, there is overproduction from the social point of view (negative externalities) and when marginal private benefits are less than marginal social benefits, there is underproduction (positive externalities). Negative externalities are uncompensated nuisances or damages to others and their property. Positive externalities were, accordingly, uncompensated benefits, the most important example of which was according to Pigou (1920, II.IX.11) scientific research. For the first time the generation of scientific and technical knowledge was argued to possess a problem for the market economy, even though in essence the similar argument had been put forward by John Rae (1834) among others, who had argued for government funding of research and development. A heated debate regarding the concept of externality and the feasibility of government intervention continued for many decades, though research activities as such were not always in the epicenter of these discussions (see, for example, Demsetz 1969).

Meanwhile, another idea regarding technological change was put forward by Joseph Schumpeter. Schumpeter (1942) argued that the capitalist economy was repeatedly transformed by a process called creative destruction. The engine of the process was entrepreneurs who constantly developed new innovations. Interestingly, Schumpeter makes a link from technical knowledge to market knowledge by arguing that the fundamental characteristic of creative destruction is that the development of new technologies makes some others obsolete. Therefore it necessitates a restructuring of much of the economy and acts as a disequilibrating force. Initially Schumpeter's argument seems not to have gained much attention, but later scholars of entrepreneurship and innovation placed him high in their ranking. A reason, perhaps, is that while Schumpeter did not offer a detailed account of technological change, he presented it as endogenous to the economy, hence something that economists can explain rather than take as given and beyond the scope of their study.

As mentioned earlier, the most prolific economist studying technical knowledge and the economics of knowledge in general was Fritz Machlup. His

1962 book, *The Production and Distribution of Knowledge in the United States*, offered taxonomies on the types of knowledge and of knowledge industries, occupations and services, including research and development, media and education. Furthermore, he studied the knowledge industries in terms of GDP and occupational structure in order to demonstrate their importance in the modern economy. Arguably Machlup was successful in popularizing the concept of the information society. Later Machlup set out to write a series of ten volumes collectively called *Knowledge: Its Creation, Distribution, and Economic Significance*, but only three of these were published before his death. These three dealt with topics such as creation, diffusion, and utilization of knowledge (1980), branches of learning (1982), and the economics of information and human capital (1984). As is apparent, the scope of topics touched by Machlup is enormous and perhaps for this reason he was unable to establish a direct following among economists, since there was no clear research agenda to pursue. Many of Machlup's ideas have stuck, however, as has his (Machlup 1980) stock and flow distinction between knowledge (stock) and information (flow).

To return back to positive externalities in the case of research activities, several papers using the Pigouvian framework appeared roughly at the same time. These include Nelson (1959), Arrow (1962b), Usher (1964) and Shell (1966). Among these, particularly Nelson (1959) and Arrow (1962) were successful in establishing the view that the free market was unable to provide sufficient incentives to generate an efficient level of research investments. Two of the most important solutions to the underprovision problem were seen in the patent system (Usher 1964) and government funding of research (Arrow 1962).

The costs and benefits of the patent system had been under discussion since the beginning (Machlup & Penrose 1950), but it is fair to say for a long time the theories of inventive activities (e.g. Wyatt 1986) automatically assumed the presence of intellectual property rights. Only more recently have studies on invention in a competitive economy appeared (e.g. Hellwig and Irmen 2001; Boldrin & Levine 2002; Boldrin & Levine 2008). Foray (2004) argues that the consensus, which was reached about 20 years ago, on the desirability of the patent system for innovation and growth is now lost.

According to Arrow (1962b), the positive externalities of technical knowledge were due to its inappropriability: the inventor was unable to capture all the benefits of his invention. Later, in the public goods literature (Musgrave & Musgrave 1973), this feature became known as nonexcludability, meaning that it was impossible to exclude other users (of knowledge), whether they had contributed to the good's provision or not. Richard and Peggy Musgrave (1973) also identified another characteristic of public goods, nonrivalness. This was particularly important in case of knowledge, since it is not rival in use and the same knowledge can be used both by infinite number of people and infinitely.

The (partial) public good nature of technical knowledge is also an important characteristic behind the two most recent theories of growth. Technical and scientific knowledge was the engine of growth behind neoclassical growth theory (Solow 1956), though the growth of knowledge was itself exogenous and not explained by the model. Endogenous growth theory (Romer 1990) attempted to fix this particular feature by putting knowledge production inside the model; the growth of knowledge was now a fundamentally economic process. Here, knowledge was partially excludable: the inventor was able to capture enough benefits to make the research worthwhile, but not all, which resulted to economy-wide growth due to the externalities. In Warsh's (2006) story the endogenous growth theory is the culmination of the study of increasing returns of knowledge, which was started by Adam Smith, and finally made the economics of knowledge come into focus.

Our story does not stop there, however. Besides inappropriability, Arrow (1962b) identified other complications for knowledge production: increasing returns and uncertainty. Increasing returns meant that knowledge production and its effects on industries would be likely to result in monopolies. A similar link between imperfect competition and innovation had been earlier made by Schumpeter (1942). The uncertainty in decision-making would later become important in the studies in the economics of information, as the presence of it implied the possibility and importance of information (Arrow 2009). Besides these supply-side issues, the demand for information seemed problematic to Arrow. Before any particular information is disclosed, the value of information is not known to the buyer, and after disclosure there is no need to buy it anymore. Later literature dubbed this discovery as "Arrow's information paradox", which provided another rationale for the need for intellectual property rights in markets for information.

A discussion of the economics of intellectual property rights would take us too far off the main track, but one line of research in that regard is worth pointing out. How should intellectual properties be allocated when much research seems to build upon past discoveries and in turn provide opportunities for further discoveries? This phenomenon of "standing on the shoulders of giants" became to interest scholars studying the optimal patent breadth, the optimal division of profit between inventors, and antitrust issues in research activities (e.g. Scotchmer 1991; Hopenhayn et al. 2006). The idea of cumulative research or sequential innovation, an issue which, as we have seen, was noted by Marshall, has gained deserved interest.

A field that gave a more direct recognition to Marshall was the geography of innovation. The field took knowledge spillovers as the central explaining factor of why most innovative activities took place in large cities. A seminal paper in this field was Glaeser et al. (1992), who distinguished between three different perspectives: 1) MAR spillovers, referred to Alfred Marshall's insight on external economies, Kenneth Arrow's learning-by-doing and Paul Romer's endogenous growth theory; 2) Porter spillovers, named for management scholar Michael Porter; and finally 3) Jacobs spillovers, for urban theorist Jane Jacobs. The first two approaches stress spillovers within a sector (intraindustrial spillovers) and the importance of geographical economic specialization, whereas Jacobs spillovers occur between sectors (interindustrial spillovers) and are therefore more abundant in a more diversified local economy. In addition, the MAR perspective favors local monopolies, whereas the other two see strong local competition as a better incubator of innovative behavior. That monopolies were more likely to come up with new innovations was also Schumpeter's (1942) view. The impact of market structure on innovation was later addressed in the industrial organization literature (e.g. Loury 1979; Dasgupta & Stiglitz 1980; Hörner 2004; Aghion et al. 2005).

Much of the work done by economic geographers, economists and other innovation scholars have been undertaken in the field of economics of innovation, broadly conceived (e.g. Klette & Kortum 2004; Jones 2009; Young 2009). Antonelli (2003a) is a good overview of the themes studied in the field. A central feature in the field today, and a result of past scholarly work, seems to be the studied two-way causation between technology and industry. The generation of technical knowledge and its effects were no longer studied in isolation and hence the legacy of Schumpeter was reanimated (see, also, Aghion 2002).

Connected to Schumpeter's legacy was also the idea of general purpose technologies. The concept was introduced by Bresnahan and Trajtenberg (1995) who pointed out that throughout the history of technology there had been critical inventions, such as steam power, electricity, laser and computers, that had a large impact on a wide set of industries. These radical innovations were what characterized the "creative destruction".

To this long list another line of research, not concerned as much with technical but scientific knowledge, needs to be added. The new economics of science (Dasgupta & David 1994) uses game-theoretic models of incomplete information to synthesize Arrow and Nelson's approach with a functional analysis of the institutional structures of science. The studies regarding truth-seeking activities of self-interested scientists have been also labeled as the economics of scientific knowledge (Hands 2001; Ferreira & Zamora-Bonilla 2006). Its niche was created with the help of the sociology of scientific knowledge. Whereas philosophy of science assumed that the truth-seeking behavior of scientists generates truthful scientific knowledge, sociologist pointed out that the argument fails because scientists are motivated by many other things besides veracity. But private vices can also yield public virtue, as is many times the case in economic phenomena. The outcome depends on the institutions of science and the incentives they impose upon scientists. Yet, the only relevant issue is not the generation of scientific knowledge but also its dissemination in the society. The study on the popular knowledge of science asks the question when and under what circumstances ordinary people can trust the opinion of experts, such as scientists (Hardin 2009). Credibility of information in communication between experts and laymen has recently been addressed in the strategic information transmission literature (e.g. Krishna & Morgan 2001; Li & Suen 2004; Li 2010). Once again, while a sustained economic analysis on these issues is lacking, we can identify some predecessors of economics of scientific research and the organization of science, such as Tullock (1966).

Hopefully at this point the reader begins to see connections between technical knowledge and market knowledge, the latter of which will be discussed next in more detail. Before going there, however, two of such connections should be highlighted. First, Schumpeter defined innovation as a commercial application of an invention. For Schumpeter, the driving force of creative destruction was not the scientist or the engineer, but the entrepreneur. To exploit an invention in a commercially successful way one, of course, needs relevant knowledge of the market.

Secondly and related to the first point, the knowledge of new technologies is not automatically disseminated and implemented. New technical knowledge is not sufficient for economic growth. This point is well made by Nathan Rosenberg and Luther Earle Birdzell (1986), who in their book, *How the West Grew Rich: The Economic Transformation of the Industrial World*, illustrate how many important technologies were originally developed outside the Western world, but in there they finally flourished and brought prosperity. Once again, institutions do matter, for technological change also. The sudden realization of the interconnectivity of these issues is revealed by the fact that books, such as North (1990), Nelson and Winter (1982) and Rosenberg and Birdzell (1986), were suddenly on the reading lists of micro- and macroeconomists alike (Warsh 2006, 315).

2.2 Decision-making, uncertainty and market coordination

The following will offer a brief overview of the history of thought regarding market knowledge. Knowledge of market conditions in general can be generated through learning by trial-and-error, deliberate search or spontaneous discovery. It can be disseminated or transferred from an individual to another in various ways and ultimately it becomes used in making decision at the individual or a more aggregate level of several individuals working together. Most of the studies concerned with these issues have adopted the term of the economics of information (or information economics), though there are some who have deliberately avoided that. As can be expected, however, these issues have longer history in the economic thought than any specific subfield as such.

For a long time, knowledge played little if any role in the theory of choice. Economists assumed, explicitly or not, that all the agents in the economy had perfect knowledge, an assumption which single-handedly brushed aside all the possible issues related to knowledge. Surprisingly perhaps, the issue of market knowledge did not first arise in microeconomic theory, but in the debate concerning the feasibility of socialism.

Hayek (1945) joined the socialist calculation debate (see, Lavoie 1985) with a question: Can the central planner know all the things required to plan the economy efficiently? Hayek's answer was "no", because the required knowledge was dispersed in the economy, held by each individual and thus not possible to collect. Hayek (1937) had earlier put forward this dispersed knowledge view, arguing that Smith's division of labor automatically implied a division of knowledge: each individual knew different things, more about the particular circumstances of their time and place. In this paper Hayek noted also that the whole concept of equilibrium in economics has much to do with assumptions of knowledge. As Richardson (1960, 44) skillfully articulated, "In order to have an equilibrium, each individual has to be as well off as he believes he can make himself and he must be able to carry out his plans without his beliefs being contradicted by his experience." Coming back to the calculation debate, however, Hayek argued that the free market, unlike socialism, was able to use efficiently the dispersed knowledge through the price system.

Hayek's contribution in the 1945 article was to study the use of knowledge given its dispersed nature and, to a lesser extent, how that knowledge was disseminated through the price system (in some sense prices do not transfer knowledge from one individual to another per se but act as knowledge surrogates). Interestingly, Hayek was later accused of not addressing the issue of (technical) knowledge production (Hirshleifer 1973; Dasgupta 1980). It is debatable whether Hayek won the argument concerning the feasibility socialism in that day, but the fall of the Soviet communism has been later taken as the final proof that Hayek was right. Nevertheless, it took a while before economists started to analyze the informational role of the price system.

In the meanwhile, two papers were published that apparently used the term of the economics of information for the first time. The first was Marschak (1960), which attempted to address some ambiguities concerning the concepts of the value, amount and cost of information. The more famous one, however, is Stigler (1961). Together with Machlup (1962) this paper is often considered as the seminal contribution to the emergence of the economics of knowledge (and information). Stigler's main contribution was to analyze the search for information from the standard economic point of view: each individual would look for new information until the marginal cost and marginal benefit of the search would be equal. Any lack of information could be then contributed to the search costs, and hence any ignorance would be rational. Predating the later theoretical developments, Demsetz and Alchian (Demsetz 1969; Alchian & Demsetz 1972) would argue that the consequences of asymmetric information, as they were later termed, did not imply market failure but were rational responses to specific information costs.

The particular type of information, which Stigler (1961) studied in his paper, was information on prices. If all sellers did not charge the same price for their product, or at least the buyer did not know if that was the case, the buyer would visit different sellers until he would find a price that satisfied his optimization problem. Contra to Hayek (1945), in Stigler's model the individuals did not know the market price(s) automatically, and therefore the informational role of prices was quite different. The informational role of prices was also later addressed by Grossman and Stiglitz (e.g. 1980). They found Hayek's reasoning faulty, because if information acquisition was costly and market prices revealed all the acquired information there was no private return for this costly activity. Knowledge of the prices was a public good with the usual problems of efficient provision. Hence, either informationally efficient markets were impossible or information was free, in which case it possessed no problem in the first place, they concluded. A contributing factor to these opposing conclusions can be found from conceptual differences regarding knowledge and information (Zappia 1996).

Much of the economics of information which was done in the 20th century was concerned with imperfect knowledge, and when knowledge was imperfect choices would involve uncertainty. Many of these studies, however, would concern choices under risk, rather than uncertainty, to use the famous dichotomy of Frank Knight (1921). According to Knight, when faced with risk, the individual does not know the final outcome but nevertheless knows all the possible outcomes and the probabilities by which each will materialize. When faced with (true) uncertainty, however, the individual does not know the finite set of outcomes and his knowledge is thus in an important sense unstructured. For Knight, uncertainty was the source of entrepreneurial profit and furthermore the more interesting feature in economic activity. Due to the relative ease with which it could be modeled mathematically, it was mostly risk in Knight's terminology that was applied in economics, however. Later it would become G.L.S. Shackle's (e.g. 1972) task to try to convince the profession that "uncertainty" in making rational choices should be taken more seriously in economic analysis. The meaning of a “choice” would be severely impaired, when it was reduced to a technical calculation problem. As said by Arrow (1962b) already, uncertainty is, of course, prevalent in decisions concerning R&D investments.

Information economics largely developed in its own path (Stiglitz 1985 and 2002, Braman 2006, and Arrow 2009 offer a perspective on these developments). The final breakthrough of the field was due to the analysis of asymmetric information. Asymmetric information considered contracts between two parties, where one knew more about the object of the contract than the other. The key contributions, the authors of which shared the Nobel Prize in Economics in 2001, were Akerlof (1970), Spence (1973) and Stiglitz (1975). Akerlof (1970) used the market for used cars as an example to demonstrate that when the seller knew the exact quality of his car and the buyer knew only the average quality of the cars in the market, it would drive all the good cars out of the market. The same analysis was soon extended to other markets beyond used cars as similar informational asymmetries seemed prevalent in many occasions. Note that this framework departs relevantly from Hayek’s view of dispersed knowledge, according to which one is more likely to know the particularities that are familiar to him, such as a car he has inspected, rather than the general structure of the market, like the quality distribution of all cars.

The information asymmetry could be decreased between the parties and two of such methods were signaling and screening. In Spence’s (1973) model the competent job seeker could signal his higher productivity to future employers by formal education. Education as such did not affect the productivity, but it was a reliable signal because it was less costly to take for those with higher productivity and hence education would reveal their innate talent. Through screening, on the other hand, the employer established a mechanism that would reveal the hidden information to him. By offering a menu of choices the employer can identify the workers’ productivity (Stiglitz 1975). In these mechanisms, information is induced from observing actions, which indeed is an important source for knowledge dissemination and indirectly what the idea of knowledge spillover implies.

Noticeably, the above communication mechanisms rely on the fact that communication is costly, which guarantees that any sent message is a true statement of a fact. Most of human communication, however, is not like that, but for a long time economists considered that as only “cheap talk” conveying the idea that it is both free and (therefore) meaningless. In the models of asymmetric information nothing prevents communication as such, but the problem is that the disadvantaged parties would report the same information as the advantaged one and nothing could be done to see who is telling the truth. In this regard, already Hirshleifer (1973) noted that manipulation of information is one of the central themes of the economics of information. Later, however, a small but growing literature, which studies the situations where the argument of uninformative communication holds or not, has emerged (e.g. Crawford & Sobel 1982; Farrell & Rabin 1996; Levy & Razin 2007; Chen et al. 2008; Mullainathan et al. 2008; Chakraborty & Harbaugh 2010). The central result that was found was that when signaling is costless and messages cannot be verified the informativeness of a message depends on how similar the agents' goals are. In other words, the dissemination of knowledge through regular, costless communication depends likewise on incentives. In some cases such communication can improve coordination of actions (Ellingsen & Östling 2010).

The assumption of a perfectly rational decision-maker who was capable of optimizing even in the presence of risk was ultimately contested by Herbert Simon. According to Simon (e.g. 1955), the actual decision-making in firms is characterized by "satisficing" rather than by optimization. Following different heuristics that they have found adequate in the past, individuals were "boundedly rational". Simon received the Nobel Prize in Economics in 1978 and his work continues most profoundly in behavioral economics and behavioral finance. Bounded rationality and behavioral economics in general, however, while also concerned with knowledge and learning, put perhaps more emphasis on the cognitive limitations of using the available information efficiently than the lack or imperfection of knowledge itself. To add to the ever-growing list of subfields, bounded rationality, when coupled with the study of institutions, has also led to a new field, the economics of the mind, which borrows ideas from cognitive science and theoretical psychology (Rizzello 1999), further obscuring disciplinary boundaries.

Simon's work has had an impact on management scholars and organization theorists as well. This is true particularly in the field of knowledge management (e.g. Nonaka & Takeuchi 1995), which is concerned with the creation, dissemination and use of knowledge in the firm. Interestingly, this field could benefit from the economists' work discussed here, such as Hayek's work on the use of knowledge in a (de)centralized society, and these paths have not been fully explored yet (see, however, Foss 1999). In addition, giving a nod to Hayek and Smith, Becker and Murphy (1992) argue that the coordination of specialized workers becomes increasingly costly and may be the true limit to the division of labor. This issue would seem especially acute in universities, and thus worth exploring by the economics of scientific knowledge.

So far we have discussed the economists' rationality assumption in passing, but not extensively its connection with assumptions about knowledge. Latsis (1972) argued that the rationality principle is void of describing the actual decision-making process if the choices are fully determined by the objective conditions. Instead of the objective conditions (and preferences) determining the choice, it is beliefs concerning the conditions that enter into the decision-making process. Bicchieri (1993) made later a similar point by arguing that it might be useful to separate the notions of “practical rationality” and “epistemic rationality”.

Practical rationality means that an agent chooses optimally, in the light of her desires and beliefs. If S desires q and believes that p is the best way to enable q, she is practically rational by choosing p. Thus practical rationality says nothing about the content of beliefs, only that the agent acts accordingly. Epistemic rationality, on the other hand, is concerned with the content of those beliefs. It refers to beliefs by saying that rational beliefs are such that 1) they are internally consistent; and 2) they are formed appropriately in the light of available evidence (Bicchieri 1993, 2). Bicchieri (1993, 13) admits that it is a legitimate question whether the double rationality requirement is necessary for explaining and predicting individual behavior, since one could do without epistemic rationality by assuming perfect knowledge. Her conclusion is nevertheless that perfect knowledge is neither the most common nor the most interesting case.

During recent decades, game theory has moved to the forefront in studying knowledge in economic decision-making. This development is due to a large extent to the fact that in strategic interaction assumptions on knowledge are especially critical, particularly when considering the justification for a particular equilibrium or studying the assumption of common knowledge and its implications. For game theoretical models it is very relevant what is assumed about what the decision-makers know about their environment and each other (Bicchieri et al. 1999). Surveys on these developments are provided by Dekel and Gul (1997), Battigalli and Bonanno (1999), and Samuelson (2004). In particular, game theory has proceeded to analyze knowledge of a higher order, i.e. knowing about knowledge that you yourself and others have (e.g. Hellwig & Veldkamp 2009).

Recent developments in the economics of market knowledge include studies of collective decision-making and the use of knowledge. The received interest is much due to the Internet, which has enabled new ways to create, disseminate and use knowledge collectively, such as Wikipedia (for detailed examples, see Sunstein 2006b). Of much interest is also the study and many applications of prediction markets through which dispersed knowledge is used in a very Hayekian manner (Wolfers and Zitzewitz 2004; Heath 2007). Sunstein’s (2006a) work on how deliberating groups often converge on falsehood rather than truth and why they are outperformed by prediction markets takes an important step in this direction. The idea of the wisdom of crowds, i.e., how a group of individuals are able to make better decisions collectively than even the brightest individuals in that group could alone, is very interesting from the point of view of the organization of economic activity in a society. Lastly, as the recent book by Hardin (2009) demonstrates, economic analysis can be extended to a very wide variety of knowledge and beliefs, such as political knowledge, religious beliefs, cultural knowledge and moral knowledge (see, also, Leppälä 2011d).

Stiglitz (2000), while known to been in disagreement on many other issues, gives Hayek full credit for pointing out how important the question on knowledge are for economic profession. Stiglitz (1985) makes the same point made by others before him that informational considerations are a foundational part of economic analysis and notes that these considerations have had both a negative and a positive impact on economics. The negative impact is that some things that were once taken as granted have been now contested and need to be reconsidered, whereas the positive side is that completely new venues of research are now open to new generations of economists. The key questions of the field according to Stiglitz (2000, 1469 & 1471) are the following: “how the economy adapts to new information, creates new knowledge, and how that knowledge is disseminated, absorbed, and used throughout the economy” and “how and how well organizations and societies absorb new information, learn, adapt their behavior, and even their structures; and how different economic and organizational designs affect the ability to create, transmit, absorb, and use knowledge and information.”

As the above quotes demonstrate, Stiglitz’s view of the domain of the economics of information is very broad. Indeed, it is very similar to Foray’s (2004) broad view of the economics of knowledge. Stiglitz (1985 & 2002) also explicitly includes technology and R&D in the domain of the economics of information. Should we then simply use the economics of information as the principal category of the discipline? While nothing, of course, prevents it, in my opinion “knowledge” is a more natural choice. While (the exchange of) information is an integral part of economic analysis of knowledge, without the concept of knowledge, the analysis of information misses some key aspects that should be considered. This issue and the connection between information and knowledge will be discussed in the next section.

3 SOME CENTRAL ISSUES IN THE ECONOMICS OF KNOWLEDGE

This section will discuss and reflect on some chosen issues that stand out in the economic analysis of knowledge. I will also in this connection highlight how the included essays in this doctoral dissertation connect and contribute to these.

3.1 The characteristics of knowledge as an economic good

Machlup (1962) was the first to explicitly study knowledge as an economic good. According to him, knowledge can appear as one of three different types of a good: 1) an investment good, (e.g. formal education or scientific research); 2) an intermediate good, (e.g. market research or financial analysis); and 3) a consumption good, (e.g. art or general literature). Furthermore, since Pigou (1920) particularly scientific and technical knowledge has been regarded, more or less, as a public good and a source of positive externalities.

While concepts to describe the exceptional characteristics of knowledge vary in the literature, the ones used to make the distinction between private and public goods, rivalry and excludability, describe them best. Nonrivalry of knowledge implies that its use is unlimited in principle (both in time and between users) and nonexcludability that its use is or cannot be limited in practice. The standard argument in the literature is that without excludability there is no private gain to invest in knowledge and therefore it must be artificially created with intellectual property rights or the investments need to be funded through taxes (e.g. Arrow 1962b and 1996). Some argue that the underproduction issue is less severe in reality, since knowledge has some partial excludability, not only due to intellectual property rights but also because of trade secrets and tacitness of knowledge. However, they do agree that excludability is desirable in principle.

Leppälä (2010c) analyzes this issue with a game-theoretic discrete public good model. Nonrivalry implies that knowledge goods are lumpy or indivisible, which suggests that they should be studied as discrete public goods. In addition, since there is a possibility for collective gain, there is also a possibility for collective, cooperative action for which a game-theoretic approach is well-suited. The results demonstrate that both pure excludability and pure nonexcludability are equally inefficient, as they create either too much or too little investment effort. The optimal level of excludability lies in between the extremes as a function of the costs and benefits of the knowledge investment. This result clarifies the controversy regarding the desirability of intellectual property rights. If the optimal level of excludability is different to different industries and types of knowledge, however, this suggests major challenges for the intellectual property law. One study cannot, of course, be conclusive, but it introduces a new and promising perspective to study the production of scientific and technical knowledge, R&D cooperation and the impact of intellectual property rights.

3.2 Knowledge spillovers and the geography of innovation

Knowledge spillovers as a generator of external but local economies have received much attention among economists and economic geographers working in the field of the geography of innovation (e.g. Glaeser et al. 1992; Feldman & Audretsch 1996). The motivation for that is easy to see: What keeps cities together? Why is most innovation done in cities despite the emergence of new communication technologies? The standard answer is that it is increasingly so because knowledge spillovers are locally bounded, which provides a reason to locate near its sources (e.g. Gertler 2003; Keller 2002).

Knowledge spillovers are local public goods generating positive externalities. But in what sense are these knowledge externalities a symptom of a market failure, caused by nonexcludability, or are they the engine of growth and development? This issue goes into the heart of endogenous growth theory (Romer 1990). Furthermore, it is not even perfectly clear that knowledge spillovers, as they are studied in the contemporary literature, are truly knowledge externalities (Breschi & Lissoni 2001a). When one studies the effect of cooperation and social networks behind innovative activities, knowledge spillovers are definitely deliberate. Patent data is also constantly used in these studies, which seems to counter the idea of externality, since patents are, at least in theory, developed to internalize social benefits. In addition, one channel of knowledge spillovers is argued to be labor mobility between firms (e.g. Audretsch & Keilback 2005). However, the labor market might be quite effective in internalizing such externalities (Møen 2005).

Behind this issue and many other obscurities regarding localized knowledge spillovers is the fact they are treated ultimately as a “black box” (Breschi & Lissoni 2001a). While there has been much empirical research on the MAR-Porter-Jacobs controversy, for example, these studies have fallen short of proving or documenting the existence of knowledge spillovers (Beaudry & Schiffauerova

2009). Largely this result is unsurprising, since these econometric studies have approached the phenomenon by trying to find links between regional attributes (size, industrial structure etc.) and development and growth. As a result, while knowledge spillovers supposedly explain the existence of agglomeration, the geographical agglomeration of economic activities is now taken as evidence of the existence of knowledge spillovers. As Leppälä and Desrochers (2010) suggest, any study of agglomeration economies should be approached from the individual or firm level to explain why the benefits of more specialized or diverse cities are both specific to a particular location and uninternalizable by firms or individual inventors themselves. Knowledge spillovers are undoubtedly an important phenomenon in this regard, but as Breschi and Lissoni (2001a) and Hansen (2002) suggest, it requires studies on how innovative know-how is actually created, diffused, adapted and combined by individuals.

A step towards this direction is taken in Desrochers and Leppälä (2011). In this study we concentrate on Jacobs spillovers, which have received less attention. How new technologies are disseminated within an industry (MAR or Porter spillovers) as well as adopted in a wide set of industries (general purpose technologies) are better documented. At the heart of Jacobs spillovers, however, is not only the dissemination of technical knowledge, but that it ultimately creates new innovation when, paraphrasing Jacobs (1969), old work is connected with new work. In this study we conducted a qualitative survey of individual inventors in which we identified three broad, although not mutually exclusive, sets of circumstances through which individuals found new uses or applications for existing products and created new combinations of existing products, processes and materials: 1) by adding to, switching or adapting specific know-how to other lines of work; 2) by observing something in another line of work and incorporating it into one’s own line of work; and 3) through formal and informal multidisciplinary teams working towards the creation of new products and processes (Desrochers & Leppälä 2011).

3.3 Knowledge as an input and output of creative activities

As already noted by Machlup (1962), knowledge is both the input and output of an R&D investment. Among others, the sequential innovation literature takes the use of past knowledge for the generation new as a requirement for research activity. In more general way as well, the different phases of both market and technical knowledge processes are highly interdependent. Thus while sometimes it is necessary to focus in generation, diffusion or use of knowledge, the linkages between them should be kept in mind.

When making a research investment, the dissemination as well as the later use of this technical knowledge is important. In addition, as noted earlier, a research investment is itself a decision, and hence a use of knowledge, under uncertainty. As is the central idea behind Jacobs spillovers (Desrochers & Leppälä 2011), generated technical knowledge is not only disseminated, but the dissemination itself can cause the creation of new knowledge. All the phases are also connected to and dependent on the available market knowledge. Interestingly enough, Jacobs spillovers were also seen as the driving force behind endogenous growth theory (Lucas 1988).

Furthermore, economic development and coordination of economic activities depends both on the use of existing knowledge and the growth of knowledge. This perspective effectively links together superficially distinct issues regarding market knowledge, on one hand, and technical knowledge, on the other. Efficient generation and dissemination of technical knowledge depends on market knowledge and efficient use of market knowledge depends on the existing technical knowledge.

The notion of creativity, whether we talk about the inventive action, the economic application of an invention or the entrepreneurial imagination to discover profit opportunities, seems central in economies of knowledge. However, as a psychological concept and process, it is not clear whether economists of knowledge have much to say about it. However, it has been long recognized that diversity, in terms of background knowledge, new ideas and modes of thought, enhances creativity (Desrochers 2001). The formal logic behind this idea was recently discovered by economists Hong and Page (2001) and Page (2007), who also demonstrated how it operates or fails to operate in different situations. This phenomenon is foundational to the wisdom of crowds and the whole Hayekian view of the use of knowledge in society.

Nevertheless, it is perhaps foremost the study of incentives (to generate, disseminate and use knowledge) in which economists have a comparative advantage and can show how these matter for economies of knowledge. To be more precise, it is the study of incentives that individuals have; the notion of which refers to methodological individualism, one of the well-recognized building blocks of economic analysis (for references, see Leppälä & Desrochers 2010). While we are not only interested in individuals in isolation but as members of groups and societies, group and societies as such do not know or act based on their knowledge. There is no direct access, i.e. telepathy, to each others' minds, and hence knowledge can only be shared indirectly. According to Arrow (1994), knowledge has an irremovable social component but can only be absorbed individually. Furthermore, there is no collective mind that has all the knowledge that the individuals have and which is capable of efficient decision-making on their behalf (Hayek 1945). For example, in the case of public good knowledge, a particular piece of knowledge may in principle satisfy the criteria of public goods but whether or not it becomes, and how and when it becomes, common knowledge is a different question.

The issue of how and if knowledge becomes commonly shared is also present in the later discussions of the informational role of the price system. The impossibility of informationally efficient markets (Grossman & Stiglitz 1980), which was presented above, is ultimately framed as a public good problem: Why would individuals make costly investments to acquire information if others are able to free-ride on their benefit? However, as argued in Leppälä (2010), the Hayekian argument is that individuals already have some local knowledge; it is only that getting direct access to the local knowledge of others that is costly. As a by-product of their transactions the local knowledge becomes incorporated into prices, though not completely communicated by them. In addition, the informational role of the price system also works to generate new knowledge when individuals have to adjust their beliefs facing the changing prices. As such, there is a large contrast to the view presented by Grossman and Stiglitz (1980).

Regarding the efficient market hypothesis, according to which prices always reflect all available information, Grossman and Stiglitz were more on target. The efficient market hypothesis has also received counter-evidence from behavioral economists (Lo 2008). To reconcile the hypothesis with behavioral anomalies, however, Lo (2008) finds recent advances in evolutionary psychology and the cognitive neurosciences promising. As such, Hayek’s view on the information role of prices with its cognitive foundations (Leppälä 2010), combined with research on social learning (e.g. Manski 2004; Blume & Easley 2006), could provide a basis for the efficient market hypothesis as a learning process.

3.4 Tacit knowledge

Tacit knowledge is a concept that we already have mentioned several times as it appears in many areas of research in the economics of knowledge. Now is a time for a short discussion of it. The origin of the concept dates back to Michael Polanyi (1958), who described tacit knowledge as the part of our knowing that we are unable to communicate to others. Later on other concepts, such as know-how (vs. know that) and procedural knowledge (vs. propositional knowledge), have been used to capture the same meaning. The standard example of tacit knowledge in the literature is riding a bicycle: one is unable to convey all the knowledge required riding a bicycle and hence the other can learn it only by practicing himself. As such tacit knowledge refers largely to different kinds of skills. Interestingly enough, riding a bicycle is the example that economists and other social scientists usually give, whereas considering the claims of prevalence and importance of tacit knowledge, one would think that other examples better related to economic and social phenomena would have been developed.

Many critics have pointed out that the seminal insight of Polanyi has been, to some extent, misrepresented (Cowan et al. 2000; Breschi & Lissoni 2001b; Brökel & Binder 2007; Perraton & Tarrant 2007). For example, is tacit knowledge uncodifiable in principle or is it simply difficult to codify (Brökel & Binder 2007, 153–154)? In fact, Wilson (2002) stresses that Polanyi's famous idea, "we know more than we can tell", implies that tacit knowledge is not only hard to convey through verbal exchange but indeed impossible. In the literature, however, tacit knowledge accounts to all and any reason for why some knowledge is not immediately communicated and become common knowledge in the society. Perraton and Tarrant (2007, 354) make an even stronger case by saying that "the concept of tacit knowledge is merely a term given to a phenomenon that the observer does not understand; as such, it has no explanatory content."

The ambiguity surrounding the tacitness of knowledge has made some suggest that the concept has become too stretched (Breschi & Lissoni 2001b), and it certainly seems so. Others, such as Gertler (2003), however, draw the opposite conclusion that the concept was originally too limited. Making the concept too broad has at least two drawbacks, however. First, the original meaning has some merit which is lost if tacit knowledge does not imply knowledge that is impossible to articulate. That kind of tacit knowledge can be important in some situations and, thus, deserves a concept and studies of its own. Sometimes propositional and procedural knowledge can, of course, be intertwined, such as in gaining human capital through formal education. Besides learning useful skills, education provides facts, but if it was only the latter the interactive process of learning in schools and universities would seem wasteful.

Secondly, the use of a broader than the original meaning of tacit knowledge can cloud the true reasons behind why some knowledge resists to become widely disseminated. Cowan et al. (2000) raise the issue that some knowledge is not codified (or communicated), not because it is impossible to do so, but because it is not economical. This brings us back to the incentives of communication. Furthermore, as is argued in Leppälä (2011a), even if something is communicated it does not necessarily imply that knowledge is transferred. Available information does not automatically translate to shared knowledge, since incentives play a role when individuals attempt to assess the truthworthiness of information. We will come back to this issue in the next subsection.

3.5 Justified true belief

Until now, we have evaded the proper discussion of the concept of knowledge. This is indeed one of the hardest but also of the most important questions when laying out the past and future scope of the economics of knowledge as a discipline. “What constitutes knowledge?” is a question for which an entire domain of philosophy, epistemology has largely devoted to. Much is then written on the nature of knowledge and we have no hope of covering that all. Instead we need to approach the issue from the narrower perspective of the economics of knowledge. What can then epistemology offer that this discipline could use as a starting point?

Since Plato’s *Theaetetus*, epistemologists have studied knowledge on the basis of three necessary and (for the time being) sufficient conditions: S knows p if and only if

1. S believes that p,
2. S’s belief that p is justified,
3. p (i.e. it is true that p)

While there was much further discussion on the nature of these conditions, it was generally agreed that knowledge equals justified true belief. The traditional definition was ultimately challenged by Gettier (1963), when he gave counter-examples of justified true beliefs, which we yet would not count as knowledge. These cases came to be known as the Gettier problems, and the basic idea behind these is that one can be justifiably believe a falsehood from which one deduces a truth, and thus one has a justified true belief but does not actually know it (Foley 2002, 178).

The general problem with the traditional definition, which the counterexamples highlight, is that while fulfilled, the three conditions can be completely independent. This is why, for example, Nozick (1981) proposed a subjunctive condition, which requires that there is a link between the belief and its veracity. In general, three possible strategies emerged to rule out Gettier type of problems: 1) show that the counter-examples are not valid; 2) accept the counter-examples and introduce a fourth condition for knowledge that rules them out; and 3) accept the counter-examples and alter, rather than add anything, the three conditions to rule out the counter-examples (Dancy 1985, 26). It seems to be the general opinion that none of these strategies has proven completely satisfactory. First of all, Gettier’s original example is quite effective and reasonable, and cannot be thus ignored. Adding or modifying the conditions has, on the one hand, produced new counter-examples and, on the other-hand, it has verged on the danger of making knowledge something that is next to impossible to achieve.

However, to quote Ancori et al. (2000), the point here is not to solve debates of other disciplines, but to point out that the given epistemological theory will affect our understanding of economic phenomena. The Gettier counter-examples showed that the traditional definition might not be sufficient for all conceivable cases, but the implication was not that the definition has lost its relevance. Despite the counter-examples, the three conditions remain necessary. Therefore, justified true belief still provides a good working definition of knowledge for economists.

To demonstrate the relevancy of justified true belief, it seems useful to first look at and then compare what working definition has usually, and mostly implicitly, been used by economists. While an all-encompassing survey is impossible, I argue that most economists either equate knowledge with true belief or just mere belief. As Faulkner and Runde (2004, 424) have noted, "mainstream microeconomic theory tends equate knowledge with true belief." As an example of "knowledge equated with true belief" I use game theory. While Bayesian probability theory is sometimes used in game theory, the issue of what justifies beliefs is not generally discussed. In addition, Bayesian theory studies choices under uncertainty, in which agents have some prior probabilities which are then updated when new information becomes available. As such it does not concern incentives or economic justification of beliefs and is thus not discussed here further. As was said earlier, developments in game theory have induced many game theorists to study epistemic logic (see e.g. Fagin et al. 1995). To see how game theorists define knowledge, it is useful to start by looking at the knowledge axioms that are usually used in this field. These axioms were first discussed by Hintikka (1962). Similar expositions are now common in epistemic logic and game theory (e.g. Fagin et al. 1991; Aumann 1999; Samuelson 2004). This exposition is from Dekel and Gul (1997):

(K1) $K_i(A) \subset A$: if i knows A then A is true;

(K2) $K_i(A) \cap K_i(B)A \subset K_i(A \cap B)$: knowing A and B is equivalent to knowing A and knowing B;

(K3) $K_i(\Omega) = \Omega$: player i always knows anything that is true in all states of the world;

(K4) $K_i(A) \subset K_i(K_i(A))$: if i knows A then i knows that i knows that A;

(K5) $\neg K_i(A) \subset K_i(\neg K_i(A))$: not knowing A implies knowing that A is not known.

Of these, the axioms of positive introspection (K4) and negative introspection (K5) are of our immediate interest. The idea behind these introspection axioms is that people are capable of some self-reflection: if they know something they are able to reflect that they know this; if on the other-hand they do not know something, they know that they do not. While these axioms have fallen out of favor among philosophers (Lenzen 1978; Sorensen 1988), their position in game theory seems very strong.

Hayek (1937) argued that in economic models it ought to be kept carefully apart what the observing economists knows and what the agents whose behavior is under explanation are supposed to know. Yet, in these models, the agents know exactly the same as the economists who build the model (Faulkner & Runde 2004, 433). This approach blurs the distinction between “knowledge of the economy’s structure” and “knowledge within the structure” (Bellante & Garrison 1988, 213).

Due to (K4), agents are always aware of what they know. It is reasonable to restrict ourselves to models in which agents have only true beliefs; otherwise the economists could introduce whatever false beliefs are needed to derive the sought conclusions. However, it is a much stricter assumption if the agents in the model are aware that their beliefs are necessarily true. Particularly, when this extends over interacting agents in a model and their beliefs about the beliefs of others and so on, we arrive at situations where, for example, the agents are unable to “agree that they disagree” (Aumann 1976). Aumann’s (1976) result is, however, less striking when one sees that it is already an implicit premise of the argument (Stalnaker 1999; Hild et al. 1999). Connected to “agree to disagree” issues is the so-called no trade theorem (Milgrom & Stokey 1982). According to the theorem an agent is never able to use his private information to his advantage. This is because when someone is willing to buy a stock, for example, as we can assume that they are valued similarly, at a price higher than the market price or willing to sell lower, others are able deduce that his has received some private information and the market price is immediately adjusted accordingly. It is certainly clear that when people trade stocks they understand that their trading partners have different beliefs concerning future profits. However, the reason that trade nevertheless occurs is that they do not think that those beliefs are true, or at least as close to it as theirs. Due to the application of the axiom of positive introspection such a scenario is not possible in these models, because each agent knows with certainty that whatever beliefs other people have or whatever information they have received is always true.

Negative introspection is similarly problematic. Particular Austrian economists and others working within the tradition of Knightian uncertainty have argued that “not knowing what we do not know” is a central ingredient in decision-making and should thus not be ignored by economists (see, for example, O’Driscoll & Rizzo 1985). In the case of technical knowledge, the axiom would imply that every researcher is completely aware of all the existing technologies that they do not yet know. The practical problem of course, as is the case in many of these situations, is that it is far from clear how it could be incorporated in formal economics. As such, it has been acknowledged for some time that the standard state-space model is incompatible with analyzing unawareness (Dekel et al. 1998).

The issue that in reality people do have false beliefs has naturally not passed unnoticed. As North (2005, 99) notes, “A thorny question is just what we mean by knowledge since human decision making has, throughout history, been guided by possessed beliefs that have more often than not proven to be incorrect. Indeed the heart of this study is about the uncertainty humans face and the way they have dealt with that uncertainty. Are beliefs knowledge?”

The possible falsity of beliefs steers North (2005, 17) to define knowledge as “the accumulation of regularities and patterns in the physical and human environment that result in organized explanations of aspects of those environments” without any “implication that such knowledge is ‘true.’” For the same reason, already Boulding (1966) was hesitant to use the word “knowledge” and prefers “image” to it, since it has no similar tendency to approach the meaning of truth. According to Boulding, image is something that its possessor believes to be true. However, these definitions deflate knowledge to mean both true and false beliefs, or, simply, a belief.

Considering economic phenomena, however, why would the mere accumulation of beliefs be good? Would not the truth of beliefs be at least connected to the benefits of knowing, if not the same thing as pragmatists claim? Hence, it would seem that, in general, we regard true beliefs to be ones that increase productivity, creativity or the well-being of individuals, and it is true beliefs that individuals are willing and eager to learn. In brief, our epistemic goals are to acquire as many true beliefs as possible and as few false beliefs as possible, and they are fundamentally connected to our pragmatic goals.

Once we acknowledge the possibility of false beliefs we require a theory of justification. Only then can we assume that over the course of time people do have a greater tendency to acquire true beliefs and revise their belief sets to discard false ones. Otherwise having a true belief would be a mere accident and there would be no reason to assume that the composition of beliefs in terms of their quality (i.e. veracity) would improve over time. Furthermore, Boland (1992, 124) has argued that the existence of false beliefs should have an important role in explaining how we arrive at true beliefs.

An example of why justification is central to our discussion is given by Nozick (1981, 170). Suppose someone, who knows nothing about the matter, separately tells you and me contradictory things, which we both come to believe. By necessity, one of us has a true belief, yet few would claim that the person knows the fact. This implies that that the epistemic value of communication should not be taken as given and that more importance is to be placed on the justification of testimonial beliefs. Only then can we confidently speak of a knowledge transfer.

The issue that truthfulness cannot be directly assessed is not a reason to abandon the condition, but a reason why these considerations should be exercised. Indeed, if we were able every time to recognize true beliefs from false ones, there would be no rational explanation for why we would ever have any false beliefs. Assuming that all beliefs are necessarily true or disregarding the question of their veracity altogether would severely hinder our understanding of the important characteristics of knowledge in a social world.

Indeed, economics has a potential role in social epistemology (e.g. Goldman 1999). While "belief" is primarily a psychological phenomenon and truthfulness belongs to the fields of metaphysics and semantics, the central issue for epistemology is justification. While traditional epistemology only addressed the issue in case of isolated individuals, social epistemology studies knowledge and justification in social context. By studying the incentives in social interaction, which seem relevant for social epistemology, the economics of knowledge can thus yield a contribution in the form of economic epistemology (see, also, Mäki 2005). The issue of justification may become increasingly important as the key challenge in the contemporary society is not anymore the access to information, thanks to the Internet and ICTs more generally, but the trustworthiness of its content (Carlaw et al. 2006). So far, however, the issue of justification has received limited interest among economists.

3.6 Knowledge and information

The difference between knowledge and information, or the lack of it, has been raised from time to time in economic literature (David & Foray 2002; Foray 2004). In particular, it has been claimed that the distinction between the concepts is what differentiates Austrian economics from mainstream economics (Boettke 2002; Metcalfe & Ramlogan 2005), as according to the former decision-makers do not just passively react to information. While it seems unobjectionable that we "must actively interpret the information we receive, and pass judgment on its reliability and its relevance for our decision-making" (Boettke 2002, 267), the ambiguity surrounding the distinction between knowledge and information and its relevance for economic analysis remains.

In 2003, *Econ Journal Watch* invited economists who work on information and knowledge to write a brief reflection on the distinction between these two terms. "Symposium on Information and Knowledge in Economics" was published in their April 2005 issue and the contributors included Brian J. Loasby, Thomas Mayer, Bruce Caldwell, Israel M. Kirzner, Leland B. Yeager, Robert J. Aumann, Ken Binmore, and Kenneth Arrow. While interesting insights were offered in the issue, it becomes clear that no common understanding of the difference between the concepts exists. Even more, the group was divided between those who regarded the distinction important for economics (Caldwell 2005; Kirzner 2005; Loasby 2005), those who did not (Aumann 2005; Yeager 2005), and those for whom it depended on the specific context in question (Mayer 2005). Roughly put, the lines were drawn on the issue of whether gaining knowledge requires interpretation and judgment of information and whether this is a critical issue for economics. Interestingly, Binmore's (2005) main argument is the important distinction between knowledge and belief instead, but he does not show that this could be relevant for the distinction between knowledge and information as well.

In practice, knowledge and information are many times used interchangeably. This practice can be seen already in the writings of Hayek and Machlup and is common to contemporary microtheory (Foray 2004). It is easy to see why, since in the world of true beliefs and true information the distinction does not matter. If you have some particular information it automatically implies that you know the fact presented by it, and if you know a particular fact you can always convey it to others in the form of information. As a consequence, having knowledge and receiving information imply the same thing.

The above equality between knowledge and information can also be seen as a motivation for adopting the concept of tacit knowledge. If some knowledge cannot be codified and conveyed as information, then this can explain why some knowledge is not commonly shared. What has remained unnoticed, however, is that available information does not need to imply shared knowledge (or belief). Information and knowledge do not necessarily correspond.

Though Arrow was at the time unable to fully participate in the above mentioned symposium, he had provided a letter with the permission to publish it as correspondence regarding the symposium. In the letter Arrow (2005) explained that he cannot think of a context that would accommodate the distinction, and hence make it meaningful, and due to other commitments he cannot concentrate on the topic before the editor's (Daniel Klein) deadline. Interestingly, it would seem, as will be explained briefly, that the information paradox provides a context that Arrow had asked for.

Arrow's information paradox, as mentioned earlier, states that ex ante the buyer has no way of knowing the value of some particular information; it can be known only after it has been disclosed. But then again, the buyer has no reason to compensate the seller ex post. Hence, there is no effective demand for information as such.

In most cases, however, it would seem that one can describe what some information is about without revealing it. Hence the uncertainty shifts from the type of knowledge to the issue whether the other party actually has it, since it has not been yet revealed. This brings us to the correspondence between information and knowledge and the issue of justification. As is argued in Leppälä (2011b), we can divide the issue of correspondence into two parts: capability and reliability. Capability concerns the issue whether the sender (or seller) has a true belief, i.e. the belief corresponds to a fact, and reliability whether the given information corresponds to that belief. When both capability and reliability are in place, also the information corresponds to a fact. Capability and reliability depend on the incentives of the sender and if the receiver perceives them both high enough, he has justification for adopting the belief presented by the communicated information.

As Leppälä (2011b) shows, if there are differences between capability and reliability which give the original source of the knowledge an upper-hand, this might prevent the market for information from collapsing even if there are no property rights to that information. It seems that this approach could be used to study a variety of markets for information. Furthermore, capability and reliability could yield useful insights into studying the problems in the use of expert witnesses and forensic science reports in courts (see, Koppl 2005), scientific knowledge in cases where scientific, political and economic interests are intertwined, such as the climate change debate, the role of media in social dissemination of knowledge, or the recent problems in audition practices, such as the Enron scandal or the behavior of credit rating agencies in the recent housing market bubble.

4 FROM PERFECT KNOWLEDGE TO QUANTITY, VARIETY, AND QUALITY: SOME CONCLUDING THOUGHTS

Edith Penrose (1959, 77) noted, that "Economists have, of course, always recognized the dominant role that increasingly knowledge plays in economic processes but have, for the most part, found the whole subject of knowledge too slippery to handle with even a moderate degree of precision […]". Hence, the slow start that the economics of knowledge had cannot likely be contributed to the past economists' narrow view, but to the fact that the assumption of perfect knowledge only made theorizing so much easier. While issues regarding the generation, dissemination and use of knowledge surfaced from time to time, usually such considerations were omitted for the sake of relative simplicity.

It took a considerable time before the weight of that omission became noticed. As Foray (2004) argues, it was also due to the rise of knowledge economies when the issue could not be anymore avoided. In the words of Brian Loasby (1986, 41), "It is now becoming widely recognised that many of the central unresolved problems in economics turn on questions of knowledge."

The first step to proceed in microeconomic theory was to see what happens if we relax the assumption of perfect knowledge a little bit. What would happen if individuals knew the structure of the economy but not some particularities of it? Hence, the perfect knowledge assumption was relaxed in terms of the quantity of available information. Economists studying research activities took similarly an interest in the quantity of knowledge: What are the incentives to invest in research and development? What type of institutions would provide sufficient incentives for individuals so that the socially optimal level of scientific research and output would be achieved?

While the issues of quantity of knowledge are naturally relevant, I would argue that now it seems that at least equally vital are variety and quality. Variety of beliefs and ideas has become increasingly recognized as the driving factor behind creativity and innovation. Production of new ideas is achieved by recombining and reconfiguring old ideas (Weitzman 1998; Desrochers 2001). When people with diverse background and education interact with each other, formally or informally, they constantly face better opportunities to incorporate the ideas of others into theirs and, as a result, create something new. This explains why more diverse regions and cities produce more innovative output and are also less likely to stagnate (Desrochers & Leppälä 2011).

Variety of knowledge implies also dispersed knowledge. No longer, however, is dispersed knowledge seen only as a challenge for its efficient use but also as an opportunity. When we have suitable institutions that allow for efficient use of dispersed knowledge, we have tapped into a great potential. When everyone needs not to know the same things, the variety of knowledge that the society can utilize is hugely increased. The understanding of why some institutions succeed or fail in this regard is useful in various situations considering the organization and decision-making in societies and smaller groups. In addition, it leads to new ways to tap into the vast knowledge base of individuals through the use of new instruments and mechanisms, such as prediction markets.

Lastly, we come to the issue of the quality of beliefs and information, which I find both the most neglected and the most promising. Many special characteristics of knowledge as an economic good have, as we have observed, been discussed in the literature. However, these include issues such as nonrivalry, nonexcludability and cumulativity of knowledge rather than quality by which I mean the truthworthiness of beliefs and information. I suspect that this is partly due to that "Many strands in economics have […] neglected the discussions on the subject of the nature of knowledge: the field of epistemics, while discussed in philosophy and in the other social science, is ignored" (Dolfsma 2001, 71). According to Stiglitz (2002), the reason for the late development of models with imperfect information (and knowledge) was that it was not obvious how to do so. Knowledge can be perfect in a single way, but be imperfect in an infinite number of ways. As is suggested here, one important way of imperfection considers the quality of knowledge.

By ignoring the basic idea of knowledge as justified true belief, economists have taken a critical shortcut by either assuming that all beliefs are true or that the issue of veracity is not an issue at all. But as I have tried to argue above, it is critical. To understand why rational actors would be more likely to have true rather false beliefs, why some information is likely to be false or correct and how rational actors react to that, can only be addressed by a theory of justification. Koppl (2006) has recently provided a general theory of epistemic systems, i.e. social processes generating judgments of truth and falsity, and shown how it can be applied, for example, to the analysis of torture or police forensics. Truthworthiness is not an issue only in dissemination, i.e. that one might receive false information, but in generation and use of knowledge as well.

The uncertainty regarding the generation of knowledge is not only that you might get no results from your efforts, but that some result may not be correct. Similarly a part of the uncertainty in decision-making comes from the fact that some beliefs on which those decisions are based on might not be true, not only from some unknown details. This is also a reason why I prefer to call the discipline the economics of knowledge, because ultimately it is knowledge proper that we are interested in. While some discussions concentrate on a more specific issue, and there a more specific category is in place, the economics of knowledge is a useful term to convey the idea of cohesiveness among these issues. At first justification might seem like a topic of which economics has little to say about, but on the other hand the dimension of quality depends on incentives as well. This revelation leads to the idea of economic epistemology, which can be useful and complementary to other approaches in a wide variety of issues and topics.

While the perspectives and the approaches within the economics of knowledge as presented here only scratch the surface, it is more than evident that while they nominally deal with the same phenomenon they are many times largely detached, mainly because research is problem-oriented. A contributing factor to this fragmentation of research can also be found from sociological factors, namely different scholarly communities with their traditions (Mirowski 2009). How should we then assess Mirowski's claim of the nonexistence of the economics of knowledge? If the standard is the existence of a single, coherent tradition and fundamental laws and theorems, as Mirowski seems to argue, we would be inclined to agree. However, a more reasonable standard for the existence (and not the success) of a scholarly discipline is serious and widespread research, even if partially incoherent, and an attempt to connect bits and pieces to advance our general understanding of a relevant theme, even if grand theories are still beyond the horizon. For the moment, the economics of knowledge is a dispersed research framework approaching various fronts in several ways, rather than a self-identified tradition which conscious development we can easily follow through the history.

Admittedly, the omnipresence of knowledge in economic issues is both the strength and the weakness of the economics of knowledge. It leads to wide applicability but also fragmentation. Due to the nature of the research object, fundamental laws of economics of knowledge will perhaps have to wait, but the fragmentation of research will not help the development of more general models either. According to D.M. Lamberton (quoted in Braman 2006), in 1976 information received its AEA classification and by 1984 at the latest questions in every AEA classification category were addressed from informational perspective. Yet, today much of the research is confined to various field journals and serious efforts to synthesize this field are few. Perhaps field journals, such as *Information Economics and Policy*, *Research Policy* and *Economics of Innovation and New Technology*, and general interest journals will help to get these strands of research together. Nevertheless, the way forward is from interaction to coherence and from coherence to general economic knowledge.

Besides the apparent fragmentation, the topics covered here overlap with studies in other sciences, such as philosophy, sociology, economic geography, psychology and management. Yet I believe that the economics of knowledge has an unquestionable niche in addressing these topics. Economics and economists have a comparative advantage in addressing the incentives and institutions in generation, dissemination and use of knowledge. This dissertation is far from the last word on the topic, but I see a potential for many interesting and relevant paths of research ahead for economists interested in studying the role of knowledge in social systems.

5 SUMMARY OF THE INCLUDED ESSAYS

The included essays in this dissertation study from different perspectives the main research agenda of the economics of knowledge: the role of knowledge in social systems and, particularly, the incentives in the generation, dissemination and use of knowledge. Essay 1 (Leppälä 2011a) concentrates on the dissemination part, i.e. knowledge transfers. In the literature the assumed difficulty behind dissemination of knowledge is motivated by tacitness of knowledge. The essay shows that the ambiguous assumption of tacit knowledge is far from necessary for motivating why and how some knowledge does and some doesn't become generally shared. Instead, we can give it an economic interpretation by referring to the incentives and institutions that affect knowledge transfers. It is argued from this perspective that the truthfulness of any information depends on capability, the likelihood that the informant's belief is true, and reliability, the likelihood that the informant reveals her belief sincerely. How to model capability and reliability in different markets creates interesting possibilities for subsequent research (Leppälä 2011b).

While the first essay is occupied with the dissemination of knowledge, Essay 2 (Leppälä 2011c) studies the generation of knowledge, more precisely research investments when knowledge is a public good. Due to non-rivalness of knowledge, the essay adopts a game theoretic discrete public goods framework to study how the other public good characteristic of knowledge, non-excludability, affects its provision. The first main result is that the creation of artificial excludability through intellectual property rights does not increase the social benefit, since the higher probability of provision is offset by duplicate research efforts if R&D cooperation is excluded. The both extremes are equally inefficient, whereas the optimal level of excludability lies in between them. With cooperation the optimal level of excludability is an interval as the level of excludability should be high enough to prevent free-riding but also low enough to prevent duplication of effort created through a patent race.

The price system is one of the key market mechanisms in the dissemination of knowledge and in the coordination of economic activity as was proposed by Hayek (1945). Essay 3 (Leppälä 2010) supplements Hayek's work on the informational role of prices with the same author's theory of the cognitive processes as these two have interesting connections. As for Hayek's cognitive theory, in contemporary cognitive and neurosciences it is considered, together with the work of Donald Hebb, as the precursor of connectionism (Edelman 1987; Fuster

1997; Başar & Karakaş 2006; Marsh 2010). From this inter-disciplinary perspective it is argued that the informational role of prices is not to convey the same knowledge to everyone, but each price is interpreted from the point of view of local knowledge. An improved articulation of the informational role also reveals to us where Austrian economics and the economics of information have talked past each other.

The role of spatial dimension in knowledge processes has received increased attention in recent years, especially in regional and urban economics and economic geography. Essay 4 (Leppälä & Desrochers 2010) points out that much work on both theoretical and empirical issues in regional agglomeration seems to lack proper microfoundations and that has led to some drawbacks. From the point of view of methodological individualism it is demonstrated that the law of comparative advantage or the local economies of scale and scope do not give support to policies targeting regional specialization. A highly important species of agglomeration economies results from localized knowledge spillovers. However, the empirical research on the topic is stuck in as much as the existence of knowledge spillovers is neither proven nor documented, which calls for research studying the actual knowledge dissemination at the individual level instead of regional aggregates.

Essay 5 (Desrochers & Leppälä 2011) tackles the aforementioned issue by studying the mechanisms inside the “Jacobs spillovers black box.” Through a qualitative survey on Canadian inventors it is studied how the required knowledge input for inventions was received and what role did the local economic diversity play in the process. The results suggest three main mechanisms behind knowledge spillovers: 1) by adding to, switching or adapting specific know-how to other lines of work; 2) by observing something in another line of work and incorporating it into one’s own line of work; and 3) through formal and informal multidisciplinary teams working towards the creation of new products and processes.

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ESSAY 1

Leppälä, Samuli

An epistemological perspective on knowledge transfers: From tacitness to capability and reliability. (*submitted to a journal*)

AN EPISTEMOLOGICAL PERSPECTIVE ON KNOWLEDGE TRANSFERS: FROM TACITNESS TO CAPABILITY AND RELIABILITY

Abstract
Various studies on knowledge transfers start from the premise that the greatest difficulty in the social sharing of knowledge results from the tacit quality of knowledge. Critics of this view, on the other hand, have pointed out that while the concept of tacit knowledge has become too vague, the current emphasis has also shifted attention away from codified or propositional knowledge. Here an attempt to fill this gap is made by studying the prerequisites for transferring propositional knowledge. Epistemological literature is utilized to demonstrate that the justification of testimony-based beliefs is of great importance. In this regard, two issues are highlighted: justification requires that the individual and the environment she is placed in are 1) capable of forming truthful and relevant beliefs, and 2) reliable in terms of communicating these beliefs to others. It is argued that these two issues, capability and reliability, are in many cases able to explain why knowledge transfers succeed or not. The ambiguity surrounding tacit knowledge seems to suggest that scholars have been implicitly aware of these issues, but the use of an incorrect term has, until now, prevented a clearly defined analysis.

Keywords: knowledge transfer, tacit knowledge, codified knowledge, capability, reliability.

1 INTRODUCTION

Increasing attention has been paid in various fields of social sciences to the importance of knowledge for the performance of individuals, firms and economies. Early studies in economics, following Arrow (1962), assumed that knowledge is a public good that once discovered comes to be known by everyone. However, more recently it has been acknowledged that the dissemination of knowledge, even in the world of modern information technologies, is far from automatic and all penetrating. The sharing of knowledge depends, among other things, on geographical, social and organizational factors. Hence, studying the actual processes of knowledge sharing and the circumstances conducive to it was taken as a relevant goal in itself.

These studies have been conducted in various academic fields and in different contexts. Economic geography, regional economics and related fields have studied the dissemination of knowledge within regions or cities (e.g. Glaeser et al. 1992; Feldman & Audretsch 1999). Management and organizational studies have studied dissemination within a firm or between subsidiaries (e.g. Nonaka & Takeuchi 1995; Argote & Ingram 2000). Dissemination across national borders has been confronted by international economics and international business studies (e.g. Coe & Helpman 1995; Bresman et al. 1999). Scholars from many other fields have participated in these discussions making them inherently multidisciplinary.

To describe the process of dissemination, scholars use concepts such as knowledge transfer, knowledge spillover and knowledge flow, although they may use them interchangeably and without providing definitions. The meaning of these concepts is thus not fixed and is far from universal. Nevertheless, what the gamut of concepts attempts to do is to describe the variety of ways in which knowledge is disseminated and exchanged between individuals.

Another observation is that the studies on knowledge transfers say little about knowledge itself or how it is actually transferred from one individual to another (Breschi & Lissoni 2001a; Hansen 2002; Brenner 2007). Why sharing knowledge is problematic in the first place is explained by referring to the tacit nature of knowledge. This tacit knowledge is understood as "knowledge embodied in many of the skills, capacities and dispositions that human actors routinely draw on without conscious reflection." (Faulkner & Runde 2004, 437). The present interest in tacit knowledge, however, has diverted attention away from explicit or propositional knowledge (Håkanson 2007).

The ambiguous use of the concept of tacit knowledge has predictably resulted in several criticisms (Cowan et al. 2000; Breschi & Lissoni 2001b; Brökel & Binder 2007; Perraton & Tarrant 2007). In their well-known paper Cowan et al. (2000) raised the issue that non-codified does not imply that the knowledge is impossible to codify. Rather, it could be that it remains uncodified simply because the cost of codification exceeds the benefits. In this paper we will take this argument further.

The central argument here will be that while knowledge transfer requires codification (or communication), it is not sufficient that "something" gets codified (or communicated). Clearly, it should be the case that what is transferred counts as knowledge and that the recipient is actually in the state of knowing after the transfer. Our attention is therefore directed at the epistemic value of transfer, and how it is connected to the epistemic and pragmatic goals that the individuals have.

The most basic epistemic goal is to acquire as many true beliefs as possible and as few false beliefs as possible (Fallis 2007). Hence, the point of departure is in propositional knowledge, which is defined as a justified true belief. Proceeding from this standard definition we attempt to scrutinize whether transferring propositional knowledge is indeed as unproblematic as assumed. Since knowledge transfer is an interpersonal phenomenon, insights provided by social epistemology[1] become relevant for the analysis. According to Arrow (1994), knowledge has an irremovable social component but can only be absorbed individually. Hence, while only individuals can know or learn, the production and sharing of knowledge are interpersonal. As Arrow (ibid.) argued, learning from other individuals can be either intended learning, through communication or education, or unintended by inferring the knowledge of others through the observation of their behaviour. Following Bandura (1977), this latter form can also be called "observational learning".

For the concept of tacit knowledge we will reserve its original meaning, i.e. knowledge that is impossible to articulate, due its procedural form, its inherent complexity or for other conceivable reasons. Besides complexity, tacitness is related to or overlaps with several other dimensions that may hinder the transfer of knowledge (see, Winter 1987). We, however, concentrate on situations where

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[1] Though social epistemology comes in many forms, the approach proposed here is Goldman's (1999) veristic social epistemology. The reason for this is that other approaches in social epistemology dismiss the relevance of truth for beliefs (because it is socially constructed, unattainable, or for some other reason).

there are no obstacles inherent to knowledge that prevent or complicate its transfer.

Furthermore, complexity might not be relevant only for the act of communication but also for understanding what is communicated. To highlight other relevant issues in knowledge transfers, it is assumed that communicating and understanding these propositions possesses no problem for the individuals, while in reality these issues are clearly important (Nightingale 1998). Lastly, while the study is made in terms of belief *expansion*, it should also be noted that the social sharing of knowledge can also operate through belief *revision*, in which communicated beliefs create further changes in the belief set (see Harman 1986, Ch. 6).

The main interest of this study lies in the epistemology of knowledge transfers, and hence in the justification of beliefs received through testimonies made by other individuals. If justification requires testimony-free evidence, our knowledge would be restricted to beliefs for which we have our own empirical evidence or that are otherwise in our area of expertise. Hence, it would seem important to consider other theories of justification that can be testimony-based. In reviewing these theories two issues stand out: First, the belief-generating mechanism should be capable of generating veristic and relevant beliefs. Secondly, the mechanism should be reliable in communicating veristic and relevant beliefs in terms of the incentives imposed by the social institutions.

These points imply that sharing propositional knowledge has difficulties of its own. Hence, the assumption of tacit knowledge is not necessary for motivating why knowledge transfers are problematic, even in this age of modern communication technologies. Many have also noted that the concept of tacit knowledge has become vague. It no longer refers to knowledge that is uncodifiable, as it originally did. This seems to imply that scholars are implicitly aware of these other equally relevant problems, but are referring to them with reference to an incorrect concept that obscures their proper analysis. Hence, fields interested in knowledge transfers could benefit from studying the capability and reliability of knowledge-generating mechanisms and their efficiency in both epistemic and economic terms.

The structure of the rest of the paper is the following. First, a few words are said about the framework which we use to study the phenomenon. Most importantly, we try to make explicit what is meant by knowledge in this context and how it differs from the usual approach taken in “knowledge transfer” literature. After that we go through a hypothetical knowledge transfer and highlight the important issues raised by our perspective. The most important difficulty in knowledge transfers seems to be the justification of testimony-based beliefs. This will be discussed in a separate section. After forming a clearer picture of the difficulties and prerequisites in transferring propositional knowledge, we reconsider the scope and necessity of the tacit knowledge assumption. In addition, the perspective is applied to some common examples of tacit and codified knowledge. The last section summarizes our discussion.

2 PROPOSITIONAL KNOWLEDGE

In the "knowledge transfer literature", knowledge, if it is defined, is usually described as a personal, subjective belief. For example, scholars in the field of knowledge management have usually followed Nonaka's (1994) and Huber's (1991) example by defining knowledge as "a justified personal belief that increases an individual's capacity to take effective action" (Alavi & Leidner 1999, 5). While traditional epistemology emphasizes the truthfulness of knowledge, in this context more importance is placed on the aspect of knowledge as a personal belief and its justification (Nonaka 1994, 15). This is because "[l]earning does not always lead to veridical knowledge", which should be taken into account when studying organizational learning (Huber 1991, 89). Moreover, knowledge management, among others, is usually interested in tacit or procedural knowledge "on which economic actors draw, but which is not of the propositional form to which predicates true or false might apply (knowledge that), but of the subconscious, tacit variety (knowledge how)" (Faulkner & Runde 2004, 425). Considerations of truth are explicitly left aside, and while justification of beliefs is occasionally mentioned its role and meaning is far from clear.

Here we consider knowledge as a justified true belief. This traditional definition was challenged by Gettier (1963), who showed that in some cases these three conditions were not sufficient for what we would intuitively regard as knowledge. Despite many attempts there is no consensus among philosophers as to how these conditions should be modified or which additional, fourth condition should be included (Dancy 1985). A general problem with the traditional definition, which the counterexamples highlight, is that while fulfilled, the three conditions can be completely independent. This is why, for example, Nozick (1981) proposed a subjunctive condition[2], which requires that there is a link between the belief and its veracity.

However, to quote Ancori et al. (2000), the point here is not to solve the debates of other disciplines, but to point out that the given epistemological theory will affect our understanding of the economic phenomena. The Gettier counterexamples showed that the traditional definition might not be sufficient for all

[2] If *p* were not true, S would not believe that *p*.

conceivable cases, but the implication was not that the definition has lost its relevance. Despite the counterexamples, the three conditions remain necessary.

In the context of economic phenomena likewise, justified true belief would seem a proper definition of knowledge. After all, mere accumulation of beliefs, whether they are true or false, hardly seems good in itself. In normal cases, the usefulness of beliefs is connected to their veracity. Hence, it would seem that, in general, we regard true beliefs to be ones that increase productivity, creativity or the well-being of individuals, and it is true beliefs that individuals are willing and eager to learn. In brief, our epistemic goals are to acquire as many true beliefs as possible and as few false beliefs as possible, and are fundamentally connected to our pragmatic goals.

One might oppose this by saying that; "isn't truth, as described by semantic realism, for example, something that is beyond the individual knower? If that is the case, why bother with such a condition after all?" However, this is exactly why we require a theory of justification. Only then can we assume that over the course of time people do have a greater tendency to acquire true beliefs and revise their belief sets to discard false ones. Otherwise having a true belief would be a mere accident and there would be no reason to assume that the composition of beliefs in terms of their quality (i.e. veracity) would improve over time.

An example of why justification is central to our discussion is given by Nozick (1981, 170). Suppose someone, who knows nothing about the matter, separately tells you and me contradictory things, which we both come to believe. By necessity, one of us has a true belief, yet few would claim that the person knows the fact. This implies that that the epistemic value of communication should not be taken as given and that more importance is to be placed on the justification of testimonial beliefs. Only then can we confidently speak of a *knowledge* transfer.

The issue that truthfulness cannot be directly assessed is not a reason to abandon the truth condition, but the very reason why it becomes of high importance. Assuming that all beliefs are necessarily true or disregarding the question of their veracity altogether[3] would severely hinder our understanding of the important characteristics of knowledge in a social world.

Within this context the reader is invited to plug in any theory of truth that she prefers, such as correspondence, minimalist or pragmatist theories of truth, since that is not expected to affect the analysis. What is considered of more importance

[3] Faulkner and Runde (2004, 424) argue that "If we set the standard for what counts as knowledge too high, we will exclude many of the beliefs that serve us very well. By the same token, if we set the standard too low we run the risk of including beliefs that verge on the plain false."

here are the different theories of justification, which are elaborated on later in this paper. While truth is a metaphysical-semantical concept, justification is inherently an epistemological concept and hence of our current interest.

3 KNOWLEDGE TRANSFER

Let us consider a basic case of knowledge transfer between two individuals: here we have an initial situation where Alice knows a proposition *p* that Bob does not. After some form of transfer they both know the proposition *p*. Of course, unlike most ‘goods’, knowledge is non-rival and after the transfer Alice does not have to give up her knowledge. However, without any form of telepathy the participants do not have any direct access to each others’ mental states. Codified knowledge is constituted by code or messages, codification being a process rather than a property (Saviotti 1998; Cowan 2001). Thus, the knowledge needs to be communicated, i.e. it is turned into some kind of information from which they are able to acquire and understand the proposition (Cohendet & Meyer-Krahmer 2001). This communication can be verbal, written, personal or impersonal.

It is, of course, necessary that the participants are first, able to understand and secondly, able to understand similarly the communicated information, so that after the message is sent they both know exactly the same thing. As Wilson (2002, 4) notes, “such messages do not carry ‘knowledge’, they constitute ‘information’, which a knowing mind may assimilate, understand, comprehend and incorporate into its own knowledge structures.” To be a source of knowledge and regarded as information, the recipient hence needs to able to understand the message. Nooteboom (e.g. 2000) has stressed that for this reason the cognitive distance between individuals cannot be too extensive. However, here we leave this issue aside and assume that the individuals have no trouble in similarly understanding the conveyed information. Cognitive proximity might, however, not only be relevant for comprehending the received information, but also for being able to form a justified opinion and therefore gain knowledge, as will be argued later. Belonging to the same “epistemic community” may therefore enhance the dissemination of knowledge in many ways (Lissoni 2001).

The veracity of a belief is in normal cases unchanged during its transfer. Only when the proposition refers to itself and its commonness can the truth value change[4]. However, it is assumed that while Alice knows the proposition *p*, Bob does not know that she knows. Hence, Alice can indicate that *p* but Bob does not know whether *p* is true. This assumption refers back to our earlier discussion

[4] For example, if Alice believes that Bob knows (does not know) what she thinks, can sharing this belief with Bob make it true (false).

about truth. While it has been noted that the difference between "knowledge" and "information" is of great importance (e.g. Ancori et al. 2000), our discussion emphasizes another important issue between the two: there is no necessary correspondence between a piece of information, the informant's belief and reality.

In the case of a knowledge transfer, Alice can communicate to Bob her belief that *p*. While the knowledge has to be articulable, i.e. not tacit, this also requires that the cost of communication (or codification) does not exceed the benefits (Cowan et al. 2000; Grimaldi & Torrisi 2001). Yet the mere act of communication is not enough for knowledge transfer. Apart from Alice's incentives, we should also consider Bob's epistemic goals for gaining true beliefs as he is not merely a passive recipient in the process. For Bob to gain knowledge, it is required that he, in the first place, forms the corresponding belief by accepting the proposition as true.

Usually, in order for Bob to believe that this is indeed what Alice believes herself, he needs to believe that Alice is sincere in sending this message. Otherwise Bob would not have any reason to assume that even Alice believes what she is communicating. Believing that Alice believes that *p* is not sufficient in itself for Bob to adopt the same belief. Bob would also need to believe that Alice's belief is correct. Otherwise, again, this would be a reason for Bob not to adopt the belief. This might require, at a minimum, that Bob does not have any other beliefs that would immediately contradict *p*. Hence, what is initially believed by Bob is important. Of course, the information might also cause Bob to change his mind.

Suppose then that for one reason or another (or for no particular reason, for that matter!) Bob accepts the proposition. When Bob comes to believe that *p*, he has now acquired a new belief that, as was assumed in the beginning, is true. Would we still be ready to claim that Bob now knows that *p*? If we do not give any consideration to the reason that could make his acceptance justified there is no reason why, in general, Bob would come to believe propositions that are true. Thus he could be accumulating false beliefs as well. While false beliefs are always a possibility, there should nevertheless be a tendency towards having true beliefs. Hence, in order to know something Bob, and not only Alice, should have a justified belief that *p*.

As was assumed in the beginning, Alice's belief is justified. But does this also justify Bob's belief? What if Bob believes, correctly, that while he cannot provide any justification for *p*, Alice can? Maybe it is too much to require that everything we can know needs to be in our area of expertise? After all, in many instances we do rely on specialists who know the specific domain better than we do. Be that as it may, it implies that justification requires additional beliefs that allow for direct or indirect justification. Thus, while under certain conditions a testimony can produce a justification, it cannot convey Alice's justification to

Bob (Audi 1998, 136). Next we will review some central theories of justification and consider their implications for the justification of testimony-based beliefs.

4 JUSTIFICATION OF TESTIMONY-BASED BELIEFS

In epistemology, ‘testimony’ is considered as a source of beliefs and knowledge, which is different from other sources, such as perception or introspection. Despite its name, testimony can refer to a very broad set of activities of conveying some information to someone. While the psychology of testimony can be relatively simple, since we might accept what others claim without any further consideration, the epistemology of justification is more complex, since this process yields knowledge and justification only when certain conditions are met (Audi 1998, 140).

The question then becomes: what justifies a testimony-based belief? With testimony-based belief we refer to a belief reported by another person (or an institution), in contrast to self-acquired beliefs such as those acquired through the senses or inference. If justification requires testimony-free evidence, then there are two main routes ahead of us: foundational and coherence theories of justification.

Foundationalism divides beliefs into two castes: foundational (or basic) beliefs that require no justification and non-foundational (or non-basic) beliefs that acquire their justification from the former. Foundational beliefs are usually thought to concern “one’s own sensory states” (Dancy 1985, 66). Such justification, however, cannot be transferred. A transferred belief about Alice’s sensory states is not foundational for Bob. Hence, a foundationalist theory of justification would require that Bob already has or will later acquire his own empirical justification for what Alice had told him before he actually has a justified belief.

Coherentism, rather than pursuing linear justification, takes a holistic view of justification. According to it, a belief is justified if it is a member of a coherent belief set, where coherence is a matter of how well beliefs “fit together, agree, or dovetail with each other” (BonJour 1985, 93). Therefore, according to positive[5] coherentism, a new belief is justified if it increases the overall coherence of an individual’s belief set (Dancy 1985). In this view, the justification of the proposition put forward by Alice does not depend on any one belief possessed by Bob but on his belief set as a whole. No specific importance is given to Bob’s sensory states, only to the extent that they most likely have a major role in the overall

[5] This is to distinguish it from negative coherentism, as elaborated on later.

quantity of beliefs and the coherence of the set therefore. Both theories of justification imply that the transfer of knowledge is greatly dependent on the recipient's previous beliefs, hence restricting the scope of knowledge transfer to such propositions for which the recipient has empirical evidence himself (in the case of foundationalism), or which are so intimately related to his overall beliefs that they improve their coherence. Similarly, if verifiability of information is required, as it is sometimes in the economics of information literature (e.g. Bull & Watson 2004), knowledge transfers would be limited to the domain of knowledge that the receiver is personally able to verify.

Much of our knowledge would quickly count as nothing more than ill-supported prejudice, however, if those justifications which depend on communication were outlawed (Faulkner 2000). While a reductionist or inductionist approach would require that all trust in testimony is based on testimony-free evidence, Goldman (1999, 126–130) considers the possibility of testimony-based belief being justified by another testimony-based belief. He indentifies four non-reductionist approaches which could serve this purpose.

- *Testimonial foundationalism*. According to this position supporting, non-testimonial evidence is not required. Something that is presented as true should be accepted unless there is a reason not to. Individuals should grant epistemic authority to others and not just themselves.
- *Negative coherentism*. This view proposes that one should accept a new belief if there is no special reason to doubt it (Harman 1986, 29). In contrast to 'positive' coherentism, it is not required that the belief increases overall coherence, only that it does not decrease it. Hence, it provides justification also for beliefs that are not (closely) connected to other beliefs that one already has.
- *Proper functionalism*. According to Alvin Plantinga's (1993) theory, justification comes from a faculty that functions properly in an appropriate environment. Hence, belief-forming process should be designed in such a way that it is successfully aimed at truth.
- *Reliabilism*. According to this theory, proposed by Goldman (e.g. 1986), justification requires a belief-forming process that is reliable. In the case of testimonial belief this means that the speaker and environment she is placed in are such that the testimonies are generally true.

Of these theories, testimonial foundationalism sounds too naïve. While it allows for the wide acceptance of new beliefs, it does little to restrict the adoption of false beliefs. As Faulkner (2000) argues, there is a great difference between testimonies made by others and beliefs received by our own perception and memory, since the former depend on intentions. Testimonial foundationalism would hence be an easy target for manipulation and abuse. In addition, it would seem that with this approach there remains no difference between any accepted belief and a justified belief; if one is ready to accept a belief that he has no reason to doubt then one is automatically justified in accepting the belief. While trust could be necessary for believing, taking it as sufficient for justification is questionable. After all, we might trust others with no good reason or even trust them when there is a reason not to.

Similarly, negative coherence would allow for the effective dissemination of knowledge. Yet, as in the case of testimonial foundationalism, one would accept any belief for which there is no countering evidence. Beliefs outside one's domain of expertise would rarely decrease the coherence of the belief set and would thus be accepted at the face value. Hence, rather than justifications, testimonial foundationalism and negative coheretism seem more like filter mechanisms, prerequisites for acceptance. Accepting new beliefs is, however, usually connected to trust between individuals. Since 'trust' by itself reveals little about what is required to justify an accepted belief, it could be beneficial to analyze the phenomenon in the light of the last two theories.

Proper functionalism discusses the capability of a system/individual/faculty to generate true beliefs, while reliabilism[6] is connected to the incentives of the individual to communicate beliefs sincerely. Hence, we could analyze knowledge creating mechanisms in a given domain in terms of their capability and reliability[7]. These both refer, not only to the speaker, but also to the existing social institutions.

4.1 Capability; or "Could she actually know it?"

In the first place, knowledge cannot be transferred unless the speaker knows the fact. The conveyed information may correspond to the belief that Alice has. However, unless that belief is true, Bob cannot receive knowledge from Alice. Thus, for Bob's belief to be justified, he should have some justification, a reason to assume that Alice is in a position to know the fact. We label this dimension capability, which refers to the likelihood that the sender or speaker is likely to know a fact of a particular kind.

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[6] Note that reliability in Goldman's terminology has a wider meaning than in ours as it also seems to include capability.

[7] A similar classification is made by Audi (1998, 136), who argues that the justification of testimonial beliefs depends on the speaker's credibility, which consists of two dimensions: sincerity and competence.

Capability requires that Alice has expertise in a specific area (such as retailing or economics) and that she is placed in such contexts where she receives constant feedback from her peers (she is an active entrepreneur or is integrated into a scientific community, for example). Harper (1996), for example, portrays the market as a learning environment, where entrepreneurs' beliefs are constantly communicated, acquired, tested and improved. An equally important part of capability, besides having a particular fact right, is the likelihood that the individual is aware of the relevant facts concerning the issue.

Besides the personal capabilities of the speaker, the social environment is important as well, because truth seeking mechanisms do not only rely on individual capabilities but also on a collective effort within a group or community. Recent studies in collective problem-solving have stressed the importance of diversity in terms of background knowledge and problem-solving methods among members of a group. For example, Hong and Page (2001) demonstrated that a collection of diverse agents with limited ability can locate optimal solutions to complex problems. It is easily conceivable that an additional member in a group increases its problem-solving capacity, but additional solutions are possible only when the perspectives of those people differ. Hence, cognitive diversity seems to be a valuable capability-increasing property (see also, Heath 2007)[8].

4.2 Reliability; or "Is that what she truly believes?"

Reliability is the other side of the justification of testimonial beliefs. Likewise it is necessary that the speaker knows the fact in the first place, a knowledge transfer requires that the information that is conveyed corresponds to this true belief. Reliability, therefore, requires that Alice is not only capable of generating true beliefs, but that she will also report her findings truthfully. This depends largely on the environment she is placed in. Such institutional factors have been studied in the mechanism design literature, where the "revelation principle" considers such mechanisms in which the individuals have the incentive to reveal their private knowledge (usually about their "type") sincerely (e.g. Dasgupta et al. 1979).

Reliability might provide another reason for why many (e.g. Nooteboom 2000) have noted that a necessary and initial condition for knowledge transfer is trust. The important issue in terms of reliability is the incentives that the agents have relative to their pragmatic and epistemic goals (Crawford & Sobel 1982; Farrell & Rabin 1996). Thus, the environment needs to have institutions that,

[8] Budzinski (2008) is a recent statement on the benefits of diversity for scientific and economic progress.

together with Alice's preferences provide her with incentives that will make her act truthfully. As Faulkner (2000) notes, testimonies are made because of certain intentions. Hence, to evaluate these intentions, we need to understand the institutional environment that has provided incentives for such testimonies. Research on such institutions has been conducted within the contexts of, for example, scientific community (e.g. Zamora Bonilla 2002; Mäki 2005) and forensic science (e.g. Koppl 2005).

The implications for the studying of knowledge transfer are that researchers in various fields could try to identify what the crucial functional and reliable mechanisms in producing beliefs in the context being studied are. Both reliability and capability must be fulfilled before knowledge can be transferred. Without any assurance that first, the sender has a true belief about a fact, and secondly, that the sent information corresponds to this belief, the requirements for knowledge can only be met by chance. Hence, the link between pragmatic and epistemic goals makes it equally well a matter of epistemic as well as economic efficiency (see, also, Hands 2001, Ch. 8). Epistemic efficiency means that the belief-generating mechanism is capable and reliable in terms of generating and transferring veristic and relevant information. Economic efficiency, in this context, means that such veristic value is produced by the most economical means available. This could provide a suitable framework for analyzing the dissemination of knowledge in various contexts and domains, such as firms, public institutions (e.g. universities, hospitals), urban or regional contexts or in other specialized fields.

5 TACIT KNOWLEDGE AND THE DIFFICULTY OF TRANSFERRING KNOWLEDGE

This study aims to show that there are many inherent difficulties in conveying propositional knowledge. Especially when taking justification as an integral property of knowledge shows us that knowledge transfer has to encompass many difficulties not examined in the "knowledge transfer" literature. In contrast, it is commonplace in the literature to explain that the inherent difficulty in the dissemination of knowledge, despite modern communication technologies, is the tacitness of knowledge. Common assertions are, for example, that on one hand, tacit knowledge, being difficult to imitate, holds the potential for a sustained competitive advantage (Barney 1991) and, on the other hand, geographical proximity still matters because tacit knowledge spreads only locally (Audretsch 2003).

Polanyi's (1958) and Ryle's (1949) seminal writings have undoubtedly provided us with much understanding about human knowledge. Many critics have however pointed out that their seminal insights have been, to some extent, misrepresented (Cowan et al. 2000; Breschi & Lissoni 2001b; Brökel & Binder 2007; Perraton & Tarrant 2007). For example, is tacit knowledge uncodifiable in principle or is it simply difficult to codify (Brökel & Binder 2007, 153–154)[9]? The ambiguity surrounding the tacitness of knowledge has made some suggest that the concept has become too stretched (Breschi & Lissoni 2001b), while for others it implies that the concept was originally too limited (Gertler 2003). Wilson (2002) stresses that Polanyi's famous idea, "we know more than we can tell", implies that tacit knowledge is not only hard to convey through verbal exchange but indeed impossible. This original meaning of tacit knowledge is undoubtedly very useful (Nightingale 2003; Balconi et al. 2007), albeit much more limited than its current use. The contemporary, less dogmatic use of "tacit knowledge" suggests, rightly, that there are many other difficulties involved for which an incorrect concept has been used to capture them.

Tacit knowledge usually refers to know-how or skills connected to performing certain tasks or to habits or used in decision-making (Balconi 2002). While these

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[9] Perraton and Tarrant (2007, 354) make an even stronger case by saying that "the concept of tacit knowledge is merely a term given to a phenomenon that the observer does not understand; as such, it has no explanatory content."

are undoubtedly important issues in individual or organizational competence, it is hard to see why they would cover everything[10]. Maybe this is due to the assumption that; if they are not tacit, then knowledge becomes almost automatically shared and, hence, possesses no reason for an inquiry. For example, Bresman et al. (1999, 446) argue that "articulated knowledge such as that found in patents or blueprints is likely to be quite straightforward to transfer between acquirer and acquired units". However, technical ease does not itself imply that all relevant information will be transferred and that all that is transferred can be considered reliable. While in some cases there might be plenty of information available, knowing what is needed, finding it and evaluating it is no less of a problem.

Not only is some part of our knowledge uncodifiable, but codifiable knowledge is difficult to convey or to have conveyed to oneself. As Cowan et al. (2000, 228) note, there are other possible reasons besides mere unarticulability which can provide reasons for why a piece of knowledge remains unvoiced. The cost of codification may exceed the benefits, and therefore the knowledge may remain unvoiced. However, in a vast variety of cases "talk is cheap" and the codification cost is itself not an issue, and yet the informativeness of the communication depends on how closely related the individuals' goals are (Crawford & Sobel 1982; Farrell & Rabin 1996; Dewatripont & Tirole 2005). Recursively, when there is a collision of interest, *costly* signalling (Spence 1973) might be more reliable than any free means of communication. Besides signalling, the verifiability of information is recognized in the economics of information to enhance the reliability of communication (Chakraborty & Harbaugh 2010). As argued earlier, however, verifiability, if required, limits the domain of transferable knowledge.

"We tell less than we know", "we tell things that we don't believe", "we don't know what to believe", "we don't believe what we are told", and "we don't know what to tell" illustrate issues that lurk behind why some have access to knowledge to which others do not. They are equally relevant as to why, in principle, only some part of our knowledge can be made available to others. Unlike tacit knowledge, the former questions do not refer to the unarticulable property of knowledge, but to the personal incentives in and the environment of communication and knowledge dissemination.

By getting a better grasp why knowledge is hard to transfer we also gain deeper understanding of why some circumstances facilitate those transfers. The epistemological basis of knowledge transfer, such as the justification of testimony-based beliefs, would seem promising for explaining why some regional, institutional or organizational structures are (un)able to promote knowledge transfers.

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[10] Perraton and Tarrant (2007) give some examples of such strong positions.

In addition to receiving new answers we could a gain better understanding of the old ones, such as why indeed face-to-face interaction, cognitive proximity or the familiarity of the environment matters in some contexts. Here, the concept of "absorptive capacity" (Cohen & Levinthal 1990) might not only be important for the assimilation of new information, but also for evaluating it.

6 SOME EXAMPLES

Lastly some examples of how the capability-reliability view of justification can be used to analyze knowledge transfers are presented. It is not argued that everything dubbed as tacit knowledge can be presented as codified, propositional knowledge. However, in many cases it would seem that our framework yields a deeper, or at least an alternative, understanding of the phenomenon. Hence, in many cases where researchers have previously referred to tacitness it would seem that the difficulties are related to capability or reliability, or both. Similarly, when a transfer is considered unproblematic it is not due to codifiability per se, but the fulfilment of these properties.

6.1 Inter-firm knowledge transfers and economic geography

Economic geography, especially so-called new industrial geography (NIG), studies regional economic performance and increasingly takes spillovers of technical knowledge between different firms as an integral contributor to economic performance (see, Beaudry & Schiffauerova 2009). Within NIG, tacit knowledge has received a sympathetic audience, because, in spite of modern computer and telecommunication technologies, one can argue that distance matters nevertheless. Due to tacit knowledge, spillovers are geographically-bounded and the location of a firm becomes (or remains) important.

Is tacit knowledge, however, necessary for this position? Even if firms could easily convey their technological knowledge, would they? When considering rival firms this does not seem likely in most cases. While modern information technology might facilitate communication of at least some technological knowledge (Steinmueller 2000), it is far from clear that firms would do so. Costs and benefits are important for codification (Cowan et al. 2000; Grimaldi & Torrisi 2001), but this does not necessarily guarantee its truthfulness. The mere act of codification does not imply to the recipient that the information is reliable. While information technology might lower the cost of codification (Cohendet & Steinmueller 2000), incentives for transferring knowledge and reporting sincerely depend on other things as well. In fact, Carlaw et al. (2006) point out that while information technology has made access to information easy, the trustworthiness of the content is low. Hence, face-to-face communication might not be relevant due to its tacitness, but for the reason that it makes it much easier to judge whether the person knows what she is talking about (capability) and if she is sincere (reliability).

Rivalness among firms, and hence conflict in terms of their pragmatic goals, does not always imply that the firms have no incentive to disclose their knowledge (Hirshleifer 1971; Pénin 2007). Competing firms might nevertheless have common epistemic goals depending on the type of the knowledge in question (see, Stein 2008). These considerations might have further implications for the debate on diverse vs. specialized regions (e.g. Glaeser et al. 1992), which has been a key area of interest in the geography of innovation for some time. Reliability of communication and the success of interaction might be different when firms belong to the same or different industry. Diverse and specialized regions might hence perform differently in their capability and reliability to transfer knowledge.

In spatial proximity firms might have others sources for gaining knowledge from others, which are important not because the knowledge is tacit, as is usually assumed, but because such means can be more reliable, or because spatial proximity might increase the firms' capabilities to produce useful technologies, and because they can learn from the other firms and use them to benchmark their own ability. Labour mobility, for example, might be an important knowledge transfer mechanism for the fact that hiring people makes them more likely to disclose relevant and valuable information (Audretsch & Keilbach 2005). And, as said, direct (i.e. face-to-face) and repeated contact might be needed for knowledge transfer, not because of tacitness (Audretsch 2003; Edler et al. 2011), but because it facilitates justification. Repeated communication builds reputation (Lichtenthaler & Ernst 2007), two-way communication creates trust, and they both enhance knowledge transfers through increasing the perceived truthworthiness of information. Hence, the locality of knowledge transfers in many situations.

6.2 Intra-firm knowledge transfers and organizational and management sciences

As a field within organizational and management sciences, knowledge management, has received some criticism for claiming to be able to manage a resource that is at the same time described as largely unmanageable (Alvesson & Kärreman 2001). In contrast to NIG, the interest lies in knowledge transfers within a firm and how a hierarchy can ease the transfer of tacit knowledge (e.g. Kogut & Zander 1992). It is easy to conceive that intra-firm communication is crucial for a firm's performance. However, to explain why this might be problematic research has often invoked tacit knowledge by explaining that the knowledge to be disseminated concerns skills, rules or habits.

Skills arguably fit very well into the usual description of tacit knowledge. Learning a skill though, can be facilitated by written instructions, as the existence of numerous guide books seems to attest. Yet many skills are highly complicated and require practice and guidance. Hence, a master-apprentice relationship might be needed, which also needs to satisfy the conditions of capability and reliability.

A firm will often require a division of labour, in which different but complementary skills are required. Learning what others know would undermine the gains made from specialized learning, and thus direction substitutes for the transfer of such knowledge (Demsetz 1988). Therefore, more important than teaching the same skill to everyone is the establishment of complementarity. This goes back to the (now) old issue in labour economics; the difficulty of assessing human capital. Only the prospective employee knows the skills he has, but anyone could claim to have them, which makes testimonies unreliable. One can attempt to solve the problem through job market signalling (Spence 1973). First there needs to be a signal, for example, a university degree or past work experience which is sufficiently correlated with the skill sought, and is thus capable of signalling the competence. Secondly, the signal must be reliable, so that the employer can trust in its veracity.

Finally, gathering knowledge of the market environment would seem crucial for a firm's success. While that kind of knowledge is largely codifiable, it possesses no less of a problem for a firm. The structure of a firm should be designed in ways that facilitate the production of veristic and relevant knowledge, on the one hand, and guarantee its reliable transfer to the right people, on the other. Similarly, the reason why hierarchy facilitates knowledge transfer (Kogut & Zander 1992) might have more to do with common epistemic goals and reliability than tacitness. Communication is simply more reliable when the parties have common interests.

Effective communication and knowledge transfers within an organization depend on the extent to which individuals share the same epistemic goals and how they attempt to reach these common epistemic goals. In the case of groups there are additional conflicts that can arise regarding these goals, particularly with reference to conflicting pragmatic goals (see, Fallis 2007). In particular, it is important that the relevant parties within a firm are informed of important changes. Yet, that goal might not be reached for reasons other than the cost of communication. There might be, for example, a problem of biased communication, when bad news or conflicting views are kept secret. This in turn can lead to information cascades and hamper the reliability of communication altogether. Organizational structure hence affects how managers acquire, transfers and use knowledge (Dessein 2002; Persico 2004; Alonso et al. 2008).

6.3 Economy-wide knowledge transfers and the Austrian school of economics

Tacit knowledge has achieved a prominent standing in the Austrian school of economics (Runde 2002), especially among more recent writers on the role of the price system in overcoming the “knowledge problem”. Hayek (1945) argued that through the price system the market is able to utilize knowledge not given to anyone in its totality. Later writers on the subject (e.g. Lavoie 1995; O’Driscoll & Rizzo 1985) have stressed that a centrally planned economy cannot achieve the same result, not only because there is too much knowledge to be collected, but because much of that knowledge cannot be collected due to its tacit, inarticulable nature.

The preferability of alternative commodities or the alternative use of production goods is not tacit knowledge in the sense that it would be impossible to articulate, however. For example, consumers and producers can announce their reservation prices in a given situation. From the capability point of view, however, it would be impossible for any single individual to keep a list of all the reservation prices in all possible situations. In the market economy this is not required, since beliefs concerning the weighting of different options are needed only on situational basis[11]. Therefore the capability to form these beliefs is less of a problem.

Furthermore, even if some particular reservation prices can be articulated to the central planner, the problem of reliability still exists. Environmental economics has used contingent valuation techniques for the valuation of non-market resources. The reliability of survey answers is, however, suspect when one does not have to commit to their announcements, which is unlike the activity in market exchanges. While a treatment of the issues that elaborates on them more is needed, the above would seem to suggest that capability and reliability issues in propositional knowledge can provide clearer insights, insights which are more in accordance with the Austrian School of economics, than mere references to tacitness.

A distinctive feature of the Austrian school is that unlike the information theoretic approach of mainstream economics it does not assume that all the infor-

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[11] And according to Harman’s (1986) clutter avoidance principle one should also avoid holding unnecessary beliefs.

mation and beliefs that economic agents possess are necessarily true (Runde 2002). However, to better appreciate this distinction, and the important implications it carries, the Austrian school would possibly improve its explanatory power by studying how agents separate between true and false, rather than by merely referring to tacit knowledge for which such categories are said not to apply. Sunstein's (2006) work on how deliberating groups often converge on falsehood rather than truth and why they are outperformed by prediction markets takes an important step in this direction.

6.4 Codified knowledge and the ease of transferring

Some types of knowledge are considered easier to transfer and this is attributed to their codifiability. Yet the ease of transferring might have less to do with the type of knowledge than with the circumstances. The mere possibility of codification is not enough if the testimonies lack justification.

Examples of easily transferable information include, among others, blueprints, patents, and financial data. But these constitute knowledge only when the recipient can rely on the informant being capable of generating veristic beliefs and can be considered to be reliable in communicating them forward. Hence, the ease of the transfer of a piece of knowledge comes less from the nature of the knowledge than from the existing institutions. Furthermore, difficulties concerning international knowledge transfers are, in part, explained by unfamiliarity with or the lack of proper institutions that facilitate the transfer, rather than by tacitness of knowledge (Martin & Salomon 2003).

An example of an attempt to solve knowledge transfer difficulties and create an institution that facilitates the transfer of knowledge is the International Standards Organization's ISO 9000 standards. The International Standards Organization can be said to be an organization which allows the tacit knowledge of a product's quality to be codified (Bénézech et al. 2001). Knowledge about a product or service's quality is then codifiable, but this in itself is not enough. After all, producers can and do inform customers about product quality. The usefulness of ISO 9000, or any such testimonies, comes from whether the standard is capable of capturing the quality that customers require, and if the ISO 9000 certificate is regarded as reliable in each case. In a more general way, the veracity aspect of information can explain why some knowledge transfers require (independent) intermediaries (e.g. Yusuf 2008; Li 2010).

7 CONCLUSION

The purpose of this study was to show that transfers of propositional knowledge have many difficulties of their own. Hence tacit knowledge, while not without use in its original meaning, should not be viewed as a necessary assumption in motivating the problem of the social sharing of knowledge. As many scholars have noted, one problem in communicating knowledge is the issue of understanding. We however, set this issue aside by concentrating on what is required for knowledge, defined as a justified true belief, to be transferred between individuals.

In a knowledge transfer case, it is first required that the recipient comes to believe the communicated proposition. This requires that the recipient has trust in the sender and has no reason to oppose the proposition. Furthermore, if we consider the transfer of knowledge, and not only a belief, the recipient also has to be able to justify the newly acquired proposition. However, according to the reductionist view, the justification itself should be testimony-free. This would require that the recipient has such familiarity with the subject that his other testimony-free beliefs support it.

Reviewing testimony-based theories of justification two central issues were highlighted: capability and reliability. The capability of a belief-generating individual or community should be such that it can produce relevant and veristic beliefs. In addition, the incentives imposed by the institutional environment should be such that reporting those beliefs can be considered reliable. Since tacit knowledge can be and has been used in other ways than its original form, knowledge that cannot be articulated, this seems to indicate that scholars are at least implicitly aware of these other difficulties in transferring knowledge. This however, forces us to conclude that the use of an incorrect concept has contributed to this negligence. It is proposed that the knowledge transfer studies conducted in many different fields could benefit from studying the mechanisms that bring epistemic value and their economic efficiency in delivering it.

Perhaps it is the sometimes assumed symmetry between knowledge and information that some scholars find objectionable. After all, if knowing implies having certain information, which again implies knowing, then, in this information technology era, having knowledge of particular facts would have little explanatory relevance since they would be immediately shared with others. Maybe that is why some scholars argue that knowing does not imply information because tacit knowledge cannot be codified or because, for some knowledge, it does not pay to codify it. However, as has been argued here, neither does having a piece of information imply knowing a fact.

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ESSAY 2

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Knowledge as a public good: The optimal level of excludability. (*submitted to a journal*)

KNOWLEDGE AS A PUBLIC GOOD: THE OPTIMAL LEVEL OF EXCLUDABILITY

Abstract: Scientific and technical knowledge is a typical example of a public good. The standard argument in the literature is that the departure from perfect competition is dependent on the degree of excludability. Adopting a game-theoretic analysis of discrete public goods it is shown that pure excludability and pure non-excludability are equally inefficient, whereas the optimal level of excludability is a function of the benefits and costs of the knowledge investment and lies in between the two extremes. With the possibility of R&D cooperation the relative performance of the extremes varies and the optimal level of excludability becomes an interval, typically in between the extremes. These results suggest major challenges for the intellectual property law.

JEL classifications: O31, H41, O34, D70, D62.

Keywords: knowledge, public goods, positive externalities, scientific research, excludability, intellectual property rights.

1 INTRODUCTION

Beginning with Henry Sidgwick and A.C. Pigou[12], scientific and technical knowledge has been considered as a typical case of a public good, a source of positive externalities that the market cannot efficiently provide. Although knowledge is arguably purely non-rival, some have argued that its non-excludability is less than perfect. Non-rivalness implies that everyone can, in principle, benefit from knowledge once generated. In practice, pure non-excludability implies that everyone receives the non-rival benefit for free once the investment is made, and with pure excludability the rights' holder is able to collect all the social benefit. As a consequence, it is commonly accepted that the problem of efficient provision depends on the degree of excludability and unless knowledge is naturally excludable it is argued that excludability should be created by intellectual property rights (IPR).

The main purpose of this paper is to study what is the optimal level of excludability for purely non-rival knowledge. This will be done within a game-theoretic framework of a discrete public good provision. Our first result is that the two extremes, the pure non-excludability and pure excludability of knowledge, are equally inefficient when there is no possibility for R&D cooperation. Our key finding is the optimal level of excludability, which as a function of the benefits and costs of the R&D investment lies in between the two extremes. Next we study the situation where there is also the possibility to participate in a joint R&D investment. In this case the relative desirability of pure excludability and pure non-excludability varies and the optimal level of excludability becomes an interval, again, typically in between the extremes. As the optimal level of excludability depends on the characteristics of the particular knowledge industry and the suboptimal levels of excludability create large inefficiency, these results suggest major challenges for the intellectual property law. In a similar vein, since the optimal level can be close to pure excludability in some cases and close to pure non-excludability in others, this finding helps us to explain the continuing controversy regarding the desirability of intellectual property rights.

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[12] See Medema (2009) for a discussion of externalities and public goods in the history of economic thought.

The starting point for this study is to combine the two strands of literature on scientific and technical knowledge and on public goods[13]. It is fair to say that these literatures are vast and include various specific topics and perspectives, which have forced us to be very selective. For the purpose of this paper, the most important studies regarding knowledge are those that discuss its special nature and those that discuss the importance of excludability and IPR. Regarding public goods literature our main interest lies in the private provision of *discrete* public goods (Palfrey & Rosenthal 1984; Dixit & Olson 2000). Lastly, this study provides some support for the newly emerged literature that impugns the need for IPR (e.g. Boldrin & Levine 2002, Boldrin & Levine 2008b; Bessen & Maskin 2009).

The paper has the following plan: The next section will review the traditional debate on scientific and technological knowledge and the more contemporary debate on excludability and intellectual property rights. This is not intended merely as an extensive literature review, but as something which will give us a firm understanding of the nature of the problem. We will argue that non-rivalry, which has not received much attention, implies that knowledge is, in fact, a discrete public good and that game theoretic analysis in this framework seems worthwhile. The third section presents the actual model which we use to compare, in the framework of the Coase theorem, the cases of the pure non-excludability and the pure excludability of knowledge. We first show that without cooperation the two extremes are equally inefficient in terms of social welfare and present the optimal level of excludability as a function of the benefits and costs of the R&D investment. Next we introduce the possibility of R&D cooperation to the model. The analysis of the pure non-excludability case with cooperation uses the model developed by Dixit and Olson (2000) as a starting point. We compare its results to a similar model with IPR. Here the relative performance between the extremes varies and the optimal level of excludability is established as an interval depending, again, on the cost and benefits of the particular knowledge in question. The last section summarizes our results and discusses some caveats as well as possibilities for subsequent research.

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[13] Surprisingly, while the connection is quite straightforward, it is not well established in the literature. d'Aspremont et al. (1998) resembles our study but their perspective is very different nevertheless.

2 KNOWLEDGE AS A PUBLIC GOOD

Throughout this study "knowledge" will refer to scientific and technical knowledge, even though the issues discussed here apply, in various degrees, to other types of knowledge as well. Nevertheless, this type of knowledge most clearly exemplifies the characteristics of a pure public good, and it is also in this case that the efficient allocation of resources has been argued to be a problem. For example, other types of knowledge may be gained without any particular investment. Furthermore, the discussion on the importance of excludability and intellectual property rights has been mainly conducted in this context.

Fritz Machlup was among the first to analyze knowledge as an economic resource. According to Machlup (1962, 29–30), knowledge can be viewed as a consumption good, an intermediate good, or an investment. Education and scientific research produce knowledge that can be regarded as investment, different forms of art can be regarded as consumption goods, and knowledge produced by market research or financial analysis can, for example, be regarded as an intermediate good.

Most goods are rival in the sense that they can be used or possessed by only one person at a time. Clearly knowledge is non-rival in the sense that me knowing a fact does not prevent you knowing the same thing. Yet there are further dimensions of non-rivalness in the case of knowledge (Foray 2004, 94). While knowledge can be used simultaneously by an infinite number of individuals, it can also be used in perpetuity without additional cost. In comparison, tangible goods can be consumed by one individual only and are many times exhausted in the process. Also intangible goods (i.e. services) are either exhausted immediately or, at least, can only be provided continuously for a limited amount of individuals at the same cost. Knowledge is unique in the sense that these restrictions do not apply to it.

Another characteristic of knowledge and public goods in general is their non-excludability. This means that it is difficult and costly, if not impossible, to exclude others from using the good. Non-excludability would obviously be a serious problem for rival goods; hence the importance of property rights. But, similarly, it has been argued that non-excludability hampers the efficient provision of non-rival goods, such as knowledge. Having non-excludability after the creation of knowledge is the first-best situation, but it is also deemed unreachable. "If information is not property, the incentives to create it will be lacking. Patents and copyrights are social innovations designed to create artificial scarcities where none exist naturally… These scarcities are intended to create the needed incentives for acquiring information" (Arrow 1996, 125).

Arrow (1962) explains that the non-excludability of knowledge comes from two sources. First, people are able to infer what is known by others by observing their actions. For example, through reverse engineering competing firms are able to copy the technology developed by their rivals. Secondly, while individuals can keep secrets, once revealed, the knowledge is beyond their control[14].

This first mechanism, described by Arrow, is nowadays referred to as knowledge spillovers (see, De Bondt 1997, for an overview). This means that R&D activities create positive externalities since the discoveries come to the attention of others without compensation for the innovator. Besides observing and replicating the products or processes of others, knowledge can also spillover through other channels, such as labor mobility (Audretsch & Keilback 2005)[15].

2.1 Traditional Pigouvian framework of positive externalities

Arthur Pigou (1920) developed Marshall's ideas of external economies further and argued that negative and positive externalities create market failure. Positive externalities were argued to create harmful inefficiencies because when social benefits are above private benefits the market underinvests in the particular good[16].

Nelson (1959) demonstrated that basic scientific research can be analyzed in this familiar Pigouvian framework of welfare economics. In the case of R&D investments, the positive externalities are created by knowledge spillovers. Figure 1 illustrates such a case and presents a situation where the social benefits are above the private benefit. Therefore, the market cannot provide the good efficiently, since the individual decision maker will only produce the good to the amount of Q', where the marginal private benefits (MPB) and costs (MC) are equal. Taking into account the overall marginal social benefits (MSB), the opti-

[14] This is not always true, since one can design such contracts that prohibit the further disclosure of knowledge. Monitoring and enforcing such contracts can, however, become costly when the number of such contracts increases.

[15] It has been argued, however, that the labor market might internalize such externalities (Møen, 2005).

[16] While positive externalities and public goods were originally perceived as different phenomena, in essence both are incentive structures and public goods can be thought as special cases of externalities (Cornes & Sandler, 1986, 5–6).

mum quantity would be Q* and the good is thus underproduced. Therefore the market solution will not be optimal when the marginal social benefit exceeds the marginal private benefits and, as a result, the competitive economy will spend less on R&D than it should (Nelson 1959). Arrow's (1962) seminal paper on the allocation of resources for R&D made a similar argument, and identified other problems for market efficiency.

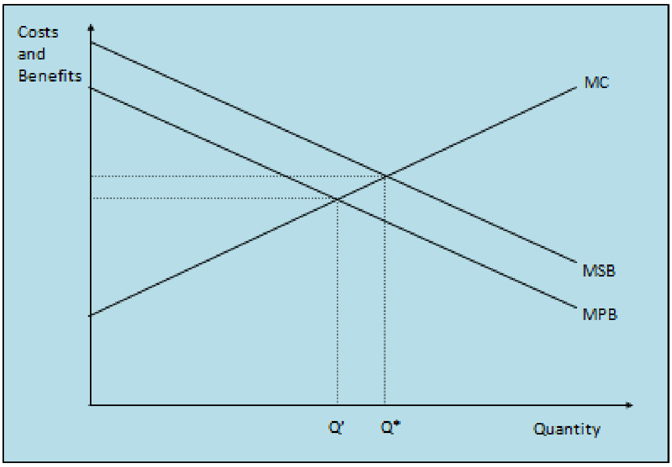

Figure 1. Pigouvian framework of positive externalities.

As can be expected, Arrow's and Nelson's position has produced some objections. Most objections argue that, for one reason or another, not all knowledge is purely non-excludable or that positive externalities, i.e. the gap between private and social benefits, are not that extensive (see also, Dosi et al. 2006). Arguments of the kind refer to the costs of learning or to the spatial or social limits of knowledge spillovers (e.g. Gertler 2003; Foray 2004; Breschi & Lissoni 2009). Due to this partial, but natural degree of excludability of knowledge the rationale for intellectual property rights is lessened.

This line of thinking does not directly question the reasoning of the Pigouvian framework; it only asserts that the problem is less severe. Hence, market failure remains a possibility and its extent becomes an empirical question. We do not contest the above considerations on excludability, but assume that there is a natural non-excludability of knowledge in order to see whether it creates a problem.

Perhaps the key evidence for our presumption that the connection between non-excludability and market failure is taken for granted comes from one of the most popular textbooks in advanced macroeconomics: “The degree of excludability is likely to have a strong influence on how the development and allocation of knowledge depart from perfect competition. If a type of knowledge is entirely nonexcludable, there can be no private gain in its development; thus R&D in these areas must come from elsewhere” (Romer 1996, 112). Again, this is the argument that will be tested here.

2.2 The case for discrete public goods analysis

There are two important features of knowledge as a public good that are not captured by the Pigouvian framework; the fundamental heterogeneity of knowledge and the possibility of strategic interaction. As will be argued shortly, the former is implied by the nature of knowledge and makes the standard marginal analysis dubious. Strategic interaction, on the other hand, is particularly important in the case of public goods, since non-rivalness implies an opportunity for collective gain and non-excludability implies difficulties for its realization (Ver Eecke 1999).

Instances of pure public goods are hard to find in reality and many typical examples have been later found unsatisfying (Buchanan & Kafoglis 1963; Cheung 1973; Coase 1974). Knowledge, however, has persistently stood up for this role since Pigou (1920, 158), who considered scientific research the most important case of positive externalities. Arguably, this is because knowledge is a purely non-rival good. Unlike other semi-public goods it does not suffer from congestion (cf. roads, natural parks) or its provision for additional users or areas does not bring any extra costs (cf. lighthouses, military defense). While the assumption of non-excludability has received some criticism, the assumption of non-rivalness has not been contested; and rightly so[17]. However, along with pure non-rivalry come other interesting implications, which will be dealt with next.

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[17] While knowledge is non-rival in use, it may have some strategic value which depends on how widely it is shared. We, however, limit ourselves to cases where knowledge has some basic value to the individuals, irrespective of its social dissemination.

Nelson (1959, 305)[18] noted that the assumption of the homogeneity of knowledge "products" is suspect and hence the Pigouvian marginal analysis might not be adequate. In fact, since knowledge is non-rival it is never homogenous[19]. There is no need to produce the same knowledge more than once, since what is already known need not be reproduced. Hence the Pigouvian framework, where we have "quantity" of knowledge on the *x*-axis, is unsuitable. Non-rivalness is therefore of great importance because once the good has been produced there is no need for continuing investment and the costs are fixed (Callon 1994). This type of public good, which has only a fixed cost, is known in the literature as discrete public good.

All this boils down to the original insight by Mises (1949, 658)[20]. The case of positive knowledge externalities can present itself in two alternative ways: 1) private benefits are above private costs, while social benefits are above both; or 2) private costs exceed private benefits but not social benefits. In the first case the knowledge gets produced privately. Even if the externalities do not benefit the producer, this does not, by any means, prevent him from providing the knowledge. In the latter case the project is not undertaken unless a sufficient number of potential beneficiaries are ready to share the cost.

Both of the above cases, however, require more detailed scrutiny from the strategic point of view. It should not yet be termed market failure if no single individual has sufficient incentive to finance the full cost of an essentially indivisible operation, as people may or may not decide to do things collectively (Buchanan 1964). Indeed, as will soon be discussed in more detail, when dealing with discrete public goods non-cooperation is not always the individually rational choice. Conversely, when an individual finds it beneficial to provide the public good on their own, we should not merely take the actions of others as given, namely the idea that they will not provide or cooperate. While there are enough incentives for a solitary provision, each and every individual would prefer it if

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[18] "Basic research certainly is not a homogeneous commodity. […] And, once the non-homogeneity of basic research is admitted, the concept of relative marginal cost becomes fuzzy. Thus one cannot make an airtight statement, based on welfare economics, that we are not spending as much on basic scientific research as we should." (ibid.)

[19] The central issue that makes knowledge and information different from other goods is that "each piece of information is different from others" (Stiglitz 2000, 1448) and "repeating a given piece of information adds nothing" (Arrow 1996, 120).

[20] Mises' argument was about positive externalities in general. Here the attempt is only to show that it applies to knowledge provision.

someone else made the investment. Furthermore, the possibility for collective action should be present in these cases as well.

2.3 Foreshadowing the model

Before moving forward to study the proper formal model it is useful to spend some time discussing the discrete public goods framework, the nature of the problem and how intellectual property rights are supposed to solve it. In the competitive case, i.e. without IPR, due to non-rivalness there is only a fixed cost C to produce the knowledge. As implied by non-excludability and non-rivalness, all individuals get the utility V if the investment is made. Without cooperation one player needs to carry the cost alone if the investment is to be made and later, when we relax this assumption, the cost can be shared. Of course, the assumed certainty of the research output is pathetically unrealistic and allows no role for individual creativity. However, since incentives are argued to play the main role in the provision of public good knowledge, our analysis focuses on the required "perspiration" instead of the less problematic "inspiration" as coined by Thomas Edison.

The relative size of V and C dictates whether the case belongs on the left or right of the private equilibrium, Q', in Figure 1, i.e. whether a single person would find it in his or her interest to make the investment if no one else participates. Based on this we make a difference between basic scientific research, where $V < C$, and applied scientific research, where $V \geq C$. This reflects well the assumption that the underprovision problem will be greater for more basic research (Arrow 1962; Nelson 1959). However, the purpose is to make a distinction between two relevant cases analytically and not to argue that every case, which is in reality considered basic or applied research, corresponds to these cost and benefit structures[21][22]. Furthermore we assume that public good knowledge is never free, but that it is always socially optimal to invest in it, hence $0 < C < NV$, where N is the population size.

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[21] *The Frascati Manual* gives the following definitions: "**Basic research** is experimental or theoretical work undertaken primarily to acquire new knowledge of the underlying foundation of phenomena and observable facts, without any particular application or use in view. **Applied research** is also original investigation undertaken in order to acquire new knowledge. It is, however, directed primarily towards a specific practical aim or objective." (OECD 2002, 30).

[22] According to Murray and Stern (2007), knowledge can have both applied and basic scientific value and this duality of knowledge is typical for the life sciences. They argue that in these cases IPR can restrict the diffusion of scientific research.

The problem with the competitive case and non-excludable knowledge is that without the possibility of cooperation investments to basic scientific research are not made at all. As per investments to applied research, there is some uncertainty regarding who should make the sacrifice, and the situation is much like the dragon slaying game (Bliss & Nalebuff 1984). It is important to note however, that this is not a prisoners' dilemma type of a game, which is said to usually describe the pattern of payoffs in the case of a public good provision[23] (Cornes & Sandler 1986, 18–19). The possibility of cooperation and shared investments costs make contribution less unattractive, but the main problem remains: while everyone prefers that the investment is made in the end, they also prefer not to take part in it if not necessary.

Intellectual property rights, most importantly patents as well as copyrights in the case of software, shift the incentives toward more probable provision, but at the cost of duplicative research. This problem of "duplication of effort" was first noted by Loury (1979). There are also other costs resulting from the patent system (Foray 2004; Scotchmer 2004; Boldrin & Levine 2008a), but they are excluded from our analysis. There is no monopoly deadweight loss in our model, since the benefit is the same for all and hence we assume that the monopolist is able to price-discriminate perfectly. Furthermore, it does not matter who will make the investment as everyone has the same cost and equal certainty of success. We also need not consider the costs of patent search or patent sharking as this is a simultaneous move game. These other costs of IPR are well-known in the literature and excluding them will allow us to concentrate on the benefits and costs of making a pure non-rival good, such as knowledge, excludable.

Here we assume that the patent race is a simple winner-takes-it-all lottery, where all who have made investment C have an equal probability to win the whole social benefit NV. For those who abstain from making the investment the benefit will be zero because there are no externalities. While the internalized social benefit makes the investment more lucrative and nullifies the incentive to free-ride on others' efforts, the problem is that it encourages multiple investments from the players whereas only one would be needed to provide the knowledge. When cooperation becomes an option, the players can also make a joint-investment where they share the expected revenue and the investment cost equally. If some choose to cooperate, which is not guaranteed as we will later see, the problem of duplication of effort decreases but does not completely disappear.

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[23] Qualitative differences between public goods and prisoners' dilemmas are studied by Conybeare (1984).

While our model concerns only the case where there is one investment option available at a time, the model could be extended to consider multiple, simultaneous investment options for different types of knowledge. In such a framework we might expect to see also hybrid forms of R&D, where some projects are undertaken in-house and others in joint projects, as in Goyal et al. (2008).

3 PUBLIC GOOD PROVISION AND EXCLUDA-BILITY

The purpose of this section is to compare the relative social utilities of public good knowledge provision between the competitive market and the market with intellectual property rights. While much of what follows would appear to be typical game theoretic public good analysis, we have argued in the previous section that the characteristics of scientific and technical knowledge strongly support this theoretical method. Our primary analysis considers multiple individuals and their mixed strategies in public good provision.

This will be done within the Coase Theorem framework to see whether the allocation of property rights matters with regard to social benefit[24]. Therefore, to see more clearly the implications of excludability, we assume that there are no transaction costs and that the property rights are perfectly defined[25]. In the competitive case there are no claims for external benefits, whereas in the IPR case the winning inventor is able to collect all the social benefits. Regarding transaction costs, negotiation is costless in both cases, likewise is the use of the patent system and the collecting of the benefits in the IPR case. In reality these costs can, of course, be non-negligible and shift the balance either way. For example, Lemley and Shapiro (2005) argue that patents are probabilistic rights, i.e. rights to attempt to exclude rather than absolute power to exclude.

In this paper, like Palfrey and Rosenthal (1984) and Dixit and Olson (2000), we proceed to study the mixed strategy equilibrium for two reasons. First, asymmetric equilibria arbitrarily require identical individuals to choose different strategies. The second issue regards the coordination problem of collectively choosing from among the asymmetric equilibria. Therefore, to take into account the uncertainty regarding the final provision we will turn to mixed strategies.

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[24] Suffice to say, the attempt here is not to test the theorem itself but to compare these alternatives. See also, Medema (2009) for an excellent discussion of the theorem.

[25] Defined in the sense that an individuals' opportunity sets are defined (Stubblebine 1972).

3.1 Basic structure and payoffs of the models

The number of players is N. Without cooperation the possible strategies are to make solitary investment (SI) and to abstain (A). Without IPR and with pure non-excludability the players' expected payoffs are $u_i(SI) = V - C$ and $u_i(A) = P(SI_{j \neq i})V$, where $P(SI_{j \neq i})$ is the probability that at least one of the other players chooses SI. With IPR all who make the investment have an equal probability to win the patent and to capture the social benefit. The expected payoffs are $u_i(SI) = NV/(1 + X) - C$, where X is the number of other players that choose SI, and $u_i(A) = 0$. After comparing these two extremes we proceed to study the optimal level of excludability. Such partial excludability may be due to either some natural level of excludability or imperfect IPR.

With cooperation, a third strategy, making a joint investment (JI), becomes available. When the knowledge is non-excludable we will compare strategies JI and A. Various different mechanisms for the private provision of public goods have been proposed over time. Of these our study follows the one developed by Dixit and Olson (2000), who further developed an earlier model by Palfrey and Rosenthal (1984), since instead of a fixed contribution their model has a fixed total cost[26]. Besides being a discrete public good model, it has two other suitable properties. First, the mechanism is very simple and realistic in comparison to many others (Bagnoli & Lipman 1989). Secondly, the individuals have a choice as to whether to participate in the mechanism, i.e. it is not imposed upon them, which is crucial when non-excludability is assumed (see, Saijo & Yamato 1999).

In short, the mechanism is as follows. The first stage is non-cooperative, where each individual decides whether or not to participate in the joint investment (i.e. choose JI or A). The second stage is a cooperative bargaining process among the participants. Similarly as earlier, the investment cost is C, the benefit for each individual is V, the population (i.e. the number of players) is N, and now the smallest number of required contributors is M, such that $M \geq C/V > (M - 1)$. If there are M or more who choose JI, the public good gets provided and the participants share the cost equally (we simply assume that they have equal bargaining abilities, since they are identical in every way). Non-participants in that case receive the knowledge for free. If less than M volunteer (choose JI), the public good will not be provided and the game is over for good. In the last case the costs and benefits are zero for everyone. Hence, the expected payoffs are $u_i(SI) = V - C/n$ and $u_i(A) = V$, if $n \geq M$, and $u_i(SI) = 0$ and $u_i(A) = 0$, if $n < M$.

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[26] Further extensions to voluntary provision models of discrete public goods consider, for example, cost uncertainty (Nitzan & Romano 1990, McBride 2006) and rebate rules (Admati & Perry 1991).

We will introduce the possibility of joint investment also to the IPR model, and in this case will compare alternative strategies JI and SI. X is again the number of other players that choose SI, and the expected payoffs are $u_i(JI) = \left(\frac{NV}{(1+X)} - C\right)/(N - X)$ and $u_i(SI) = NV/(1 + X) - C$, if no one chooses JI, and $u_i(SI) = NV/(2 + X) - C$, if at least one chooses JI.

To characterize the resulting equilibria, we use the standard pure strategy Nash equilibrium condition, $x_i \in \{SI, JI, A\}, x_i \neq x_i^*: u_i(x_i^*, x_{-i}^*) \geq u(x_i, x_i^*)$, and the mixed strategy Nash equilibrium condition, $\sigma_i \in \mathcal{P}(SI, JI, A), \sigma_i \neq \sigma_i^*: u_i(\sigma_i^*, \sigma_{-i}^*) \geq u(\sigma_i, \sigma_i^*)$, where $\mathcal{P}$ is the set of probability distributions on the available strategies and the conditions hold for all players *i*. Our fundamental interest lies in the comparative social benefits that these two models yield in alternative scenarios. For simplicity, we use the Utilitarian notion of social benefit, hence $U = \sum_{i=1}^{N} u_i$. Then we do not have to take into account how benefits and costs are distributed, and the social benefit is simply $U = P * NV - E[X]C$, where P is the probability that at least one investment is made and $E[X]$ is the number of all expected investments. Again, after comparing the two extremes, we proceed to study the optimal level excludability, which in the cooperative case is the level of excludability that guarantees that everyone participates in the single joint investment.

3.2 Research investment without cooperation

As stated earlier, the investment cost is *C*, the benefit for each individual is *V*, and the population (i.e. the number of players) is *N*. Throughout the paper, U^1 denotes the social benefit in the mixed strategy equilibrium without IPR and U^2 with IPR. We will first compare these models when R&D cooperation is not allowed. Perhaps surprisingly then, we will see that both pure excludability and pure non-excludability are equally inefficient, since both models result in the same social benefit.

Proposition 1. *If there is no possibility for cooperation, i.e. only strategies SI and A are available, then* $U^1 = U^2$.

Proof. See Lemmas 1 and 2.

In the case of basic scientific research, no player is willing to carry the investment alone (choose SI) and therefore they all abstain (choose A), if there are no IPR or possibility to make a joint investment. Hence, U^1 = 0 quite straightforwardly. In the IPR model there are $\binom{N}{X}$ pure strategy equilibria in which each of the exactly X solitary investments are made so that $X \leq \frac{NV}{C} < X + 1$. Naturally, when $X = 1$ the equilibria are Pareto optimal, which holds when $2C > NV$. Note that we assume that forming coalitions is prohibited and at this point the individuals cannot enter into R&D cooperation (choose JI). In reality this might be the case due to antitrust legislation, for example (see, Jorde & Teece 1990).

Lemma 1. *If there is no possibility for cooperation and C > V, then* $U^1 = U^2$.

Proof. Because A is the dominant strategy, the mixed strategy equilibrium is the same as the pure strategy equilibrium: every player abstains and $U^1 = 0$. Regarding the mixed strategies in the IPR model, assume that q is the probability that an individual makes a solitary investment and takes part in the patent lottery (chooses SI). Thus, in the equilibrium, N – 1 should play the mixed strategy by which the last individual is indifferent regarding the choice. Because all investments are random and independent, the number of investing players is binomially distributed along the parameters (N, q) and the expected utility is therefore

$$\sum_{n=0}^{N-1} \frac{(N-1)!}{n!(N-1-n)!} q^n (1-q)^{N-1-n} \frac{NV}{n+1} - C = 0 \qquad (1)$$

On the LHS we have the expected value of choosing SI which depends on the number of all the other participants, n, and the probability for each such realization. We subtract the certain value of the investment C from this, and this should be equal to the RHS, which is zero since there are no external benefits for anyone who abstains (chooses A). With a few simple steps, moving C to the RHS, multiplying $(N - 1)!$ by N and $n!$ by $(n + 1)$ on the LHS, multiplying both sides of the equation by q/V, and changing the index n to start from 1, we have manipulated (1) to

$$\sum_{n=1}^{N} \frac{N!}{n!(N-n)!} q^n (1-q)^{N-n} = q\frac{C}{V} \qquad (2)$$

The LHS of the equation is the cumulative probability that one or more individuals make the investment. Accordingly, the social utility in the IPR case is

$$U^2 = \sum_{n=1}^{N} \frac{N!}{n!(N-n)!} q^n (1-q)^{N-n} [NV - nC] \qquad (3)$$

Note that the LHS of (2) is equal to $(1 - (1 - q)^N)$. Let us rearrange (3) to get

$$U^2 = \sum_{n=1}^{N} \frac{N!}{n!(N-n)!} q^n (1-q)^{N-n} NV - \sum_{n=1}^{N} \frac{N!}{n!(N-n)!} q^n (1-q)^{N-n} nC \qquad (4)$$

Note that the last term is

$$-\sum_{n=1}^{N}\frac{N!}{n!(N-n)!}q^n(1-q)^{N-n}nC =$$

$$-C\sum_{n=1}^{N}\frac{N!}{n!(N-n)!}q^n(1-q)^{N-n}n = -C\sum_{n=0}^{N}n\frac{N!}{n!(N-n)!}q^n(1-q)^{N-n} \qquad (5)$$

This is simply –*C* multiplied by the expected number of successes

$$-C\sum_{n=0}^{N}nP(X=n) = -CE[X] = -CNq \qquad (6)$$

By plugging $(1 - (1 - q)^N)$ and equations (2) and (6) into (4) we have

$$U^2 = NV(1-(1-q)^N) - CNq$$
$$= NV(1-(1-q)^N) - NV(1-(1-q)^N) = 0 \qquad (7)$$

Thus, always when $C > V$ we have that $U^2 = 0 = U^1$. ■

Thus, the duplicative research has crowded out all the social utility and has essentially made the situation like a zero-sum game. This result is less surprising if we remind ourselves that it is a general outcome of all pay auctions, which have also been argued to characterize patent races as well (Dasgupta 1986). While the "bid" (i.e. the investment cost) is here fixed and the same for everyone, the use of mixed strategies achieves the same outcome, namely that the sum of the expected research costs equals the social benefit.

In the case of applied research, the lack of cooperation does not deter the investment since $V \geq C$. There we have *N* pure strategy equilibria where one of the players makes the investment. All are naturally Pareto optimal, but that is changed in the mixed strategy equilibrium as will be shown below. For the IPR model the case is simpler, since in the case of applied research making the investment is the dominant strategy and we have only one pure strategy equilibrium where everyone makes the investment.

Lemma 2. *If there is no possibility for cooperation and* $V \geq C$*, then* $U^1 = U^2$.

Proof. p will be now the probability that a player makes the investment (chooses SI) in the competitive market and $(1 - p)$ is the probability that he abstains (chooses A). In the mixed strategy equilibrium, $N - 1$ play the mixed strategy by which the last individual is indifferent regarding the choice. Because all investments are again random and independent, the number of investing players is binomially distributed along the parameters (N, q) and the expected utility is therefore

$$V - C = \sum_{n=1}^{N-1} \frac{(N-1)!}{n!(N-1-n!)} p^n (1-p)^{N-1-n} V. \qquad (8)$$

On the LHS we have the secure benefit the player makes the solitary investment himself, and RHS is the benefit from abstaining and hoping to free ride on others' contribution. Since the probability that at least one makes the investment is easy to simplify, (8) becomes

$$V - C = (1 - (1-p)^{N-1})V \,, \qquad (9)$$

which permits us to find

$$p = 1 - \sqrt[N-1]{\frac{C}{V}} \,. \qquad (10)$$

Social benefit in this case is

$$U^1 = \sum_{n=1}^{N} \frac{(N)!}{n!(N-n!)} p^n (1-p)^{N-n} NV - CNp \qquad (11)$$

or

$$U^1 = (1 - (1-p)^N)NV - CNp, \qquad (12)$$

where we have that the social benefit depends on the probability that at least one makes the investment minus the expected number of investments.

For the IPR model making the investment is the dominant strategy, and hence the mixed strategy equilibrium is $q = 1$. The social benefit is therefore simply

$$U^2 = N(V - C). \qquad (13)$$

Now, insert (10) to (12) to get

$$U^1 = \left(1 - \left(\frac{C}{V}\right)^{\frac{N}{N-1}}\right) NV - CN(1 - \sqrt[N-1]{\frac{C}{V}}) \qquad (14)$$

Rearrange (14) to get

$$U^1 = N\left(V - C - V\left(\frac{C}{V}\right)^{\frac{N}{N-1}} + C * \sqrt[N-1]{\frac{C}{V}}\right) \qquad (15)$$

Note that the last term is

$$C * \sqrt[N-1]{\frac{C}{V}} = V\frac{C}{V}\left(\frac{C}{V}\right)^{\frac{1}{N-1}} = V\left(\frac{C}{V}\right)^{\left(1+\frac{1}{N-1}\right)} = V\left(\frac{C}{V}\right)^{\left(\frac{N-1+1}{N-1}\right)} = V\left(\frac{C}{V}\right)^{\frac{N}{N-1}} \quad (16)$$

Replace (16) into (15) to get

$$U^1 = N\left(V - C - V\left(\frac{C}{V}\right)^{\frac{N}{N-1}} + V\left(\frac{C}{V}\right)^{\frac{N}{N-1}}\right) \quad (17)$$

From (17) we see that $U^1 = N(V - C) = U^2$, which completes our proof. ■

As a result, we have demonstrated that when there is no possibility to cooperate it does not whether we have pure excludability or pure non-excludability. While the downside of excludability, i.e. the duplication of effort, was already noted by Loury (1979), it is quite interesting to see that pure excludability creates exactly the same outcome as pure non-excludability. This, of course, makes the question of what is then the optimal level of excludability very interesting.

Note that in the both cases the social benefit is given by $U = (1 - (1 - r)^N)NV - CNr$, where r is the probability that a player chooses SI. By taking the partial derivative of this function with respect to r we have

$$\frac{\partial U}{\partial r} = N^2V(1 - r)^{N-1} - CN. \quad (18)$$

Since $\frac{\partial^2 U}{\partial^2 r} = -(N - 1)N^2V(1 - r)^{N-2} < 0$, we find the optimal probability to invest by setting (18) equal to zero, which therefore is

$$r^* = 1 - \sqrt[N-1]{\frac{C}{NV}}. \quad (19)$$

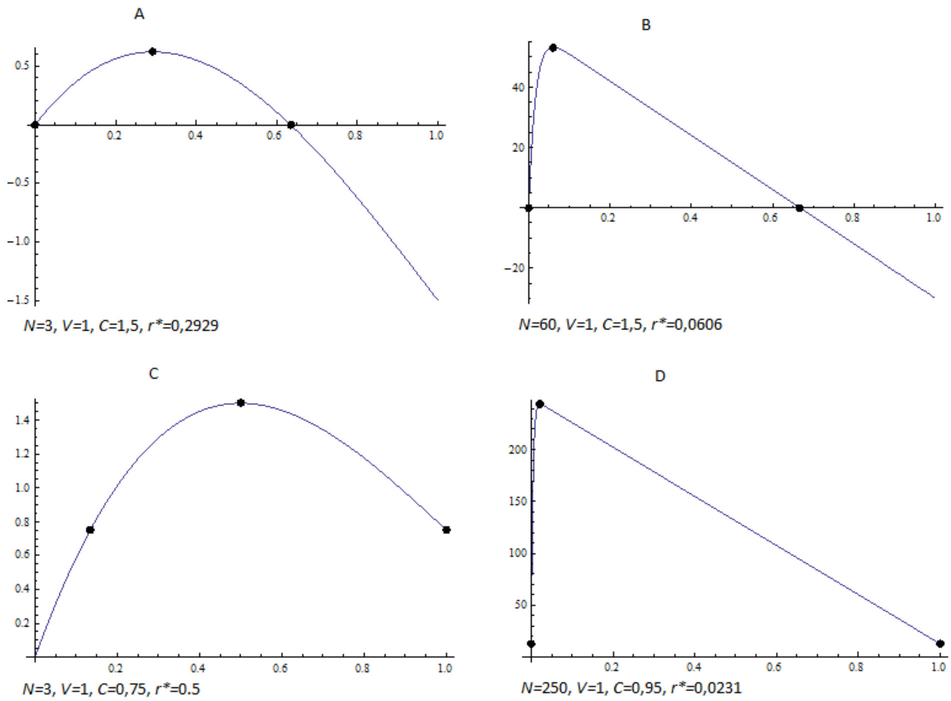

Figure 2. Social benefit, $U(r)$, and the individual probability to invest, r, without cooperation.

Figure 2 plots the resulting social benefit, $U(r)$ on y-axis, against the individual probability to invest, r. The optimal probability to invest, r*, lies at the top of the each curve, whereas the point on the left of it marks the individual probability to invest with pure non-excludability and the point on right of it is the same with pure excludability. As our previous results already stated, the resulting social benefit is equal in pure non-excludability and pure excludability. The upper row describes two cases of basic research and hence the two extremes result in zero social benefit. The lower row describes two cases of applied research. Here the social benefit is above zero in the case of the both extremes, but again significantly lower than what could be achieved with the optimal probability to invest. Hence, it becomes very interesting to find out what level of excludability would create this optimal level. This brings us to our main result:

Proposition 2. *The optimal level of excludability, α^*, is a function of N, V and C, i.e.* $\alpha^* = \frac{(1-\sqrt[N-1]{\frac{C}{NV}})(1-N)}{(1-\frac{NV}{C})}$.

Proof. The mixed strategy equilibrium with a varying level of excludability, α, is given by

$$\sum_{n=0}^{N-1} \frac{(N-1)!}{n!(N-1-n)!} r^n (1-r)^{N-1-n} \frac{(N-1)V\alpha+V\alpha}{n+1} + (1-\alpha)V - C = (1 - (1-r)^{N-1})(1-\alpha)V. \tag{20}$$

The first term on the LHS is the expected benefit from winning the patent, which now depends on the level of excludability. The next term, which is the received externality, and the investment cost incur whether or not the patent is won. Note that with pure excludability $\alpha = 1$ and (20) is the same as (1). Likewise, pure non-excludability, i.e. $\alpha = 0$, transforms (20) into (9). After a couple simplifying steps (20) can be presented as

$$(1-(1-r)^N)\alpha V = (C-(1-r)^{N-1}(1-\alpha)V)r. \tag{21}$$

Solving (21) for α gives

$$\alpha = \frac{r(C(r-1)+(1-r)^N V)}{(r-1+(1-r)^N)V}. \tag{22}$$

The optimal level of excludability should produce the optimal probability to invest. Therefore, we substitute (19) into (22), which gives us

$$\alpha^* = \frac{(1-\sqrt[N-1]{\frac{C}{NV}})(-C*\sqrt[N-1]{\frac{C}{NV}}+V\left(\frac{C}{NV}\right)^{\frac{N}{N-1}})}{-V*\sqrt[N-1]{\frac{C}{NV}}+V\left(\frac{C}{NV}\right)^{\frac{N}{N-1}}} = \frac{(1-\sqrt[N-1]{\frac{C}{NV}})(1-N)}{(1-\frac{NV}{C})}. \tag{23}$$

This completes our proof. ■

Table 1 illustrates how the optimal level of excludability, α^*, varies for different values of *N* and *C* (*V* is standardized to 1) in the case of basic research. Here, the individual investment probability with pure non-excludability, *p*, is always zero. With pure excludability the individual investment probability, *q*, is positive, but the resulting social benefit is nevertheless zero in the both cases. Table 2 makes the same comparison in the case of applied research. Now, *p* is positive and *q* is always one, and both result to the same positive level of social benefit. When compared to the social benefit achieved by the optimal level of excludability, *U**, in both tables we see the extent of inefficiency. However, the tables also illustrate the high variance in the optimal level of excludability; in some cases it is close to pure excludability, whereas it is close to pure non-excludability in others.

Table 1. *R&D investments in basic research and the social benefit without cooperation*

Individual probability, p, of choosing SI (when α=0) and the resulting social benefit U^1

Individual probability, q, of choosing SI (when α=100) and the resulting social benefit U^2

The optimal level of excludability, α*, and the resulting social benefit U*

	C = 1,1					C = 1,5					C = 1,9				
N	p	q	$U^1=U^2$	α^*	U^*	p	q	$U^1=U^2$	α^*	U^*	p	q	$U^1=U^2$	α^*	U^*
3	0	0,9084	0	0,4568	1,0322	0	0,6340	0	0,5858	0,6213	0	0,4276	0	0,7053	0,3241
6	0	0,9091	0	0,3230	3,3175	0	0,6657	0	0,4036	2,6839	0	0,5199	0	0,4760	2,1482
15	0	0,9091	0	0,1886	11,2782	0	0,6667	0	0,2359	10,3152	0	0,5263	0	0,2786	9,4502
60	0	0,9091	0	0,0722	54,6468	0	0,6667	0	0,0917	53,1361	0	0,5263	0	0,1097	51,7285

	C = 9,1					C = 9,5					C = 9,9				
N	p	q	$U^1=U^2$	α^*	U^*	p	q	$U^1=U^2$	α^*	U^*	p	q	$U^1=U^2$	α^*	U^*
15	0	0,0767	0	0,7572	1,4323	0	0,0696	0	0,7762	1,2308	0	0,0629	0	0,7947	1,0468
30	0	0,1061	0	0,5089	10,2646	0	0,1009	0	0,5225	9,7896	0	0,0961	0	0,5358	9,3314
50	0	0,1096	0	0,3726	25,6623	0	0,1048	0	0,3830	24,9874	0	0,1005	0	0,3933	24,3291
200	0	0,1099	0	0,1462	162,9978	0	0,1053	0	0,1508	161,7737	0	0,1010	0	0,1554	160,5664

	C = 49,1					C = 49,5					C = 49,9				
N	p	q	$U^1=U^2$	α^*	U^*	p	q	$U^1=U^2$	α^*	U^*	p	q	$U^1=U^2$	α^*	U^*
60	0	0,0070	0	0,9016	1,0729	0	0,0067	0	0,9054	0,9931	0	0,0064	0	0,9092	0,9166
100	0	0,0165	0	0,6837	16,0998	0	0,0163	0	0,6868	15,8151	0	0,0161	0	0,6899	15,5336
150	0	0,0193	0	0,5414	46,2713	0	0,0191	0	0,5440	45,8249	0	0,0189	0	0,5466	45,3817
250	0	0,0202	0	0,3965	121,2454	0	0,0201	0	0,3985	120,5955	0	0,0199	0	0,4006	119,9488

Table 2. *R&D investments in applied research and the social benefit without cooperation*

Individual probability, p, of choosing SI (when α=0) and the resulting social benefit U^1

Individual probability, q, of choosing SI (when α=100) and the resulting social benefit U^2

The optimal level of excludability, α*, and the resulting social benefit U*

	C =	0,001					*C* =	0,05			
N	*p*	*q*	$U^1 = U^2$	α*	*U**		*p*	*q*	$U^1 = U^2$	α*	*U**
3	0,9684	1	2,997	6,55E-04	2,99704		0,7764	1	2,85	0,0295	2,8629
5	0,8222	1	4,995	7,05E-04	4,9955		0,5271	1	4,75	0,0276	4,8132
25	0,2501	1	24,975	0,0003	24,9907		0,1173	1	23,75	0,0110	24,6762
100	0,0674	1	99,9	0,0001	99,9881		0,0298	1	95	0,0037	99,5842
250	0,0274	1	249,75	0,0000	249,9869		0,0120	1	237,5	0,0017	249,5313
	C =	0,25					*C* =	0,5			
N	*p*	*q*	$U^1 = U^2$	α*	*U**		*p*	*q*	$U^1 = U^2$	α*	*U**
3	0,5000	1	2,25	0,1293	2,3943		0,2929	1	1,5	0,2367	1,9082
5	0,2929	1	3,75	0,1110	4,2229		0,1591	1	2,5	0,1945	3,6247
25	0,0561	1	18,75	0,0423	23,7024		0,0285	1	12,5	0,0737	22,6951
100	0,0139	1	75	0,0146	98,2966		0,0070	1	50	0,0259	96,9205
250	0,0056	1	187,5	0,0068	248,0468		0,0028	1	125	0,0123	246,4312
	C =	0,75					*C* =	0,95			
N	*p*	*q*	$U^1 = U^2$	α*	*U**		*p*	*q*	$U^1 = U^2$	α*	*U**
3	0,1340	1	0,75	0,3333	1,5000		0,0253	1	0,15	0,4053	1,2192
5	0,0694	1	1,25	0,2666	3,1170		0,0127	1	0,25	0,3188	2,7588
25	0,0119	1	6,25	0,1009	21,8032		0,0021	1	1,25	0,1208	21,1457
100	0,0029	1	25	0,0361	95,6696		5,18E-04	1	5	0,0436	94,7288
250	0,0012	1	62,5	0,0173	244,9436		2,06E-04	1	12,5	0,0210	243,8147
	C =	0,99									
N	*p*	*q*	$U^1 = U^2$	α*	*U**						
3	0,0050	1	0,03	0,4192	1,1674						
5	0,0025	1	0,05	0,3288	2,6916						
25	4,19E-04	1	0,25	0,1246	21,0191						
100	1,02E-04	1	1	0,0451	94,5458						
250	4,04E-05	1	2,5	0,0217	243,5942						

Corollary 1. *The optimal level of excludability, α*, is increasing in C, decreasing in V, and decreasing in N for* $N > Max\{N_0 N_1\}$*, where* N_0 *and* N_1 *can be calculated.*

Proof in the appendix.

Intuition behind the result is such that higher *C* or lower *V* makes the individual commitment less likely and hence a higher degree of excludability is required. While with higher *N* each individual becomes less pivotal it also causes the duplication of effort become more severe problem. This latter effect becomes soon dominant, which explains the direction. While the optimal level of excludability is not always decreasing in *N*, based on our computations, this seems to be generally so. Only in one case with $C = 0.001$ and $V = 1$ did an increase in *N*, $(3 \rightarrow 5)$, result to an increase in α^*, $(0.00065471 \rightarrow 0.00070500)$. In all the other cases α^* was decreasing in *N*.

3.3 Research investments with cooperation

In this game there is one symmetric pure strategy equilibrium where no one participates (always the case when $M \geq 2$) and $\binom{N}{M}$ asymmetric equilibria, in all of which the public good knowledge will be provided. The symmetric equilibrium yields no social benefit, $U^1 = 0$, whereas the asymmetric equilibria are Pareto optimal, $U^1 = NV - C = U^*$. We may consider the Pareto optimal equilibrium as a focal point (Janssen, 2001), and assume that the individuals are able to coordinate accordingly when everyone's participation is required. In general, however, as long as $M < N$ there is some uncertainty regarding who will participate and, henceforth, whether or not the knowledge will be provided, which is what we will attempt to capture by analyzing the mixed strategies of public good provision.

In the mixed strategy equilibrium $N - 1$ players' probability of participation *p* should be such that each individual is indifferent regarding the choice. This gives us the equation

$$\sum_{n=M}^{N} \frac{(N-1)!}{(n-1)!(N-n)!} p^{n-1}(1-p)^{N-n} \left[V - \frac{C}{n}\right] = \sum_{n=M}^{N-1} \frac{(N-1)!}{n!(N-1-n)!} p^{n}(1-p)^{N-1-n} V \quad (24)$$

On the LHS we have the utility from choosing JI, which is positive only if at least $M - 1$ of the remaining $N - 1$ people choose in and the number of all participants, *n*, is thus *M* or higher. We multiply the sum of probabilities for each such situation by individual benefit minus the share of the cost based on the number of participants. On the RHS we have the utility from choosing A. For non-participants, receiving *V* depends on the probability that there are already at least as many as *M* participants.

By rearranging equation 1 (see, Dixit and Olson 2000) we have

$$\sum_{n=M}^{N} \frac{N!}{n!(N-n)!} p^{n}(1-p)^{N-n} = \frac{N!}{M!(N-M)!} p^{M}(1-p)^{N-M} \frac{MV}{C} \quad (25)$$

Now, on the LHS we have the probability that the good will be provided and on the RHS the probability that one individual is the pivotal player times the fraction *M*, *V* and *C*. The monotonic properties of (25) (see, Dixit and Olson 2000) imply that it has a single solution for *p* when the other variables are known. This equation gives us the equilibrium mixed strategy, but unfortunately it is not possible to solve the equation explicitly for it. We can, however, observe some values that *p* takes for different *C*s, *M*s and *N*s (*V* is normalized to 1). In Table 3 we see the results for basic scientific research, which are the same Dixit and Olson (2000) gained[27], namely that *p* tends to become very small as the distance between *N* and *M* increases or decreases between *V* and *C*, which is consistent with the normal assumptions about public good provision (Olson 1965).

Furthermore, the social utility in the competitive case is

$$U^1 = \sum_{n=M}^{N} \frac{N!}{n!(N-n)!} p^n (1-p)^{N-n} [NV - C] \qquad (26)$$

which due to low *p* in some cases tends to fall far behind from the Pareto optimal case

$$U^* = NV - C. \qquad (27)$$

Dixit and Olson (2000) conclude that while private provision is possible, it is not very probable. However, it is incorrect to use this as a benchmark. To avoid the so-called nirvana fallacy we should compare alternative real institutional arrangements (Demsetz 1969). Hence we need to similarly calculate the mixed strategies and the social utility for the IPR alternative.

To have a comparable IPR model with possibility for cooperation, we include a third available strategy. Besides making the investment alone and abstaining altogether, players can also choose to participate into a joint investment (JI). Those who participate in it share the profit equally.

Interesting feature persists, however. Since cooperation requires by definition at least two participants, we always have the previous mixed strategy Nash equilibria where no one cooperates. Hence we keep in mind this result while we proceed further to see if there are other mixed strategy equilibria with cooperation. If there is mixed strategy equilibrium between strategies JI and SI with non-negative expected payoff, we have a plausible alternative outcome where duplication of efforts is less of a problem.

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[27] In five cases the rounded values are not exactly the same but the difference is negligible, nevertheless.

Regarding the pure strategy equilibria, we have now $\binom{N}{X}$ more of them, where X solitary investments are made and the remaining players, $N-X$, make a single joint investment. The number of solitary investments is defined by the conditions that none of the solitary investors wants to take part in the joint investment, $\frac{NV}{X+1}-C \geq \frac{\frac{NV}{X}-C}{N-X+1}$, and none of the joint investors wants to secede, $\frac{\frac{NV}{X+1}-C}{N-X} \geq \frac{NV}{X+2}-C$. That is, $N-\frac{\frac{NV}{X+1}-C}{\frac{NV}{X+2}-C} \leq X \leq N+1-\frac{\frac{NV}{X}-C}{\frac{NV}{X+1}-C}$. If $X=0$, there is only the joint investment and the equilibrium is Pareto optimal. This is the only possible symmetric pure strategy equilibrium.

The mixed strategy equilibrium between strategies SI and JI is defined by the following equation:

$$\sum_{n=0}^{N-1}\frac{(N-1)!}{n!(N-1-n)!}q^n(1-q)^{N-1-n}\left(\frac{\frac{NV}{n+1}-C}{N-n}\right)=\sum_{n=0}^{N-2}\frac{(N-1)!}{n!(N-1-n)!}q^n(1-q)^{N-1-n}\left(\frac{NV}{n+2}-C\right)+q^{N-1}(V-C) \tag{28}$$

Here q is the mixed strategy for choosing SI. LHS is the expected utility for the last player to choose JI. The probability of winning depends on the number of other players for choosing SI and the profit is shared with others that choose JI. RHS is the expected utility for choosing SI. The first term is expected profit when other players from 0 to $N-2$ choose SI and the second term when they all choose SI. We will spare the reader from the tedious steps, since q cannot be solved even then, but in its simplest form (28) becomes

$$\frac{C}{NV}=\frac{1-(1-q)^N+q(-1+(1-q)^N+N(-1+q)+q-q^N)}{(1+N)q^2(1+N(-1+q)-q^N)}. \tag{29}$$

Typically this equation holds for two different mixed strategies, the other one being $q=1$. This strategy, however, gives a negative expected utility. Since the players are always better of abstaining completely, we will only consider only the other mixed strategy equilibrium with non-negative expected payoff. The resulting social benefit is given by

$$U^2=NV-qNC-(1-q^N)C, \tag{30}$$

where from the certain aggregate benefit, *NV*, we deduct the expected number of independent investment and the cost of the joint investment depending on the probability that at least one chooses that strategy.

Table 3 compares these two models and the resulting social benefits for different population sizes, benefits and investment costs in the case of basic research. The shaded boxes mark the cases where either pure non-excludability or pure excludability yields higher social benefit. We can observe that the relative performance is typically in the favor of pure excludability when the population is small and the cost is relatively high relatively to the private benefit.

Table 3. *R&D investments in basic research and the social benefit with cooperation*

Individual probability, p, of choosing JI (when α=0) and the resulting social benefit U^1

Individual probability, q, of choosing SI (when α=100) and the resulting social benefit U^2

The upper and lower bound of the optimal level of excludability, α^*, and the resulting social benefit U^*

	C = 1,1							C = 1,5							C = 1,9						
N	*p*	U^1	*q*	U^2	*upper*	*lower*	*U**	*p*	U^1	*q*	U^2	*upper*	*lower*	*U**	*p*	U^1	*q*	U^2	*upper*	*lower*	*U**
3	0,7105	1,51454	0,0000	1,9	1,4667	0,3667	1,9	0,5000	0,7500	0,0000	1,5	2,0000	0,5000	1,5	0,1364	0,0558	0,0000	1,1	2,5333	0,6333	1,1
6	0,3058	2,90231	0,6573	0,6503	0,4583	0,1833	4,9	0,1756	1,2817	0,3769	1,1126	0,6250	0,2500	4,5	0,0369	0,0760	0,1827	2,0173	0,7917	0,3167	4,1
15	0,1114	7,09306	0,8342	0,2084	0,1579	0,0733	13,9	0,0594	3,0065	0,5905	0,2146	0,2154	0,1000	13,5	0,0116	0,1671	0,4472	0,3550	0,2728	0,1267	13,1
60	0,0266	28,092	0,8921	0,0255	0,0373	0,0183	58,9	0,0138	11,7161	0,6495	0,0408	0,0509	0,0250	58,5	0,0026	0,6358	0,5091	0,0654	0,0644	0,0317	58,1

	C = 9,1							C = 9,5							C = 9,9						
N	*p*	U^1	*q*	U^2	*upper*	*lower*	*U**	*p*	U^1	*q*	U^2	*upper*	*lower*	*U**	p	U^1	q	U^2	*upper*	*lower*	*U**
15	0,1689	1,46E-04	0,0000	5,9	1,3067	0,6067	5,9	0,1003	1,06E-06	0,0000	5,5000	1,3641	0,6333	5,5	0,0216	3,04E-13	0,0000	5,1	1,4215	0,6600	5,1
30	0,0477	1,59E-05	0,0561	5,5798	0,6283	0,3033	20,9	0,0269	7,56E-08	0,0503	6,1650	0,6560	0,3167	20,5	0,0055	1,33E-14	0,0449	6,7772	0,6836	0,3300	20,1
50	0,0244	1,28E-05	0,0841	2,6540	0,3716	0,1820	40,9	0,0136	5,63E-08	0,0791	2,9484	0,3879	0,1900	40,5	0,0027	9,07E-15	0,0744	3,2609	0,4043	0,1980	40,1
200	0,0052	2,65E-05	0,1046	0,4570	0,0915	0,0455	190,9	0,0029	1,09E-07	0,1000	0,5004	0,0955	0,0475	190,5	5,79E-04	1,64E-14	0,0957	0,5459	0,0995	0,0495	190,1

	C = 49,1							C = 49,5							C = 49,9						
N	*p*	U^1	*q*	U^2	*upper*	*lower*	*U**	*p*	U^1	*q*	U^2	*upper*	*lower*	*U**	*p*	U^1	*q*	U^2	*upper*	*lower*	*U**
60	0,0842	6,58E-43	0,0000	10,9	1,6649	0,8183	10,9	0,0486	1,02E-54	0,0000	10,5	1,6784	0,8250	10,5	0,0101	1,13E-88	0,0000	10,1	1,6920	0,8317	10,1
100	0,0180	1,37E-57	2,46E-04	49,6933	0,9920	0,4910	50,9	0,0101	5,12E-70	7,85E-08	50,4996	1,0001	0,4950	50,5	0,0020	1,26E-104	7,60E-09	50,1000	1,0082	0,4990	50,1
150	0,0091	7,48E-61	0,0095	31,1692	0,6591	0,3273	100,9	0,0051	2,31E-73	0,0093	31,7380	0,6645	0,3300	100,5	0,0010	4,68E-108	0,0091	32,3113	0,6698	0,3327	100,1
250	0,0046	1,10E-62	0,0151	15,6984	0,3944	0,1964	200,9	0,0025	3,10E-75	0,0149	16,0073	0,3976	0,1980	200,5	5,10E-04	5,70E-110	0,0147	16,3208	0,4008	0,1996	200,1

Next we do the same comparison in the case of applied science, where we have that *V* > *C*. In the competitive case all the *N* pure strategy equilibria are Pareto optimal, and the investment is made by one individual alone in each of these cases. The mixed strategy for participation in the public good provision is given by equation 2 when we note that *M* = 1, which now yields

$$\sum_{n=1}^{N}\binom{N}{n}p^n(1-p)^{N-n} = Np(1-p)^{N-1}\frac{V}{C} \quad (31)$$

This can be simplified to

$$1-(1-p)^N = Np(1-p)^{N-1}\frac{V}{C} \quad (32)$$

Once again, we are unable to solve for *p* directly, but we can take a look at the values it gets for different *C*s and *N*s (*V* is again normalized to 1) in Table 4. The equilibrium mixed strategy gives us the expected social benefit, which is

$$U^1 = \sum_{n=1}^{N}\frac{N!}{n!(N-n)!}p^n(1-p)^{N-n}[NV-C] \quad (33)$$

For IPR model, the equations (28) and (30) are unchanged for applied research. In every situation, $q=1$ is the equilibrium mixed strategy and this time it is also feasible. In a few cases there is also another equilibrium mixed strategy with some level of cooperation, and when available, we have used it for comparison. Table 4 compares the models in several cases.

Table 4. *R&D investments in applied research and the social benefit with cooperation*

Individual probability, *p*, of choosing JI (when α=0) and the resulting social benefit U^1

Individual probability, *q*, of choosing SI (when α=100) and the resulting social benefit U^2

The upper and lower bound of the optimal level of excludability, α*, and the resulting social benefit *U**

	C = 0,001							C = 0,05						
N	*p*	U^1	*q*	U^2	*upper*	*lower*	*U**	*p*	U^1	*q*	U^2	*upper*	*lower*	*U**
3	0,9816	2,9990	1	2,997	0,0013	3,33E-04	2,999	0,8611	2,9421	1	2,85	0,0667	0,0167	2,95
5	0,8771	4,9989	1	4,995	5,33E-04	2,00E-04	4,999	0,6480	4,9233	1	4,75	0,0267	0,0100	4,95
25	0,3116	24,9968	1	24,975	8,35E-05	4,00E-05	24,999	0,1692	24,7073	1	23,75	0,0042	0,0020	24,95
100	0,0876	99,9886	1	99,9	2,02E-05	1,00E-05	99,999	0,0444	98,8861	1	95	0,0010	5,00E-04	99,95
250	0,0359	249,972	1	249,75	8,03E-06	4,00E-06	250	0,0179	247,2430	1	237,5	4,02E-04	2,00E-04	249,95

	C = 0,25							C = 0,5						
N	*p*	U^1	*q*	U^2	*upper*	*lower*	*U**	*p*	U^1	*q*	U^2	*upper*	*lower*	*U**
3	0,6496	2,6317	1	2,25	0,3333	0,0833	2,75	0,4417	2,0651	1	1,5	0,6667	0,1667	2,5
5	0,4233	4,4471	1	3,75	0,1333	0,0500	4,75	0,2606	3,5053	1	2,5	0,2667	0,1000	4,5
25	0,0918	22,5224	1	18,75	0,0209	0,0100	24,75	0,0507	17,8208	1	12,5	0,0417	0,0200	24,5
100	0,0233	90,2751	1	75	0,0051	0,0025	99,75	0,0126	71,4721	1	50	0,0101	0,0050	99,5
250	0,0093	225,778	1	187,5	0,0020	0,0010	249,75	0,0050	178,772	1	125	0,0040	0,0020	249,5

	C = 0,75							C = 0,95						
N	*p*	U^1	*q*	U^2	*upper*	*lower*	*U**	*p*	U^1	*q*	U^2	*upper*	*lower*	*U**
3	0,2324	1,2324	0	2,25	1,0000	0,2500	2,25	0,0492	0,2879	0	2,05	1,2667	0,3167	2,05
5	0,1261	2,0838	1	1,25	0,4000	0,1500	4,25	0,0250	0,4817	0,7156	0,8290	0,5067	0,1900	4,05
25	0,0226	10,5517	1	6,25	0,0626	0,0300	24,25	0,0042	2,4164	1	1,25	0,0793	0,0380	24,05
100	0,0055	42,2898	1	25	0,0152	0,0075	99,25	0,0010	9,67	1	5	0,0192	0,0095	99,05
250	0,0022	105,765	1	62,5	0,0060	0,0030	249,25	4,08E-04	24,18	1	12,5	0,0076	0,0038	249,05

	C = 0,99						
N	*p*	U^1	*q*	U^2	*upper*	*lower*	*U**
3	0,0100	0,0595	0	2,01	1,3200	0,3300	2,01
5	5,00E-03	0,0993	0,6692	0,8302	0,5280	0,1980	4,01
25	8,36E-04	0,4966	0,9670	0,5046	0,0826	0,0396	24,01
100	2,03E-04	1,9866	1	1	0,0200	0,0099	99,01
250	8,06E-05	4,9667	1	2,5	0,0080	0,0040	249,01

From Table 4 we see that the cases where the IPR model is superior, again marked by shaded boxes, are less common than earlier. We see them again where the population is small or *C* is relatively large to *V*, i.e. when the positive externalities would otherwise be small.

How do these results then compare to the optimal level of excludability in the case of R&D cooperation? If we are able to enforce cooperation, we will reach the Pareto optimal situation where everyone participates in the single joint R&D investment. On the one hand, this requires that no single player has an incentive to free-ride on others' investment. On the other hand, no player should neither have an incentive for trying to acquire the patent through solitary investment. The optimal level of excludability becomes hence an interval, which is our last main result.

Proposition 3. *With the possibility of joint R&D investment, the optimal level of excludability is an interval depending on the values of N, V and C, i.e.* $\alpha^* \epsilon \left[\frac{C}{NV}, \frac{2C(N-1)}{NV(N-2)}\right]$.

Proof. To ensure joint investment with probability 1, the level of excludability should be high enough so that no single player wishes to deviate and abstain from the investment. This holds when

$$V - C/N \geq V(1 - \alpha) \quad (34)$$

or

$$\alpha \geq \frac{C}{NV}. \quad (35)$$

The level of excludability should neither be too high in order to ensure that no single player has the incentive to deviate for solitary investment. This holds when

$$V - \frac{C}{N} \geq \frac{\alpha NV}{2} - C + V(1 - \alpha) \quad (36)$$

or

$$\alpha \leq \frac{2C(N-1)}{NV(N-2)}. \quad (37)$$

Combining these two conditions gives us the optimal level of excludability, which is

$$\alpha^* \epsilon \left[\frac{C}{NV}, \frac{2C(N-1)}{NV(N-2)}\right]. \quad (38)$$

This completes our proof. ■

Table 3 provides a comparison in the case of basic research and Table 4 in the case of applied research. Here, the optimal level of excludability is an interval with upper and lower bounds. In the few cases where the upper bound is 1 or greater, the boundary does not hold. As such, the case of pure excludability is there able to achieve the Pareto optimal outcome, but typically both pure excludability and pure non-excludability are outside these boundaries. When R&D cooperation is possible, i.e. it is not prevented by antitrust law or negotiation costs, the optimal level of excludability is an interval. This gives more leeway to intellectual property law. However, as the boundaries change with respect to the benefits and costs of the knowledge investment, this implies that there are no optimal IPR that would suit all industries.

Corollary 2. *The upper and lower bounds of the optimal level of excludability, α*, are decreasing in C and increasing in V and N.*

Proof in the appendix.

Intuition behind the result is such that again a higher degree of excludability is required to compensate for low V or high C in order to enforce participation in the joint investment. While the upper bound is not restrictive for low N, a solitary, competing investment for acquiring the patent, which value is increasing in N, becomes soon lucrative unless the level of excludability is decreased.

4 CONCLUSION

It is probably fair to say that a large number of economists share the argument made by Usher (1964, 279): “A patent system is required to create an artificial and uneconomic scarcity of newly-created knowledge so that profit-seeking people of firms have an incentive to invent. At this level of abstraction the patent system is surely the lesser evil.” Yet others have questioned the need for IPR by pointing out different reasons for why knowledge is not naturally non-excludable in the first place. Furthermore, some tend to agree with David and Foray (2002, 19), who argue that “[p]eople are striving to create artificial shortages in fields where abundance prevails, thus giving rise to an enormous amount of waste. To understand this, one has to realize that knowledge is not like any other kind of property. Intellectual property cannot be placed on equal footing to physical property for the simple reason that knowledge and information possess a specific characteristic that economists refer to as ‘non-rivalry in use’.” As such, Foray (2004, 145) argues that the consensus on the desirability of the patent system, which was reached among economists about twenty years ago, has recently collapsed.

In this paper we found out that the optimal level of excludability is not the same over all types of knowledge investments but depends on their costs and benefits. This may help to clarify the controversy on the desirability of IPR and provides support to Cooley and Yorukoglu’s (2003) claim that the optimal policies for protecting ideas should be different for goods that require more or less R&D investments. This suggests major challenges for the intellectual property law, however. Our results also demonstrated that the possibility of R&D cooperation can be welfare improving, having important implications for antitrust law as R&D cooperation has been traditionally treated as highly suspect by antitrust scholars (Jorde & Teece 1990). R&D cooperation gives also more leeway to intellectual property law as the optimal level of excludability is no longer a single point but an interval.

Naturally, major issues require now subsequent research: how does uncertainty[28] or sequential innovation (e.g. Scotchmer 1991; Bessen & Maskin 2009) af-

[28] The wasteful nature of duplicative research efforts is less harmful if there is uncertainty regarding the investment output (Scotchmer 2004).

fect the optimal level of excludability? How much natural excludability there exists without IPR? What is the actual level of excludability created by current IPR? How is excludability connected to patent breadth and length (Gilbert & Shapiro 1990) or to other reward mechanisms for invention (Hopenhayn et al. 2006)? Which knowledge sectors would benefit from higher excludability, which from less? As such, this paper is hardly the last word on the topic, but hopefully it helps to clarify some past disagreements and show new possibilities for future research on the topic.

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Appendix

Proof of Corollary 1

The relevant values of N, V and C are given by $N \geq 2, V > 0, NV > C > 0$. The optimal level of excludability without R&D cooperation is

$$\alpha^* = \frac{\left(1-\sqrt[N-1]{\frac{C}{NV}}\right)(1-N)}{\left(1-\frac{NV}{C}\right)}. \tag{39}$$

The partial derivatives are

$$\frac{\partial \alpha*}{\partial C} = -\frac{(1-N)N\left(1-\left(\frac{C}{NV}\right)^{\frac{1}{N-1}}\right)V}{C^2\left(1-\frac{NV}{C}\right)^2} - \frac{(1-N)\left(\frac{C}{NV}\right)^{-1+\frac{1}{N-1}}}{(N-1)NV\left(1-\frac{NV}{c}\right)} = \frac{(N-1)NV+\left(\frac{C}{NV}\right)^{\frac{1}{N-1}}(C-N^2V)}{(C-NV)^2} \tag{40}$$

$$\frac{\partial \alpha*}{\partial V} = \frac{(1-N)N\left(1-\left(\frac{C}{NV}\right)^{\frac{1}{N-1}}\right)}{C\left(1-\frac{NV}{C}\right)^2} + \frac{C(1-N)\left(\frac{C}{NV}\right)^{-1+\frac{1}{N-1}}}{(N-1)NV^2\left(1-\frac{NV}{C}\right)} = -\frac{(N-1)NV+\left(\frac{C}{NV}\right)^{\frac{1}{N-1}}(C-N^2V)}{\frac{V}{C}(C-NV)^2} \tag{41}$$

$$\frac{\partial\alpha*}{\partial N}=\frac{(1-N)\left(1-\left(\frac{C}{NV}\right)^{\frac{1}{N-1}}\right)V}{C\left(1-\frac{NV}{C}\right)^2}-\frac{1-\left(\frac{C}{NV}\right)^{\frac{1}{N-1}}}{1-\frac{NV}{C}}-\frac{(1-N)\left(\frac{C}{NV}\right)^{\frac{1}{N-1}}\left(-\frac{1}{(N-1)N}-\frac{\ln\left[\frac{C}{NV}\right]}{(N-1)^2}\right)}{1-\frac{NV}{C}}=$$
$$\frac{(N-1)N(V-C)+\left(\frac{C}{NV}\right)^{\frac{1}{N-1}}\left(C(N-1)^2+N(NV-C)\ln\left[\frac{C}{NV}\right]\right)}{\frac{1}{C}(N-1)N(C-NV)^2} \tag{42}$$

In (40) the denominator is always positive in the relevant range. We form a new function of the numerator:

$$f(C)=(N-1)NV+\left(\frac{C}{NV}\right)^{\frac{1}{N-1}}(C-N^2V), \tag{43}$$

and derivate it with respect to *C* to get

$$\frac{\partial f(C)}{\partial C}=\left(\frac{1}{NV}\right)^{\frac{1}{N-1}}C^{\frac{1}{N-1}-1}\frac{1}{N-1}(C-N^2V)+\left(\frac{C}{NV}\right)^{\frac{1}{N-1}}=\left(\frac{C}{NV}\right)^{\frac{1}{N-1}}\left(\frac{1}{N-1}\left(1-\frac{N^2V}{C}\right)+1\right)<\left(\frac{C}{NV}\right)^{\frac{1}{N-1}}\left(\frac{1}{N-1}\left(1-\frac{N^2V}{NV}\right)+1\right)=\left(\frac{C}{NV}\right)^{\frac{1}{N-1}}\left(\frac{1}{N-1}(1-N)+1\right)=0 \tag{44}$$

Therefore, $f'(C)<0, \forall C\in(0,NV)$.

$$f(NV)=(N-1)NV+1*(NV-N^2V)=0 \tag{45}$$

Hence, when $f'(C)<0, \forall C\in(0,NV)$, it implies that $f(C)>0, \forall C\in(0,NV)$, and therefore $\frac{\partial\alpha*}{\partial C}>0$.

In (41) the denominator is again positive and the numerator is the same as (43). Since we already know that $f(V)>0, \forall C\in(C/N,\infty)$, we therefore conclude that $\frac{\partial\alpha*}{\partial V}<0$.

The denominator in (42) is positive and the term, $\left(\frac{C}{NV}\right)^{\frac{1}{N-1}}$, in the numerator in increasing in *N* when

$$\frac{\partial\left(\frac{C}{NV}\right)^{\frac{1}{N-1}}}{\partial N}=\left(\frac{C}{NV}\right)^{\frac{1}{N-1}}\left(\frac{-N\ln\left[\frac{C}{NV}\right]-N+1}{(N-1)^2M}\right)>0 \tag{46}$$

$$\leftrightarrow N\left(-\ln\left[\frac{c}{NV}\right]-1\right)+1>0 \tag{47}$$

$$\leftarrow -\ln\left[\frac{C}{NV}\right] - 1 > 0 \tag{48}$$

$$\leftrightarrow \ln\left[\frac{C}{NV}\right] < -1 \tag{49}$$

$$\leftrightarrow \frac{C}{NV} < e^{-1} \tag{50}$$

$$\leftrightarrow N > \frac{Ce}{V} \tag{51}$$

Therefore, we know that $\left(\frac{C}{NV}\right)^{\frac{1}{N-1}}$ is increasing for $\forall N > \text{Max}\left\{\frac{Ce}{V}, 2\right\}$. Thus,

$$1 > \left(\frac{C}{NV}\right)^{\frac{1}{N-1}} > \left(\frac{C}{\frac{Ce}{V}V}\right)^{\frac{1}{\frac{Ce}{V}-1}} = \left(\frac{1}{e}\right)^{\frac{1}{\frac{Ce}{V}-1}}, \text{ when } N > \frac{Ce}{V} > 2, \text{ and} \tag{52}$$

$$1 > \left(\frac{C}{NV}\right)^{\frac{1}{N-1}} > \frac{C}{2V}, \text{ when } N > 2 > 1 > \frac{Ce}{V}. \tag{53}$$

In the following we use notation

$$k = \frac{C}{\text{Max}\left\{\frac{Ce}{V}, 2\right\}V}^{\frac{1}{\text{Max}\left\{\frac{Ce}{V}, 2\right\}-1}} \tag{54}$$

Then it holds that $1 > \left(\frac{C}{NV}\right)^{\frac{1}{N-1}} > k$.

Next we rearrange the numerator in (42) into a polynomial function:

$$p_1(N) = (N-1)N(V-C) + \left(\frac{C}{NV}\right)^{\frac{1}{N-1}}\left(C(N-1)^2 + N(NV-C)\ln\left[\frac{C}{NV}\right]\right) = N^2\left(V - C + \left(\frac{C}{NV}\right)^{\frac{1}{N-1}}\left(C + V\ln\left[\frac{C}{NV}\right]\right)\right) + N\left(C - V + \left(\frac{C}{NV}\right)^{\frac{1}{N-1}}\left(-2C - C\ln\left[\frac{C}{NV}\right]\right)\right) + \left(\frac{C}{NV}\right)^{\frac{1}{N-1}}C \tag{55}$$

Inside the first coefficient, a_1,

$$C + V\ln\left[\frac{C}{NV}\right] < 0 \text{ when } N > \frac{e^{\frac{C}{V}}C}{V}. \tag{56}$$

Therefore,

$a_1 < V - C + k\left(C + V\ln\left[\frac{C}{NV}\right]\right)$, when $N > \text{Max}\left\{\frac{e^{\frac{C}{V}}C}{V}, \frac{Ce}{V}, 2\right\}$. (57)

Now,

$V - C + k\left(C + V\ln\left[\frac{C}{NV}\right]\right) < 0$, when $N > \frac{C}{V}e^{\frac{C(k-1)+V}{Vk}}$. (58)

Therefore, $a_1 < 0$ when $N > \text{Max}\left\{\frac{C}{V}e^{\frac{C(k-1)+V}{Vk}}, \frac{e^{\frac{C}{V}}C}{V}, \frac{Ce}{V}, 2\right\}$. Hence, $p_1(N) < N^2\left(V - C + k\left(C + V\ln\left[\frac{C}{NV}\right]\right)\right) + a_2N + \left(\frac{C}{NV}\right)^{\frac{1}{N-1}}C$, and

$a_2 < C - V + 1 * \left(-2C - C\ln\left[\frac{C}{NV}\right]\right)$, when $N > \frac{e^2C}{V}$, since (59)

$-2C - C\ln\left[\frac{C}{NV}\right] > 0$, when $N > \frac{e^2C}{V}$. (60)

Therefore,

$p_1(N) < N^2\left(V - C + k\left(C + V\ln\left[\frac{C}{NV}\right]\right)\right) + \left(C - V + \left(-2C - C\ln\left[\frac{C}{NV}\right]\right)\right)N + C = p_2(N)$, when $N > \text{Max}\left\{\frac{C}{V}e^{\frac{C(k-1)+V}{Vk}}, \frac{e^{\frac{C}{V}}C}{V}, \frac{Ce^2}{V}, 2\right\}$. (61)

Then,

$$\begin{aligned} p_2(N) &= \ln\left[\frac{C}{NV}\right](kVN^2 - CN) + N^2(C(k+1) + V) + N(-V - C) + C \\ &= \ln\left[\frac{C}{NV}\right](N^2\left(kV - \frac{C}{N}\right) + N^2(C(k+1) + V) + N(-V - C) + C \\ &< \ln\left[\frac{C}{NV}\right](N^2(kV - C) + N^2(C(k+1) + V) + N(-V - C) + C \\ &= N^2\left(C(k-1) + V + (kV - C)\ln\left[\frac{C}{NV}\right]\right) + N(-V - C) + C \end{aligned} \tag{62}$$

Where, $C(k-1) + V + (kV - C)\ln\left[\frac{C}{NV}\right] < 0$, when $N > \frac{C}{V}e^{\frac{C-Ck-V}{C-kV}}$. (63)

We choose $N_0 = \text{Max}\left\{\frac{C}{V}e^{\frac{C-Ck-V}{C-kV}}, \frac{C}{V}e^{\frac{C(k-1)+V}{Vk}}, \frac{e^{\frac{C}{V}}C}{V}, \frac{Ce^2}{V}, 2\right\} + 1$. (64)

Then,

$$p_2(N) < N^2 \left(C(k-1) + V + (kV - C)\ln\left[\frac{C}{N_0 V}\right]\right) + N(-V - C) + C = p_3(N) \quad (65)$$

$p_3(N)$ is a degree 2 polynomial, which is zero when either

$$N = \frac{C+V+\sqrt{(-C-V)^2-4C(C(-1+k)+V+(-C+kV)\ln[\frac{C}{N_0V}])}}{2(C(-1+k)+V+(-V+kV)\ln[\frac{C}{N_0V}])} = \frac{2C}{C+V-\sqrt{C^2(5-4k)-2CV+V^2+4C(C-kV)\mathrm{Log}[\frac{C}{N_0V}]}} = N_1 \quad \text{or} \quad (66)$$

$$N = \frac{C+V-\sqrt{(-C-V)^2-4C(C(-1+k)+V+(-C+kV)\ln[\frac{C}{N_0V}])}}{2(C(-1+k)+V+(-V+kV)\ln[\frac{C}{N_0V}])} = \frac{2C}{C+V+\sqrt{C^2(5-4k)-2CV+V^2+4C(C-kV)\ln[\frac{C}{N_0V}]}} = N_2. \quad (67)$$

Since (66) is the greater of the two, we conclude that $p_3(N) < 0$ for $\forall N > N_1$. As a summary: $p_1(N) < p_3(N) < 0$ for $\forall N > \mathrm{Max}\{N_0, N_1\}$ and therefore $\frac{\partial \alpha *}{\partial N} < 0$ for $\forall N > \mathrm{Max}\{N_0, N_1\}$. ■

Proof of Corollary 2

The lower bound of the optimal level of excludability in the case of R&D cooperation is

$$\underline{\alpha} = \frac{C}{NV} \quad (68)$$

and its partial derivatives are simply

$$\frac{\partial \underline{\alpha}}{\partial C} = \frac{1}{NV} > 0 \quad (69)$$

$$\frac{\partial \underline{\alpha}}{\partial V} = -\frac{C}{NV^2} < 0 \quad (70)$$

$$\frac{\partial \underline{\alpha}}{\partial N} = -\frac{C}{N^2V} < 0 \quad (71)$$

since *V*, *C*, and *N* all are positive. The upper bound is given by

$$\overline{\alpha} = \frac{2C(N-1)}{NV(N-2)}. \quad (72)$$

Note that this is not binding when $N = 2$. We will therefore proceed to study cases where $N \geq 3$. The partial derivatives are now

$$\frac{\partial \overline{\alpha}}{\partial C} = \frac{2(N-1)}{NV(N-2)} > 0 \tag{73}$$

$$\frac{\partial \overline{\alpha}}{\partial V} = -\frac{2C(N-1)}{NV^2(N-2)} < 0 \tag{74}$$

$$\frac{\partial \overline{\alpha}}{\partial N} = \frac{2CNV(N-2)-2C(N-1)(V(N-2)+NV)}{N^2C^2(N-2)^2} = -\frac{2C(N^2-2N+2)}{N^2V(N-2)^2} < 0 \tag{75}$$

for all $N \in [3, \infty)$. ■

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ESSAY 3

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ESSAY 4

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The division of labor need not imply regional specialization

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ABSTRACT

The regional specialization of economic activities is generally deemed desirable for three reasons: (1) the law of comparative advantage; (2) localized economies of scale; and (3) knowledge spillovers. Taking a methodological individualist perspective, we claim that: (1) the law of comparative advantage, while valid for individuals and firms, does not necessarily imply regional specialization when regions are viewed as consisting of heterogeneous individuals; (2) localized economies of scale are seldom specific to one industry and external in all but the regional level; and (3) the study of knowledge spillovers is inconclusive and would benefit from a more disaggregated perspective.

1. Introduction

The division of labor can be envisaged at the individual, social and spatial levels (Scott, 1986). The first refers to individuals specializing in different tasks within a firm, while in the second case specialization occurs between independent firms. Finally, the spatial level refers to firms specializing in the production of the same type of commodities or services at different geographical scales. The spatial division of labor is thus akin to regional economic specialization and is viewed as a preferable outcome, whether through spontaneous market processes or deliberate public policy planning, by analysts and policy makers who invoke either the efficient geographical allocation of scarce resources through trade or, in the case of dense networks of related firms (such as Silicon Valley), a self-reinforcing setting for innovative behavior (Johansson and Forslund, 2008).

While empirical observations have long challenged the relevance of this perspective to describe some real-world trade and location patterns,[1] several arguments also support the greater desirability of more diversified economies. The most common are transportation costs; localized economies of scope (or urbanization economies) which benefit firms in diverse industries; a greater "multiplier effect" when new activities are added to the local economy; greater resilience than specialized regions

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[1] The most pressing, of course, being the "similar–similar problem" in international trade, i.e., "the huge role in world trade played by exchanges of similar products between similar countries" (Krugman, 2009, 561).

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whose fate rests on the demand for a particular good or service; and "Jacobs" spillovers, i.e., the diffusion and adaptation of technical how-know between different industrial sectors which is said to be facilitated by an economically diversified local economy (Polese, 2005).

We attempt to shed new light on this debate by arguing that the traditional case on behalf of regional specialization is ultimately untenable because of a failure to apply a consistent methodological individualistic perspective to its three main supporting arguments: (1) the law of comparative advantage; (2) localized economies of scale; and (3) knowledge spillovers. Our contention is that while each of these arguments is correct at the individual level, they actually undermine to a large extent the case for regional specialization. Regions, after all, are not single, acting units but are made up of heterogeneous individuals pursuing their separate ends.

The paper is structured as follows. In Section 2, we review the basic tenets of methodological individualism and draw some relevant implications for the study of regional economies. Building on this perspective, we then argue that the division of labor should be thought of along the lines of individual skills and firm competencies, rather than final products or industrial classification systems. As such, it is inapplicable to purposeless units such as cities, regions or countries, and therefore need not imply the regional specialization of economic activities. It is demonstrated that regional specialization is efficient only when it is derivative of individual, not regional, comparative advantages. In Section 4, the argument that the benefits of decreasing costs support the case for regional specialization is similarly found unconvincing in as much as such economies would need implausibly to be internal to a single industry at the regional level and external at the individual, interregional, international and interindustrial levels. We then turn our attention to knowledge creation mechanisms and suggest that the claims that a specialized setting is more (or less) likely to promote the development of new combinations than a more diversified one is problematic in as much as analyses at the regional level are unable to unveil processes that actually take place at the individual level. The last section is our conclusion.

2. Methodological individualism in regional studies

Methodological individualism is a well recognized, if controversial, principle of inquiry in the social sciences.[2] Although there are many versions, its central tenets are that all social phenomena are in principle only explicable in terms of individual interactions in which "any one individual acts (rationally) on the basis of his own aims and interests" and "takes into account the existence of other individuals with aims and interests" (Agassi, 1960, 244). In other words, methodological individualism does not deny interaction between individuals ("methodological atomism") and its fundamental ontological or metaphysical principle is that all social phenomena result from individual beliefs, purposes and actions and should therefore be explained in terms of individuals and their interactions.

A methodological individualistic perspective can be applied to both firm-level and regional studies, for even though management scholars and regional scientists may study the impact of non-social factors on human activities, their foremost task is ultimately to understand social phenomena such as the spatial concentration of production or innovative activities. We suggest, however, that methodological individualism has more important implications for the study of regions than of firms. Of course, there are several notions of regions and possible ways of identifying or classifying them, such as their physical characteristics or cultural commonalities among their inhabitants. More relevant in the context of this paper, however, are factors such as political institutions ("administrative regions") and selective spatial interactions by economic agents, sometimes across political jurisdictions ("functional regions") (Noronha and Goodchild, 1992). As Behrens and Thisse (2007, 458) further observe, regional analysts typically "use interchangeably different, yet equally unclear, words such as locations, regions or places without being aware that they often correspond to different spatial units." Be that as it may, the key issue in our discussion revolves around whether or not regional policy makers should design and try to implement economic specialization policies within their areas of jurisdiction, whatever its geographical size.

While a firm is not an individual unless it is completely operated by one entrepreneur, it is nonetheless a goal-oriented organization with well-defined boundaries that, despite its typically multi-product nature, is built around one or a few core competencies.[3] Outside the context of a centrally planned system, however, geographical units do not share these fundamental characteristics.[4] Thus, a consistent application of methodological individualism implies that only individuals and not "learning regions," "regional networks," or "regional systems of innovation" have skills, capabilities and tastes. Besides, unlike firms, geographical units whose boundaries are arbitrarily defined do not enter and exit markets, nor do they produce or trade goods and services, an argument which similarly applies to countries and therefore to theories of international trade. In short, regions do not act like individuals or even organizations (Boschma, 2004; Frenken and Boschma, 2007). Yet this fundamental difference becomes problematic when, for example, the competing agent is often not clearly defined in the interregional competition literature (Lagendijk and Oinas, 2005). Our contention is that

[2] While ontological individualism is less disputed, the question of whether methodological individualism necessarily ensues is more controversial. More recent debates on the issue revolve mostly around the analysis of individual interactions. Sometimes methodological individualism is mistakenly associated with ethical or political individualism, but the term was originally coined by the economist Joseph Schumpeter to distinguish it from political individualism (Elster, 1982; Hodgson, 2007; Udehn, 2001).

[3] Udehn (2001, 265–272) is a more detailed discussion of methodological individualism in the theory of firm.

[4] Krugman (1994) essentially conveys this point in his critique of the frequent practice of treating competition between nations and firms in a similar fashion.

regions do not act at all (but individuals within them do) or compete against each other (whilst individuals within them might).

A methodological individualist perspective on regional growth and development however, does not imply that local attributes have no effect on individual activities, but rather that they do not unilaterally determine what individuals are capable of doing and what they actually do. As the economist von Mises (1957, 324–325) pointed out in his discussion of geographical determinism, an individual's surroundings "provides on the one hand a provocation to act and on the other hand both means that can be utilized in acting and insurmountable limits imposed upon the human striving for betterment," but while it "provides a stimulus," it does not provide a response.

The socio-spatial ontology historically favored by most economic geographers however, eschews a strict adherence to methodological individualism (Plummer and Sheppard, 2006). One reason for this intellectual stance could be that the *explananda* of regional studies is at a somewhat indeterminate "meso-level"[5] situated between micro- and macrolevels. Another is a rejection of a perspective according to which economic actors are assumed to be fully rational or autonomous and empirical tools too confining for the analysis of complex space-economies (Plummer and Sheppard, 2006). A methodological stance that treats individuals as the basic agents of change however, does not necessarily imply any specific assumptions about their beliefs, preferences and interactions, nor about how to incorporate these into mathematically defined economic models (Arrow, 1994).

Again, our fundamental argument is that individuals, not spatially defined entities, are the appropriate level of analysis, a less controversial claim. Of course, abstraction is often necessary, while acting collective units, such as regions or countries, can be helpful metaphors or examples (Behrens and Thisse, 2007). As a critic of the dominant version of methodological individualism among economists points out however, attributing intent to collectives is a misleading and often unsatisfactory explanatory short cut (Hodgson, 1986).

Our methodological take will therefore include both firms and individuals as acting units. While being usually more than one entrepreneur, the firm is nevertheless a legal entity and a contracting party that is created for a specific goal(s). It is usually made up of several individuals whose specialized tasks and skills are required to accomplish particular ends. The firm's organizational capabilities, or routines, are directly affected by individual skills (Nelson and Winter, 1982, 124), while regions and other geographical units, however, do not share this connection with individuals. In addition, from the perspective of most other economic actors the firm is typically seen as a single entity which is why, in our opinion, it can be studied in accordance with a methodological individualistic perspective within the context of regional economies. Of course, such a perspective would be inadequate to study its inner dynamics and spin-offs created by departing employees.

In short, the perspective put forth in this paper is not merely ontological since we do not insist that every study should depart from the individualistic level, but rather methodological as we argue that an individualistic perspective should be adopted when aggregation affects the derived results. Thus, we suggest that disaggregation becomes necessary when causal explanations are sought in the context of regional growth and development, as will now be illustrated.

3. Comparative advantage and regional specialization

David Ricardo's law of comparative advantage and Adam Smith's division of labor are often treated by analysts as being superficially similar, as both arguments support the geographical specialization of economic activities. There are, however, important differences between Smithean and Ricardian logics and analysis (Buchanan and Yoon, 2002). While Smith explained his idea in terms of individuals and might not have viewed foreign trade as being intrinsically different than trade between individuals (Maneschi, 1998), Ricardo dealt with countries that exchanged goods. According to Smith, trade emerges because specialization is productive due to increasing returns that do not necessarily result from individual differences. In other words, even two individuals possessing similar intellectual and physical endowments will find it advantageous to specialize in the production of different goods, as both will become increasingly efficient over time, and achieve a higher standard of living through trade. In short, for Smith, individual differences were the consequence, not the cause, of the division of labor (Cannan, 1893).

In the Ricardian framework[6] however, "specialization and subsequent trade become advantageous because of the inherent differences among potential trading parties" (Buchanan and Yoon, 2002, 400). In other words, two (or more) countries are better off when each specializes in producing one product and trades the surplus for the other product(s) than they would be in a state of autarky, but only if their opportunity costs differ. In this context, it does not matter if one trading party is better in producing all commodities (i.e., has an absolute advantage in producing every commodity) than the other, since both will always have a comparative advantage in one particular product. By specializing in the production of the goods in which they are relatively better (or least disadvantaged), they can both benefit from transacting with the other. Only

[5] Note that we are referring here to a spatial meso-level, whereas in evolutionary economic geography "meso" typically refers to rule systems (Dopfer et al., 2004) or networks and sectors (Boschma and Frenken, 2006). There is a connection between these concepts, however, since they usually operate at local or regional levels.

[6] Robert Torrens shares the credit of discovering the principle and it was Haberler who later formulated it in terms of opportunity costs (Maneschi, 1998). Interestingly, and contrary to the textbook version, Ricardo had diminishing returns of labor in mind and never suggested complete specialization (Maneschi, 1998, 59).

Table 1
Maximum production capacities of computers and medicine.

	a_1	a_2	A	b_1	b_2	B
Max Q_c	10	5	15	8	10	18
Max Q_m	8	10	18	10	5	15

transportation costs are an exception to the rule that specialization is the desirable outcome, thus leading to the existence of non-traded goods sectors.

The belief that regional specialization is the beneficial outcome of market processes was logically derived from the application of the law of comparative advantage at the sub-national level. This is a general feature of regional economics, where many models and techniques are mere extensions of those used at the national level (Behrens and Thisse, 2007). For example, the economist Yeager (1954, non-paginated) argues that, along with improved transportation, free trade "promotes interregional specialization and increases through trade the results that a country gets from its productive powers." As could be observed at the time of his writing: "Iowa raises corn and hogs, Virginia grows tobacco, and Massachusetts makes shoes. Iowans get their tobacco and shoes from Virginia and Massachusetts, paying in part with money earned by selling corn and hogs outside the state. The people of Virginia and Massachusetts likewise import many products, paying in part with products they do make." The geographer Renner (1955, 511) expressed this idea most forcefully[7] when he stated that with increased commercial competition, "any region will, unless prevented from doing so by political controls, tend to specialize in the production of those commodities for which it possesses a natural or technological advantage" and that "wherever there are several alternative uses for land and other resources, that use which is most advantageous will be selected." Reflecting the widespread influence of Porter's (1990) "cluster" framework, Karlsson and Stough (2002, 1) wrote more recently that economic development "is no longer a question of national specialization and competitive power but of regional specialization often based on clusters and geographical competitive advantages."

The traditional case for comparative advantage has been challenged most prominently by factor based models (Heckscher–Ohlin), the infant industry argument and more dynamic models that all invoke some form of increasing returns. We will now suggest, however, that the apparent incompatibilities of perspectives based on increasing returns and (inherent or learned) differences between acting units can be resolved by a consistent application of the principle of comparative advantage to its logical end (i.e., the individual level), in the process undermining the alleged benefits of regional specialization.

Table 1 illustrates such an outcome in the context of two regions (A and B), each capable of producing and trading two commodities (computers and medicine), and each consisting of two individual subunits ($a_1, a_2 \subseteq A$ and $b_1, b_2 \subseteq B$). The numbers in Table 1 represent the maximum amount of computers and medicine that can be produced in a certain amount of time. What a region can produce is the sum of what the individuals in the region are capable of producing. In the chosen example, these two regions are perfect mirror images of each other. Region A has a comparative advantage in producing medicine $((15/18) < (18/15))$, whereas B has a comparative advantage in producing computers.[8]

In light of regional comparative advantages, region A should specialize in producing medicine and region B in producing computers, resulting in the more desirable total output of 18 computers and 18 units of medicine. As expected, the division of labor in this case delivers a bigger pie as a result of specialization and trade. As will now be argued however, this situation is not optimal. If each individual in regions A and B was to specialize according to their individual comparative advantages, world production could be even larger; a_1 and b_1 could thus produce 10 computers, whereas a_2 and b_1, by specializing in the production of medicine, could produce 10 units of the latter. The total world production would therefore be 20 computers and 20 units of medicine, higher for both goods than would be the case under the conventional regional specialization scenario.

How is this result derived? Our example does not question the validity of comparative advantage and specialization when there are differences in opportunity costs. We argue however, that these differences should be analyzed at the most disaggregated level possible. This example could be criticized on the basis that there are more agents than goods, but the case against regional specialization would also hold in n-good and n-agent models.[9] Otherwise, it is conceivable that some commodities would not be produced.

If regions within a country differ in terms of comparative advantages, they should specialize according to those differences. The same logic holds true, however, when individuals within a region are heterogeneous, i.e., specialization should ultimately come down to the individual level. In theory, regional specialization is optimal only when the individuals within a region have the same comparative advantage, as compared to the individuals in another region (see Appendix A for the proof). Even in such a case however, regional specialization is derivative of individual specialization, not the other way around.

Individual comparative advantages are partly affected by their local or regional circumstances. For this reason, it could be that theoreticians, from Ricardo who did not explain the origins of technological differences (or labor productivities)

[7] Renner (1955) does not specify what type of advantage he has in mind to back up his argument.
[8] In the example, the comparative advantages are also absolute advantages, but this does not affect the results.
[9] See Deardorff (2005) for list of assumptions under which comparative advantage does and does not hold.

between countries to the more recent models offered by Fujita et al. (1999), have mostly discussed comparative advantages in terms of geographical attributes, especially in the context of agricultural production. Besides natural factors (landscape, climate, mineral endowments, etc.), however, individual comparative advantages are also determined by skills, technical know-how and human capital, whichever concept one prefers, that can also vary within a region. It would be reasonable to expect their importance to be significant, especially in the context of a modern service-oriented or "knowledge-intensive" economy.

The optimality of regional specialization becomes increasingly unlikely if we consider comparative advantages in dynamic, rather than static, circumstances.[10] Changing demand and supply factors can transfer the comparative advantage from one product or service to another. Individual skills are not static either. Individuals might not just improve in terms of what they have been doing up to one point in time, but they might also find their talents or skills useful in another setting or line of work. In the course of time, new production possibilities appear. Therefore, even if regional specialization happened to be the derivative of individual specialization, it would likely remain so only temporarily.

Recently, Unger (2007, Ch. 2) criticized the "doctrine" of comparative advantage on the grounds that there are multiple possible solutions depending on the choice of the model, while no considerations of dynamic properties or different institutional settings are included. As a result, no top-down blueprint is possible and no answer can be given as to what production a given country or region should specialize in. However, our contention is that the actual division of labor should be a bottom-up process, and that the law of comparative advantage, if useless as a specific policy guide, nonetheless retains its value as a vehicle for conveying the mutually beneficial character of trade.

To summarize, while fundamentally correct at the individual level, the law of comparative advantage is too easily taken as a sufficient argument for regional specialization. This in turn, opens the doors to skeptics such as Driskill (2007) for whom the argument for the mutually beneficial character of trade collapses, because individual-model analogies are inadequate for actual trading situations where several heterogeneous individuals are involved. Again, our position is not the latter, but rather that regional specialization can only be theoretically efficient when individuals within a region possess the same comparative advantages.

4. Localized economies of scale and scope

While regional specialization is in most cases inefficient from the perspective of individual opportunity costs and aggregate output, one could argue that such inefficiencies could be countered by the positive externalities generated as an outcome of individuals congregating in different locations on the basis of identical or closely related skills. Such a perspective can be found in Krugman (1987) dynamic model of comparative advantage based on the concept of 'learning-by-doing' (Arrow, 1962a).[11] One rationale for increasing returns is thus localized economies of scale.

In the case of an individual firm, economies of scale arise in a situation "when the increased size of a single operating unit producing or distributing a single product reduces the unit cost of producing or distributing" (Chandler, 1990, 17). In a regional economy, localized economies of scale arise when the addition of a new firm in a region reduces unitary costs for all firms in the region. This cost reduction takes place indirectly via reduced costs of skilled labor, intermediate inputs, transportation, financing, marketing, infrastructure, etc., as a result of increasing demand for these products and services when they are characterized by decreasing marginal costs.

Since regional specialization implies a concentration of several similar firms, the mere existence of decreasing costs is clearly insufficient in this respect. As Maskell (2001) has noted, an agglomeration theory of localized economies of scale should explain why there is a cluster of N co-localized firms of size S undertaking related activities, rather than a single firm of size $N \times S$ producing the same goods or services. In other words, these economies of scale need to be external to a firm but internal to a region, otherwise a firm could achieve identical results simply by expanding its output, in which case there would be nothing regional about these economies (see also Parr, 2002). As Stigler (1951, 186) put it, if economies are internal to an industry, then the resulting organizational configuration would tend towards monopoly. For regional specialization to be an optimal outcome, however, such economies also need to be local and thus unattainable beyond regional boundaries.

By analogy, Ethier (1979) has demonstrated in the case of international trade that if increasing returns depend upon the size of the world market rather than national output, the tendency towards interindustry specialization disappears and intraindustry trade in intermediate goods emerges. The perfect internalization of localized economies of scale would require immobility of labor and intermediate goods between regions. In addition, it is less clear whether the cost of a skilled labor force would be lower when N co-localized firms are competing for it. Conversely, a single firm of size $N \times S$ would have some monopsony power in the labor market. Again, the assumption underlying localized economies of scale seems to be that a region is a coherent acting unit, while no attention is paid to realistic microfoundations.

To make this point more apparent localized economies of scale can be broken down in two distinct categories, localization and urbanization economies, with the former being available to all local firms within the same sector whereas the latter are

[10] According to Maneschi (1998), while being a useful pedagogical device, the textbook 'Ricardian' model does not do full justice to Ricardo's insights into the dynamic aspects of international trade.

[11] Krugman's argument can be summarized as follows: "It is not the case that nations specialize in what they are good at so much as they are good at what they specialize in" (Pinch and Henry, 1999, 816).

available to all local firms irrespective of sector (Parr, 2002). Therefore, only localization economies are specific to regional specialization, whereas urbanization economies are achieved by mere agglomeration, irrespective of the line of work local firms are active in. Yet there is often a connection between agglomeration and diversity. As increasing agglomeration tends to reduce the degree of specialization (Ricci, 1999), growing cities, just like growing mature ecosystems, tend to get more diversified over time (Jacobs, 1969).

In as much as localization economies are not urbanization economies, human capital and other inputs must be specific to only one industry. If however, these inputs can be used profitably elsewhere, they yield localized economies of scope. In the case of individual firms, economies of scope are “those resulting from the use of processes within a single operating unit to produce or distribute more than one product” (Chandler, 1990, 17). At the regional level, the geographical concentration of firms engaged in diverse lines of work can sometimes achieve a similar result, a phenomenon now sometimes referred to as Jacobs externalities (Frenken et al., 2007).[12] Localized economies of scope occur from making use of the same raw and semifinished materials and the same intermediate processes, such as distribution or marketing, to “handle more than a single product line” (Chandler, 1990, 41). Since research and development is even less product specific in terms of facilities and organizational capabilities, the opportunities to exploit economies of scope are even greater (*ibid.*). If however, economies of scope are internal to a firm, the result should theoretically be a multi-product firm (Panzar and Willig, 1981). Hence localized economies of scope should be external to firms, providing a rationale for firms to co-locate.

But as in the case of similar co-located firms, this begs the question as to why several firms are operating within one product chain rather than simply merging into one large vertically integrated firm, or several firms producing different products rather than one multi-product firm. While the relationship between organization and transaction costs has typically been used to explain the former (Coase, 1937), it might be that the gains from the (social) division of labor could be another part of the answer; expanding the activity beyond one’s core competencies could mean facing increased costs as economies of scope are thus external to a firm.

In the case of localized economies, labor and other inputs must *de facto* be so specialized that they cannot be used in production, distribution or research in other lines of work. Such a situation makes these suppliers completely dependent on the parent industry. However, the driving force in the growth of the modern industrial enterprise and industrial capitalism has been to exploit organizationally based competitive advantages such as economies of scope (Chandler, 1990). In other words, firm managers continually and actively look for such economies, as well as opportunities to work with or expand into different industries; a rationale which can ultimately be traced back to newly generated know-how with other potential applications (Teece, 1980).[13] We thus suggest that regional diversity provides arguably better circumstances for the discovery and development of new economies of scope when the required resources to exploit them are relatively more accessible.

Localized economies of scope are arguably harder to detect than localized economies of scale. This feature is even stronger when these economies are built on know-how that is not easily observable to outsiders. For example, firms active in different industries can use the same inputs, networks, distribution channels and specialized consultants, or else produce goods and services for each others’ use. There are numerous possibilities in this respect and it is less clear why the benefits of agglomeration would necessarily be greater when all firms are engaged in the production of similar outputs. At this point, the debate is an empirical question and the effect of localization economies must be compared with those of localized economies of scope, which are due to facilitative industries or other industrial interrelationships (Renner, 1947).

Often forgotten in abstract discussions of regional economic infrastructure, however, is the fact that, by their very nature, some production activities directly benefit from the co-location of dissimilar production activities. Most striking in this respect is a type of linkage now typically referred to as “industrial symbiosis” in which the unavoidable residuals of one line of work become the valuable input of another (Chertow, 2000; Jacobsen, 2006). Although often thought of as a recent phenomenon, much historical evidence suggests that industrial symbiosis is as ancient as economic activity. To give a few historical illustrations, glue factories were often located in close proximity to meat-packing and fish processing plants in order to have easy access to their non-edible residuals. Some cement and glass plants were built adjacent to steel producers in order to use their slag. The origins of countless firms in the modern petro-chemical industry can be traced back to ventures that initially fed on the residuals of coal gas and petroleum refining operations (Desrochers, 2008, 2009).

Interestingly, the recent “rediscovery” of industrial symbiosis paved the way for a few planning exercises through which public officials attempted to develop local economies around by-product linkages. While so-called “eco-industrial parks” have typically failed to live up to expectations in practice (Deutz and Gibbs, 2004), their planning stage has nonetheless highlighted the fact that specialization-oriented cluster development is fundamentally incompatible with the spontaneous emergence of industrial symbiosis. Indeed, a recurring argument in this literature is that local diversity increases the probabilities of developing commercially successful symbiotic relationships (Korhonen, 2005; Templet, 1999, 2004; Wells and Darby, 2006).

[12] Frenken and Boschma (2007, 642) note that Jacobs externalities are economies of scope at the regional level. The explanation for such a macro phenomenon should however stem from economies of scope at the individual level. In the following section, we further distinguish such “Jacobs externalities” from the geographically localized interindustrial knowledge diffusion process referred to as “Jacobs spillovers.”

[13] This idea comes close to so-called ‘related variety’ (Frenken et al., 2007). However, it should be kept in mind that due to generic skills and know-how, different industries can be related in many ways, most of which are indirect.

It seems that while the relative importance of localized economies of scale and scope is ultimately an empirical question, it once again leads us back to the issue of whether skills (or human capital) used in the production of certain final goods, along with services and capacities used for the production of intermediate goods for those industries, are bound to be so specialized that they cannot be used in other lines of work. While such specificity varies between industries, our contention is that the opposite is often truer. Many functions in firms are performed by specialists such as sales and marketing people, accountants, R&D personnel, engineers and technicians with particular expertise, and so on. These occupations show a deep division of labor at the individual level, but they can be used in a wide variety of businesses and industries. For suppliers, specialization in cross-cutting base processes, base components or base services enables the development and retention of large and diverse customer bases (Sturgeon, 2002). Indeed, as Marshall (1923, 10) observed last century in the context of industrial machinery:

> *Modern work is more narrowly specialized*, *in so far as the number and variety of the operations performed by a modern worker are on the average less than those of elementary skilled handicraftsman*; *but it is less narrowly specialized*, *in the sense than an operative*, *who has mastered the accurate*, *delicate and prompt control of machinery of any kind in one industry*, *can now often pass, without great loss of efficiency*, *to the control of similar machinery in an industry of a wholly different kind*, *and perhaps working on different material.*

As argued above, a dynamic view of localized economies of scope implies that firms are constantly looking for new ways to put their specific capabilities to new uses. In addition to cost advantages, firms and individuals might adopt this strategy for 'portfolio' reasons, as they do not want to become too dependent on one product line due to changing demand conditions, new competition, or potential offshoring. Again, it is logical to believe that firms will be in a better position to find and develop new economies of scope in a diverse region due to perceptible local opportunities.

While the above remarks deal mostly with supply-side issues, it should be appreciated that demand conditions, i.e., the extent of the market, were important for Adam Smith's argument on behalf of the benefits of the division of labor. First, with nonhomothetic preferences, consumption patterns will change as income grows, resulting correspondingly in more diversified production patterns (Imbs and Wacziarg, 2003). Second, when markets expand due to potential trading partners, greater specialization becomes feasible. Through wider markets, individuals can specialize in completely new tasks. This process however, implies specialization within societies, not between them. Thus, the increasing division of labor due to expanding markets *à la* Adam Smith suggests that a larger market makes individual specialization feasible, but not that regions should become more specialized.[14] This proposition is further supported by the first formal research on the mutual dependence between the division of labor and the extent of the market, demonstrating that firms become more specialized when the total population increases (Zhou, 2004).[15]

The division of labor is not the same as regional specialization. Indeed, Kim (2006) has proposed that the former should be measured by the level of industrial diversification. Many studies have suggested that it would be beneficial for firms to locate in cities and industrial regions characterized by a pre-existing abundance of other firms. However, since there are many sources for agglomeration economies, finding evidence of their existence is not the same as identifying their source (Hanson, 2001). Congruently, neither should the empirical fact of the existence of specialized regions be taken as an evidence of the superiority of regional specialization. As could perhaps be expected, empirical studies on agglomeration economies seem very context-dependent (Melo et al., 2009). To gain better understanding of the sources of these economies, studies at the firm-level, rather than at the aggregate or regional level are called for.

5. Knowledge spillovers

In their influential paper, Glaeser et al. (1992) sum up "dynamic" arguments on behalf of industrial agglomeration under the heading of MAR (for the insights of economists Marshall, 1890; Arrow, 1962a; Romer, 1986), (management scholar) Porter (1990) and (urban theorist) Jacobs (1969) knowledge spillovers. Since knowledge spillovers are especially sensitive to the "friction of distance," they provide a rationale for firms engaged in the same or similar industry to co-locate, with the primary intermediating mechanism in diffusing knowledge usually thought to be interacting skilled labor within the industry. MAR and Porter spillovers are similar in as much as they occur within the same industry, but differ to the extent that the former suggest that large and resource-rich firms are most likely to capture them, while the latter views a region with numerous small and fiercely competing firms as the best incubator. By contrast, Jacobs spillovers are based on the idea that innovation results from new combinations and "new work being added to old" across different industries, often through the interaction of people possessing different skill sets and know-how. Jacobs spillovers thus support the contention that a diverse region will be more innovative.

[14] According to Richardson (2003, 92–93): "Later theorists responsible for the model of perfect competition, so influential since its development a century after Smith, in effect rejected this famous principle (the division of labor is limited by the extent of the market) by assuming the existence of many firms doing the same thing."

[15] The total number of goods however, is exogenously given in the model. Without such restrictions, individual specialization and the heterogeneity of production patterns would most likely increase.

Malmberg and Maskell (2002) consider knowledge creating mechanisms a more valid explanation for agglomeration than cost savings. Variation between different firms, both at the horizontal and vertical levels, creates knowledge which is too extensive to be captured in its entirety by a single firm, no matter its size. Additionally, the tacit or unarticulable character of much useful knowledge and the importance of face-to-face interaction in its communication is said to explain why knowledge spillovers occur mostly within regional boundaries.[16]

Tacit knowledge usually refers to skills, capacities or unconscious dispositions to act, but it remains unclear why these would be key components of innovative behavior. A more plausible view is that while much knowledge could be codified (i.e., turned to information), "being there" displaces this need and delivers the same (or better) results at a fraction of the cost. Individuals working for a firm can observe novel ideas being developed in particular circumstances and learn spontaneously without searching for new knowledge (Malmberg and Maskell, 2002). For insiders, there might not be any incentive to codify and distribute this knowledge, while outsiders would first have to know what to look for before they could search for it. In addition, it would be hard, if not impossible, for third parties to act as intermediaries and trade the knowledge due to Arrow (1962b) information paradox.[17]

Much empirical work has been conducted on the relative importance of intra- and interindustrial knowledge spillovers, and both types have found support in different contexts (Döring and Schnellenbach, 2006). Partially due to this lack of decisive results, new approaches that would be more squarely based in methodological individualism (without using the exact term) have been called for. Hansen (2002, 261) thus writes that regions, networks and information technologies are innate entities that cannot learn or innovate, and that "more meaningful analyses" would require "disaggregated empirical studies of how knowledge in fact passes among persons." Similarly, Breschi and Lissoni (2001) describe localized knowledge spillovers as a 'black box,' since studies on the topic do not prove or even document their existence. In their opinion, this debate would benefit from "additional evidence on the identity and the activities of individual firms and inventors" (*ibid*. 1001). In short, more disaggregated data and hypotheses on how knowledge in fact passes among individuals, the effect of regional factors on these processes, and how these processes ultimately result in greater innovativeness, would reduce the discrepancy between empirical and theoretical models.

At the moment researchers are perplexed about what knowledge is transferred, how it is transferred, and what the role of the local economy is in this respect (e.g. Brenner, 2007; Henderson, 2007). Studying how individuals innovate by recombining different know-how and artifacts can nonetheless shed much light on the issue. Using as our point of departure Jacobs' insight, we conducted a qualitative survey of individual inventors in which we identified three broad, although not mutually exclusive, sets of circumstances through which individuals found new uses or applications for existing products and created new combinations of existing products, processes and materials: (1) by adding to, switching or adapting specific know-how to other lines of work; (2) by observing something in another line of work and incorporating it into one's own line of work; and (3) through formal and informal multidisciplinary teams working towards the creation of new products and processes (Desrochers and Sautet, 2007).

Besides studying the individual creative process, taking account of differences between and within industries could also shed more light on the debate (Oinas and Lagendijk, 2005). Be that as it may, a case can be made that current knowledge spillovers research is caught in a circular causality bind similar to the cost advantage argument. In other words, while knowledge spillovers supposedly explain the existence of agglomeration, the geographical agglomeration of economic activities is now taken as evidence of the existence of knowledge spillovers.

6. Conclusion

Our goal in this paper was to examine critically the arguments traditionally used to make the case for the regional specialization of economic activities through the consistent application of the principle of methodological individualism. Cast in this light, comparative advantage was found problematic when regions are viewed as consisting of heterogeneous individuals. Indeed, if individuals differ in terms of opportunity costs, a consistent application of the principle of comparative advantage reveals that regional specialization becomes inefficient. Gains from specialization or the division of labor are reaped when all individuals in a society specialize in things they do best (in a comparative sense), not when everyone specializes in doing the same thing. It is specialization according to individual, not regional, comparative advantages which guarantees efficiency.

What then should be the role of regional policy when specialization is a matter of individual comparative advantages? In our opinion, the relevant question becomes "who knows these comparative advantages best?" Following Hayek (1948) seminal writings, we suggest that it is very difficult and rare for individuals working for a central planning authority to know more or even as much as all the individuals living within a particular polity. While we may grant the (heroic) assumption that a group of experts knows the overall maximum production of different commodities, and can thus establish regional

[16] It must be pointed out, however, that the concept of tacit knowledge has long been criticized on several counts. For example, is tacit knowledge uncodifiable in principle or is it simply difficult to codify (Brökel and Binder, 2007, 153–154)? Perraton and Tarrant (2007, 354) go so far as stating that tacit knowledge "is merely a term given to a phenomenon that the observer does not understand; as such, it has no explanatory content."

[17] "[T]here is a fundamental paradox in the determination of demand for information; its value for the purchaser is not known until he knows the information, but then he has in effect acquired it without cost." (*ibid*. 615).

comparative advantages on this basis, our demonstration suggests that top-down regional specialization would only deliver the optimal outcome when every individual within the region possesses the same comparative advantage. In all other circumstances, "bottom-up" market processes through which individuals specialize according to their comparative advantages would result in a greater degree of diversity. The law of comparative advantage is therefore not a sound justification for publicly planned regional specialization. This does not mean that regional specialization can never be beneficial; indeed, there are plenty of well-documented cases of thriving regional clusters. Our claim is only that regional specialization should not be viewed as the ultimate goal for policy makers. Furthermore, most persistent regional clusters have arisen largely spontaneously, at least in their initial stage (Desrochers and Sautet, 2004).

In a dynamic economy where individual comparative advantages are constantly being created and lost, the challenges for regional policy are even more profound. Regional specialization policy thus increases the danger of lock-in and weakens the capacity of local actors to adjust to changing circumstances. Again, we believe that individuals as economic agents are better equipped to notice and create new opportunities than any centralized authority, and that advantage is increased when people differ in terms of perspectives, backgrounds and abilities (Heath, 2007).

In addition to geographical differences, cost advantages can be achieved through specialization in the presence of decreasing costs. Arguably, sharing the cost of infrastructure is beneficial from a firm's perspective, but such structures are seldom unique to an industry. Furthermore, in addition to be specific to an industry, localized economies of scale should be somehow internal to a regional setting, but external to a firm or to any spatial unit larger than a region. To be satisfactory as a causal factor, localized economies of scale would need to explain the additional benefits they provide to what individual firms can achieve by themselves.

Knowledge creation mechanisms, such as knowledge spillovers, are arguably more internalized through close geographical proximity and a more convincing explanation for agglomerative tendencies. Recent empirical tests, however, have found support for both intra- and interindustrial spillover theories, while being unable to document their existence. Interestingly, while knowledge spillovers were supposed to explain the existence of industrial agglomeration, the ubiquitous fact of industrial agglomeration is now invoked to prove the existence of knowledge spillovers. More disaggregated approaches are hence called for.

Assuming that our analysis is correct, we will now venture a rejoinder to the Nobel laureate Paul Samuelson's (1969, 9) 'comparative advantage' answer to the mathematician Stanislaw Ulam's challenge to name "one proposition in all of the social sciences which is both true and non-trivial." Samuelson argument was on the following grounds: "That it is logically true need not be argued before a mathematician; that it is not trivial is attested by the thousands of important and intelligent men who have never been able to grasp the doctrine for themselves or to believe it after it was explained to them." And yet, while it is true and non-trivial in the context of individuals, such as Samuelson's famous example of the best lawyer/typist in town, it does not logically follow that the same holds true in the context of regions or nations. Indeed, what "many intelligent men (and women)" have probably always objected to is the subsequent step in the argument that regions or nations should similarly specialize in one commodity or service that will inevitably be subjected to economic downturns and/or decrease in economic value over time. In the end, it might be that this apparently trivial insight has escaped generations of economists.

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Appendix A. Appendix A

A.1. Regional Specialization and Individual Opportunity Costs

The following is to demonstrate that regional comparative advantage is not sufficient in itself for regional specialization to be efficient. As illustrated, this can only be the case when all individuals within the region have a comparative advantage in the commodity in which the region specializes.

In this model there are two regions (the second is separated with *) and two individuals within each region. There are also two goods, medicine (m) and computers (c), and the production possibility curve between the two is

$$Q_m^i = \frac{L^i}{a_m^i} - \frac{a_c^i}{a_m^i} Q_c^i.$$

The production of each region is the sum of the production of individuals within the region $Q_m = Q_m^1 + Q_m^2$ and $Q_m^* = Q_m^{*1} + Q_m^{*2}$ (and similarly for computer production).

We assume that the first region has comparative advantage in computer production:

$$\frac{a_c}{a_m} \leq \frac{a_c^*}{a_m^*}.$$

Our target function is the overall production of medicine

$$Q_m + Q_m^* = \frac{L^1}{a_m^1} - \frac{a_c^1}{a_m^1}Q_c^1 + \frac{L^2}{a_m^2} - \frac{a_c^2}{a_m^2}Q_c^2 + \frac{L^{*1}}{a_m^{*1}} - \frac{a_c^{*1}}{a_m^{*1}}Q_c^{*1} + \frac{L^{*2}}{a_m^{*2}} - \frac{a_c^{*2}}{a_m^{*2}}Q_c^{*2}.$$

The inequality constraint is $Q_c^1 + Q_c^2 + Q_c^{*1} + Q_c^{*2} \geq (L^1/a_c^1) + (L^2/a_c^2)$,

which means that the computer production has to be at least as much as when both individuals within the first region produce only computers.

If the optimal solution is such that the first region specializes in computers ($Q_c^1 = (L^1/a_c^1), \quad Q_c^2 = (L^2/a_c^2)$) and the second in medicine ($Q_c^{*1} = Q_c^{*2} = 0$), from the first order conditions we get that $(-a_c^1/a_m^1) + \lambda = (-a_c^2/a_m^2) + \lambda = 0$ and therefore $\lambda = (a_c^2/a_m^2) = (a_c^1/a_m^1)$. Since other conditions tell us that $(-a_c^{*1}/a_m^{*1}) + \lambda \leq 0$ and $(-a_c^{*2}/a_m^{*2}) + \lambda \leq 0$, we have that $(a_c^1/a_m^1) \leq (a_c^{*1}/a_m^{*1})$, $(a_c^1/a_m^1) \leq (a_c^{*2}/a_m^{*2})$, $(a_c^2/a_m^2) \leq (a_c^{*1}/a_m^{*1})$ and $(a_c^2/a_m^2) \leq (a_c^{*2}/a_m^{*2})$.

Regional specialization is efficient only when both individuals within the region have a comparative advantage in the good in which they are specialized compared to both individuals in the other region.

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Opening up the 'Jacobs Spillovers' black box: local diversity, creativity and the processes underlying new combinations

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Abstract

Despite numerous attempts to isolate the respective importance of intra- and inter-industrial localized knowledge spillovers, their underlying processes have remained hidden. This article aims to provide a better theoretical understanding of the nature of inter-industrial or 'Jacobs spillovers' through a broad interdisciplinary literature review and additional evidence gained from a qualitative survey of Canadian inventors. The main stylized processes identified are: (i) adding to, switching or adapting specific know-how to other product lines; (ii) observing something and incorporating it in another environment; and (iii) formal or informal collaboration of individuals possessing different skills and backgrounds. Local economic diversity was found to facilitate these processes in several ways.

Keywords: knowledge spillovers, Jane Jacobs, local diversity, creativity
JEL classifications: O18, O31, R11, L60
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1. Introduction

Following Glaeser et al.'s (1992) influential article, several econometric studies have attempted to assess the relative importance and impact of localized knowledge spillovers[1] through the lenses of economists Alfred Marshall (1890), Kenneth Arrow (1962) and Paul Romer (1986) (known by the acronym MAR); management scholar Michael Porter (1990); and urban theorist Jane Jacobs (1969). While they differ on the issue of firm size and number (one large versus several smaller competing firms), MAR and Porter emphasize the relatively greater economic importance of intra-industrial knowledge spillovers that result from the frequent interaction of workers possessing

1 Our discussion of knowledge spillovers does not assume that they are necessarily knowledge *externalities* for two reasons. First, not all important knowledge transmission mechanisms are externalities in the economic sense (Breschi and Lissoni, 2001). Second, in empirical research, as in our case studies, the criteria of knowledge externality (i.e. free and unpreventable benefits for third parties) are hard if not impossible to certify.

similar or closely related skills, a stance which supports the regional specialization of economic activities as a more innovative setting. By contrast, Jacobs is said to argue that local economic diversity facilitates interactions between individuals possessing different knowledge bases, resulting in more innovation and better economic performance. Various analysts have claimed statistical evidence on behalf of either or both types of spillovers using empirical tests based on unrelated inputs (greater or lesser regional diversity or specialization of larger or smaller firms) and outputs (such as Research and Development expenditures, patents, job creation, economic growth per capita and innovation counts) (Beaudry and Schiffauerova, 2009).

The MAR–Porter–Jacobs studies, however, have been criticized on at least two fundamental levels. The first is that knowledge spillovers account for whatever measure of growth or innovation is arrived at, a stance which neglects the obvious importance of factors such as urbanization economies, a sudden increase in the global demand for some locally-produced goods or services, and the fact that a growing economy is more likely to attract diverse types of businesses than a stagnant one (Hansen, 2002; Polèse, 2005; Brenner, 2007; Henderson, 2007). The second is that 'virtually no contribution has explored the ways in which knowledge is actually transferred among people located in the same geographic area' and that knowledge spillovers are a convenient 'black box' providing researchers 'with an escape route to avoid studying the specific mechanisms through which (geography and innovation) are linked' (Breschi and Lissoni, 2001, 994, 976). In a recent review of 67 such studies, Beaudry and Schiffauerova (2009, 320) not only observe that the 'exact spillover mechanism is not yet fully understood and documented', but also that there is 'no direct proof of the existence of knowledge spillovers' and that 'there probably never will be'. In a recent meta-analysis, de Groot et al. (2009) found that while the positive effects of diversity seem stronger, it is also the case that different aspects of study designs influence outcomes. In addition, another meta-study by Melo et al. (2009) found that estimates for agglomeration economies, more broadly, may have little relevance beyond specific empirical contexts. Puga (2010) further argues that among the causes of agglomeration economies, learning in cities and its microeconomic foundations are the least understood (see also Rosenthal and Strange, 2004). Disaggregated and more detailed approaches could thus improve our understanding of the root causes of knowledge spillovers and observed differences between empirical studies.

The criticism levelled at the various methodologies and indicators used in the localized knowledge spillovers literature should not be considered surprising inasmuch as they do not radically differ from those used in previous and similarly unsatisfactory studies on the measurement of local diversity and of technology flows between industries.[2] Following Hansen (2002), we suggest that the only way forward in this debate is to document how innovative know-how is actually created, diffused, adapted and combined by *individuals* with different occupations, skills and backgrounds. Because much has already been written on localized intra-industrial knowledge spillovers in numerous qualitative studies of 'industrial districts', 'innovative milieux',

2 Econometric studies on the latter topic have been conducted under various labels such as 'inter-industry technology flows,' 'technological convergence,' 'techno-economic paradigms' and 'general purpose technologies.' Attempts to measure local diversity were often motivated by 'local economic base' and 'portfolio' considerations. The main conceptual problems of these studies are examined in more detail in Desrochers (2001).

'clusters', 'regional systems of innovation' and 'learning regions' (Rutten and Boekema, 2007), our focus is on Jacobs (or localized inter-industrial) spillovers.

The remainder of the paper is structured as follows. Section 2 discusses the emergence and shortcomings of 'Jacobs spillovers' in the economics literature and identifies precedents of this perspective. We then review the economic and cognitive rationales underlying new combination of existing artifacts, materials and know-how. In section 4, we further document these patterns and discuss the importance of local economic diversity and the recent 'related variety' controversy through illustrative evidence collected in two qualitative surveys of Canadian individual inventors. Drawing on this material, our conclusion contains further thoughts on the current 'creative class' and 'social proximity' debates. As such, our contribution is limited to theory-building and does not attempt to isolate or measure the specific impact of Jacobs spillovers.

2. Local economic diversity and new combinations

Jane Jacobs' (1969, 3) own favorite book, *The Economy of Cities*, was the outcome of her 'curiosity about why some cities grow and why others stagnate and decay'. Looking at cities as problems in organized complexity, she developed a dynamic theoretical framework that combined previously unrelated issues and insights gleaned from a wide array of sources and disciplines. Without getting into the details of her contribution, she proposed a new theory of agricultural origins and discussed, among other subjects, the sources of technically innovative behavior, the relocation of mature urban industries to rural areas, the importance of agglomeration economies for new business formation, the sources of financial capital for new ventures and the economic impact of political barriers to entry in various lines of work. Her overall conclusion was that high and sustained levels of innovative behavior and entrepreneurship inevitably result in the increased diversification and complexity of the local economic base over time and that a diversified urban economy provides the best setting for entrepreneurial and innovative behavior. As she would argue in a later book: 'The usefulness of cities is that they supply contexts... in which insights and adaptations can be successfully injected into everyday economic life' (Jacobs 1984, 193).

Lucas' (1988) and Glaeser et al.'s (1992) characterization and emphasis of what came to be known as 'Jacobs spillovers', however, is better understood as a rejoinder to then current debates on the *New Growth Theory* (NGT). In short, while NGT theorists' highlighted the importance of human capital and knowledge spillovers, their effort amounted to developing 'a theory of knowledge production that tries to do an end run around describing the creative act that produces the new ideas' (Weitzman, 1998, 332). The Jacobsian insight that Glaeser et al. (1992, 1131–2) deemed most relevant in this context was that 'the crucial externality in cities is cross-fertilization of ideas across different lines of work'. As Jacobs (1969, 59) indeed observed, 'the greater the sheer numbers and varieties of divisions of labor already achieved in an economy, the greater the economy's inherent capacity for adding still more kinds of goods and services. Also the possibilities increase for combining the existing divisions of labor in new ways'.

Most of Jacobs' examples illustrating the importance of local economic diversity, however, are entrepreneurial in nature and typically involve the launching of a spin-off or start-up business that occupies a new niche by building on existing skills and diverse local suppliers and customers. For instance, a 'chest and wardrobe manufacturer is starting, for a fee, to analyze what is wrong with one's household or office storage arrangements; a playground designer is starting to make and sell equipment for playgrounds and nursery schools; a sculptor is starting a line of jewelry' (Jacobs 1969, 53–4). Consistent with the Glaeser et al. (1992) framework, however, the various (and typically imprecise) definitions of 'Jacobs spillovers' used in later econometric studies refer to cases of technology breakthroughs or transfers involving the application of skills and know-how used in one context to another existing business active in a different line of work. To our knowledge, the only such straightforward case provided by Jacobs (1969) herself involves the transfer of skills used in making and setting of sails to the creation and display of a huge street banner when a retired sailmaker was called upon by protesters. Another relevant issue in this context is that most analysts of localized knowledge spillovers have ignored Jacobs (1969, 61) comment that while industrial classification systems are useful for some type of analysis, 'insofar as they are relevant at all to understanding how old work leads to new, they interfere with our understanding'.[3]

As we will later argue in more detail, the Jacobs spillovers argument is commonsensical in light of what is known about human creativity, at least inasmuch as innovations are always the results of new combinations of pre-existing know-how, skills, ideas, processes, materials and artifacts (Sternberg, 1999; Gassman and Zeschky, 2008). The pairing up of local specialization and creativity, however, seems odd and results perhaps from the mistaken application of the idea of specialization from the individual to the regional level (Leppälä and Desrochers, 2010). To sum up, creativity 'generally involves crossing the boundaries of domains' while creative people typically 'love to make connections with adjacent areas of knowledge' (Csikszentmihalyi, 1997, 9). Indeed, successful creative individuals tend to be 'ever alert to what colleagues across the fence (i.e. in other disciplines) are doing' (idem: 88). In this context, creativity can be defined as 'any act, idea or product that changes an existing domain or that transforms an existing domain into a new one,' while a creative person is 'someone whose thoughts or actions change a domain, or establish a new domain' (idem, 28).

Prominent economic analysts going back at least to Adam Smith have taken note of the combinatory nature of innovation (Desrochers, 2001). For example, Usher (1929, 11) observed that invention 'finds its distinctive feature in the constructive assimilation of preexisting elements into new syntheses, new patterns, or new configurations of behavior.' Ayres (1943, 113) wrote that 'the history of every material is [. . .] one of novel combinations of existing devices and materials in such a fashion as to constitute a new device or a new material or both.' Machlup (1962: 156) distinguished between the 'retardation school' of technological change whose proponents believed that 'the more that has been invented the less there is left to be invented' and the 'acceleration school' according to which 'the more that is invented the easier it becomes to invent still more' because 'every new invention furnishes a new idea for potential combination with vast numbers of existing ideas' and the 'number of possible combination increases geometrically with the number of elements at hand.'

3 The functional (as opposed to end use) classification of the patent system is less problematic in this respect, although patent data have other problems of their own (Desrochers, 2001).

This latter idea of 'recombinant growth' was more recently formalized by Weitzman (1998).

Perhaps not surprisingly in this light, a few writers anticipated the 'Jacobs spillovers' argument before Jacobs. For example, the social theorist Herbert Spencer (1889/1857, 52) viewed the 'evolution of a homogeneous society into a heterogeneous one' as the inevitable result of innovative activities and an ever-increasing division of labor. For example, the development of bronze meant that in time some people specialized in its production, while other developed from it artifacts that were previously made of stones, bones and other materials, while others found for it hitherto unknown uses. Millenniums later, the advent of the steam engines drastically impacted different lines of work such as mining, transportation and manufacturing activities. Describing these cases along with the countless economic and social impacts brought by the railroad on the already diversified British economic base, Spencer (idem, 55) observed that these were but a few illustrations of a widespread pattern of outcome, i.e. that a developing society had been 'rendered more heterogeneous in virtues of the many new occupations introduced, and the many old ones further specialized.' He further added that in settings characterized by a 'fixed and multiplying community' which were already more heterogeneous, 'the results are in a yet higher degree multiplied in number and kind.'

Conversely, the negative impact of a specialized local economy on the creative potential of its inhabitants was obvious to the geographer and economist Malcom Keir (1919, 47):

> From the point of view of employees, [geographically-specialized] localization is bad because it also tends toward narrowing the minds of the townspeople. A young man brought up in Fall River [Massachusetts], say, has but little choice of occupation; he must become a weaver or a loom-fixer or some other artisan connected with cotton manufacture, because by upbringing, education and example he is forced into that path, and furthermore he goes to work at an early age. It may happen that many a square peg is rammed into a round hole in this way, or a life constricted which might under better conditions have expanded. There is something deadening to the human mind in uniformity; progress comes through variation, therefore in a town of one industry a young man loses the stimulus for self-advancement.

In his discussion of the 'interdependence of knowledge of the various parts of the universe in which we human beings operate' such as, for instance, when 'discoveries and inventions in the field of tensile strength of metals contribute to discoveries and inventions in the field of electric currents,' the economist Simon Kuznets (1960, 328–9) observed that 'creative effort flourishes in a dense intellectual atmosphere, and it is hardly an accident that the locus of intellectual progress (including that of the arts) has been preponderantly in the larger cities, not in the bucolic surroundings of the thinly settled countryside'. This was attributable to the 'existence of adequately numerous groups in all fields of creative work' and the 'possibility of more intensive intellectual contact, as well as of specialization, afforded by greater numbers'.

In summary, we suggest that the discussion of 'Jacobs spillovers' predates Jane Jacobs' writings; that the argument that greater levels of local economic diversity will increase the probability of new combinations being created is uncontroversial; and that the processes underlying 'Jacobs spillovers' have remained an intellectual black box. We will now attempt to gain a better theoretical understanding of the latter issue by examining briefly the processes underlying new technological combinations.

3. On the processes conducive to inter-industrial knowledge spillovers[4]

The fact that most innovations developed for some specific purposes end up having numerous other uses is as old as the varied uses of wood and bones in weapons, tools, jewelry and housing or the uses of fire in lighting, cooking, heating, as a weapon and to clear up land. Among well-known recent examples are Post-it Notes (developed from a weak glue without any initial useful application); tea bags (first used as packaging for loose tea samples); Teflon (mechanical lubricant); and microwaves (unexpected discharge from a radar system) (Berkun, 2007, 41). While the phenomenon is ubiquitous, its economic and creative rationale are rarely discussed in the MAR–Porter–Jacobs literature.

3.1. Economic rationale and analysis of inter-industrial knowledge spillovers

A more concrete examination of actual inter-industrial knowledge spillovers and their economic rationale can be found in the work of economic historian Nathan Rosenberg. Looking at cases such as the application of sewing machines to the manufacture of boots and shoes, ready-to-wear clothing, awnings, tents, sails, pocketbooks, rubber goods, saddlery, harnesses and bookbinding, Rosenberg (1963, 419) illustrates that American industrialization 'was characterized by the introduction of a relatively small number of broadly similar productive processes to a large number of industries' (422); metal-using industries 'were continually being confronted with similar kinds of problems which required solution and which, once solved, took their place in short order in the production of other metal-using products employing similar processes' (425); and the machine-tool industry played a dual role in which 'new skills and techniques were developed or perfected… in response to the demands of specific customers' and, once acquired, were then applied 'to the entire machine-using sector of the economy' (426). As a result, industries achieved high rates of productivity growth by becoming 'increasingly dependent… upon skills and resources external to, and perhaps totally unfamiliar to, themselves' (Rosenberg, 1979, 43). In this context, talks about 'interindustry' flows have long been based on 'an outmoded concept of an industry' (Rosenberg, 1979, 47).

Of course, from an economic perspective developing new applications for one's existing expertise has always been a more sensible (if not always successful) proposition than developing a new product or expertise from scratch. The ways in which innovations in one line of work improves productivity growth and technological progress in another, however, defy 'easy summary or categorization', some having evolved over considerable periods of time, others proceeding very quickly through the sales of new intermediary goods following some rapid advances in terms of new products or processes (Rosenberg, 1979, 44).

Later, Rosenberg (1998) looked at chemical engineering and the Corliss steam engine in light of the influential concept of 'general purpose technologies' (GPT) that are said to perform 'some generic function that is vital to the functioning of a large number

4 Following the localized knowledge spillovers literature, our discussion is essentially limited to new technological combinations, but the same principles obviously apply to managerial and financial innovations.

of using products or production systems' (Rosenberg and Trajtenberg, 2004, 65). Consistent with his lifelong insistence on the greater economic importance of incremental innovations, he nevertheless came to observe that 'the question arises as to whether the Corliss steam engine ought to be regarded as a GPT in itself, or rather as a particular episode along the evolutionary path of the steam engine GPT' and added that, at any rate, 'it is inherently very difficult to delimit what exactly constitutes a GPT in its own terms, and one cannot expect decisive answers' (idem, 68).

As is also obvious from this and other detailed case studies written within the GPT framework (Goldfarb, 2005; Thoma, 2008), the genesis of every GPT is a new combination and considerable amounts of time and innumerable unforeseen improvements were typically required to adapt them to new uses. Their 'general purpose' character was therefore hardly intrinsic or ontological, but rather only became so through countless actions of a more incremental kind. Furthermore, commercially successful technologies that remain confined to a single purpose over time are probably few and far between, or have perhaps even never existed in the first place. In this light, the GPT approach can perhaps be described as the latest incarnation of a perspective that emphasizes the greater importance of radical breakthroughs as opposed to another view according to which technological change is much more incremental in nature while alleged radical departures are typically arbitrary selections on a broader continuum (Machlup, 1962). The engineer Michael Fores (1980, 69) thus wrote about the propensity of social scientists and historians to analyze technological change as a 'stream of revolutions, crisis, insights, breakthroughs, discontinuities, and the rest, composed in a manner that looks needlessly hysterical to those who are more familiar with ordinary work places'. Building on the incremental view of technological change, we will now discuss briefly some basic cognitive processes and environmental factors underlying new combinations, a stance broad enough to encompass all current perspectives on Jacobs spillovers.

3.2. Cognitive processes and environmental factors in the creation of new combinations[5]

New technological combinations are ultimately the result of individuals finding a new use for their existing expertise or incorporating something new (to them) to their current activity (Desrochers, 2001). Cattani (2006, 287) describes the phenomenon as 'the emergence of a new technology as a result of re-deploying existing knowledge into a new selection environment' and documents it for fiber optics. Of course, a creative individual's experience is both suggestive and limiting. For example, Shane (2000) documents how, because of their previous know-how, eight sets of entrepreneurs saw different opportunities to exploit a single MIT invention. By contrast, the other side of the creative coin—incorporating something new to one's expertise—does not necessarily require direct prior experience in another line of work, as sometimes observation

5 It seems fair to say that the study of creativity is still a somewhat marginal specialty in psychological research; that the study of technological creativity has generated little interest compared to artistic, scientific, children and managerial creativity; that most writings on the former subject have examined the work of historically important figures or significant recent commercial successes; and that despite this the relevant literature is too large to be reviewed in any detail in this section, hence our emphasis on widely accepted features of the process. For a recent article that covers many of these issues, see Gassman and Zeschky (2008).

and subsequent learning can be sufficient. George Westinghouse thus developed his train brake by reading a description of the compressed air technology used in tunnel drilling (Skrabec, 2006). Bandura (1977) refers to this process as 'observational learning', i.e., learning by observing, through deliberate search or luck, without tedious trial and error.

One essential ability to create new combinations is therefore the capacity to look beyond the normal application context of artifacts and ideas, a skill often highlighted in the 'pragmatic' literature intended to foster creativity in corporate settings.[6] To give but one example:

> One game... is called 'What Is This?' Look at any object around you: a pen, a cup, this book. Ask yourself, what else can it be used for? Take, for starters, this book in your hand; it's a doorstop, a weapon, a plate to get your boss to be less of an idiot, a waste of $25, and on it goes... The point is that anything can be used for things other than its intended purpose. We assume everything has one function, but that's wrong: you can use anything (although it might not work well, you can try). There's nothing stopping you from using this book as underwear to paper your walls. The game forces you to turn your filters off. Many great ideas come from the repurposing of one thing for something else. Laser beams were used to make CD players and supermarket checkout scanners. Even attempting to reuse something in a novel way, and failing, can lead to ideas no one else has thought of before (Berkun, 2007, 93).

Another facilitating factor is the opportunity for specialists to explore 'areas (in which they are) not experts in' (Berkun, 2007, 89), including working 'on several project at once, using different methods' as this keeps them from 'getting bored or stymied' and 'produces unexpected cross-fertilization of ideas' (Csikszentmihalyi, 1997, 272).

Intrinsic factors are obviously only one aspect of Jacobs spillovers, the other being the setting in which search procedures and developmental activities take place. In this respect, it has long been recognized that 'talent is only as good as the environment it's in' (Berkun, 2007, 96); that 'creativity is more likely in places where new ideas require less effort to be perceived' (Csikszentmihalyi, 1997, 9); that the 'importance of seeing people, hearing people, exchanging ideas, and getting to know another person's work and mind' (idem, 66) is crucial; and that 'certain (geographical nodes and) environments have a greater effervescence of ideas; therefore, they prompt the person who is already inclined to break away from conventions to experiment with novelty more readily than if he or she had stayed in a more conservative, repressive setting' (idem, 130).

Also directly relevant is the fact that, as John Stuart Mill (1848, Book III, Ch. XVII) observed, the interaction among persons with dissimilar modes of thought and action is one of the primary sources of progress. More systematic studies of this issue have been conducted in academic and corporate settings. For example, in 20 case studies of creative scientific research accomplishments in nanotechnology and human genetics, Heinze et al. (2009, 610) highlight the importance, among other factors, of 'small group size, organizational contexts with sufficient access to a complementary variety of technical skills,' and 'timely access to extramural skills and resources.' In some cases, breakthroughs had been accomplished because group leaders had 'changed their research field, for example from chemistry to optics, or from semiconductor physics to

6 The term 'pragmatic' is used by scholars who take a more systematic and rigorous approach to the study of creativity to describe more intuitive approaches (Sternberg, 1999, 5).

biophysics,' and in others, such as in Rockefeller University which is organized 'around laboratories rather than scientific disciplines and fields,' because research organizations were environments in which 'scientists communicate across disciplinary and thematic borders, and where research leaders provide strategies for integrating scientific diversity with rigorous standards of scientific excellence' (idem, 620).

We now turn to our own attempt to document, examine and analyze these insights and processes in the context of diversified local economies.

4. On the processes underlying Jacobs Spillovers: evidence from two groups of Canadian inventors

Using a methodology similar to some of the most influential research projects on human creativity (Csikszentmihalyi, 1997), we tried to examine the validity of the processes described in previous sections, along with the importance of local economic diversity for these processes, through semi-structured interviews conducted with over 80 French and English–Canadian individual inventors belonging to two inventor associations.[7] While we were obviously unable to come up with rigourous quantitative measures through our approach, we hope to demonstrate the relevance of theory-building in the context of the localized knowledge spillovers literature and that simply because something is immeasurable does not mean that it is necessarily unobservable, unintelligible or unimportant. As Einstein reportedly said: 'Everything that can be counted does not necessarily count; everything that counts cannot necessarily be counted'.

The selection of individual inventors as units of analysis was based on four considerations. First, virtually all accounts describing the lives and professional trajectories of individual inventors reveal a high propensity to move between different lines of work (Jewkes et al., 1969; Brown, 1988). Second, individual inventors are

7 Jewkes (1969, 72) define an individual inventor as choosing the field in which he works, as employing his own resources or acquiring them from others who exercise no control over his work, and as standing to gain or lose directly from his inventive success or failure. Unlike corporate inventors, an individual inventor typically works with limited resources and with colleagues subject to his guidance and leadership. To provide a brief description of our research project, two rounds of semi-structured interviews were conducted in Canada's two most economically diverse regions to explore, among other things, 85 inventors' lives, diverse work experiences and creative approaches. The first, conducted in collaboration with a Montreal-based French-Canadian inventors association (the now defunct *Le monde des inventions québécoises*) between 1997 and 1999, involved 45 Southern Quebec inventors. These results were not published in the academic literature because of other professional obligations. The main deficiency of this study was that a majority of the interviewees were reluctant to engage in any form of long-distance business relationships with English-speaking individuals because of linguistic deficiencies. In order to address this issue, another round of interviews was conducted between 2006 and 2009 with a group of forty English-Canadian inventors in collaboration with the Toronto-based *Concept to Creation Cooperative*. Even though all the individuals interviewed in this latter phase were Canadian citizens or residents, the diversity of their backgrounds turned out to be quite remarkable, not only because of cultural differences between French and English-Canadians, but also because several Torontonians were born and educated in foreign countries. Because our objective was theory-building, the evidence presented in the remaining portions of this article is the result of a constant iterative process between scholarship and other literature which helped sharpen lines of questioning and topics raised during interviews which suggested the exploration of previously unfamiliar sub-disciplines or lines of works. Because of this, we are confident that, despite undeniable limits or local peculiarities, the evidence presented in the remainder of this article illustrates both the universality of human creative processes and the recurring problems faced by most individual inventors. Other details and limitations of our approach are covered in Desrochers (2000).

typically not bound by confidentiality agreements and can therefore freely discuss technological innovations in a wide variety of contexts. Third, the majority of individuals working mostly alone usually limit themselves to projects or ideas that do not require complex technologies or significant capital investments, thereby providing researchers with a broad, but relatively easy to understand, array of cases. While this could be viewed as a liability or, at any rate less interesting than the few 'high-tech' sectors that are the focus of considerable social science research, 'mundane' inventions nonetheless represent a significant component of the industrial world (Hirsch-Kreinsen, 2008). Fourth, while some inventors limit themselves to one or a few inventions, most can be described as compulsive problem solvers who tackle a broad array of problems.

In the context of market activities, we define 'innovation' as 'new products and processes that are actually used' and that show(ed) potential marketability or other economic value.[8] By using this definition, many individuals interviewed did develop over a hundred innovations during their lifetime, the near totality of which, of course, remained confined to their houses or places of employment. Their main economic impact is therefore overwhelmingly embodied in otherwise undocumented innovations created and used in factories or plants where they were employed ('shop floor' innovations) rather than in commercially (un)successful consumer or industrial products. While our perspective is incompatible with the traditional linear economic approach to 'invention' (the development of a new product or process), 'innovation' (the commercialization of an invention) and 'diffusion' (the adoption of innovations by other individuals and firms), we believe it sheds a different and complementary light to the existing literature.

Studying inventors can be problematic on two counts, especially when relying on the account of one individual: (i) most inventors tend to simplify and to idealize their stories; (ii) there is often little agreement among collaborators as to where the emphasis of a story should be laid (Jewkes et al., 1969, 71–2). These problems could not be avoided. Regarding the former, it sometimes proved difficult to trace the origins of an inventor's new idea, as the individual was often himself unaware of the basis of a creative insight or did not remember it at the time of the interview. In the end, however, we believe that the new knowledge gained from the use of potentially imperfect qualitative information is too valuable to ignore.

As could be expected from the literature discussed in the previous sections, we identified three broad, although not mutually exclusive, sets of circumstances through which individuals found new uses or applications for existing products and created new combinations of existing products, processes and materials: (i) by adding to, switching or adapting specific know-how to other lines of work; (ii) by observing something in another line of work and incorporating it into one's own line of work; and (iii) through formal and informal collaboration between individuals possessing different skills and working towards the creation of new products and processes. All of these, of course, first began with the identification of a problem, a point made most forcefully by Petroski (1992, 22) who argued that the 'form of made things is always subject to change in response to their real or perceived shortcomings, their failures to function

8 While some might disagree with this definition, most patents—key inputs in numerous innovation studies—do not even meet this criterion.

properly. This principle governs all invention, innovation and ingenuity; it is what drives all inventors, innovators and engineers'. Indeed, 'since nothing is perfect, and, indeed, since even our ideas of perfection are not static, everything is subject to change' (idem).

We will now provide a few illustrations of the processes we documented. Of course, the cases described in the remainder of this article were selected not only because of the broader patterns they illustrate, but also for the relative easiness with which they could be conveyed.

4.1. Adding to, switching or adapting specific know-how to other lines of work

Applying know-how gained in one setting to another often took place as a result of individuals moving between different lines of work. Representative cases of the latter phenomenon include an individual who had worked in various corporate contexts with electronics, digital devices, early IT and telephone technologies before striking out on his own as a consultant to a broad customer base. One Quebec engineer had worked for firms involved in concrete preparation, textile manufacturing, nuclear-based electricity production, small business financing and garage door manufacturing. An industrial technician worked in the steel, chemical, aeronautical and armament industries before launching his own ceramic-making business.

This widespread pattern of employment across different lines of work seems attributable in part to the fact that technically creative individuals get bored very quickly with routine work. As one Quebec engineer who had worked in the cement-making, ore refining and manufacturing (cars, trucks, plastics) sectors put it: 'As an engineer, I could never stay more than two or three years in the same business... After two or three years, I knew everything. I had done everything. I needed new challenges. I was soon looking elsewhere'. Other considerations include a lack of interest or the formal education (few individuals interviewed had completed university degrees) needed to transition into administrative work. Of course, finding a new job was also an imperative when a firm downsized, went out of business or when an employee was asked to relocate to a region he disliked. Whatever the cause, however, this widespread pattern of job mobility facilitates the spontaneous transfer of know-how across otherwise seemingly unrelated lines of work. As the last engineer mentioned put it:

> You always carry your experience and know-how with you from one line of work to the other... I would even go so far as to say that a lot of things are strikingly similar... I call that a food processor, a cake recipe. Whether you're in mining, plastics, working for General Motors, everywhere you see pumps, compressors, tanks, pipes... in all lines of work... except when I was working for a truck box manufacturers, but even there you had a lot of systems to move parts that are similar to those you will see in other industries.

One of the most interesting cases was that of a software engineer who worked as an IT consultant when we interviewed him. Years before, while working as an IT manager for a large supermarket chain, he came to understand that money in this line of work was not so much in the sale of food per se, but in the shelf space 'real estate' owned by retailers. He explained: 'It doesn't matter what product they put on the shelf. They charge premiums on the location on the shelf'. Later on, having now become a web designer, he applied this model to his new line of work and began charging different premiums for advertisements based on their location on the web page. 'So you take along what other people are doing in different industries and put it into your industry' he observed, before adding: 'You tend to take up information from one area and try to implement it on the other to make simple mimics. If one area works, you try to mimic the same process in another area to make it work for you'.

Another interesting case involved the transfer of some basic know-how from the newspaper printing business to asphalt production. A recurring problem in the latter line of work was the cleaning up of residual asphalt that would be found sticking inside tanks after long holidays such as Christmas or Easter. In a particular asphalt firm, people actually climbed in the tank to scrape the residual, a laborious and equipment-damaging process. After noticing this, an individual interviewed pointed out to his then new employer that, in the printing business where he was formerly employed, large tanks were cleaned by pouring hot water in them. Why couldn't a similar approach be tried in the asphalt tank? This technique was tried and proved successful, in the process saving a significant amount of money.

4.2. Observing know-how and materials and incorporating them in a different setting

Several cases of 'observational learning' were raised during our interviews. For example, a chemical engineer once worked for a company with plants in remote locations at a time when his employer needed to reduce his manpower, but was reluctant to do so in isolated plants for fear that employees working alone would be left unattended for several hours if hurt. This individual knew of devices that alerted emergency response personnel when a button was pushed, but this approach would obviously be inadequate if a worker was knocked unconscious. The engineer contacted a company supplying this service and requested that motion detectors be incorporated in their system so that an emergency call would automatically be placed if no motion was detected after a predetermined amount of time. As a result of this new combination, the company was able to reduce costs without risking the safety of its employees. An additional feature was then added to the system to allow it to work as a burglar alarm when activated by the employee.

Another case involved a dental technician who, dissatisfied with existing materials, set out to develop a new type of acrylic for making dentures after observing mouth guards used in contact sports that were first warmed under hot water and then shaped in the mouths of athletes. After much trial and error, he finally developed a compound which proved superior to other existing materials out of which dentures could be created and could easily be molded with warm water while possessing controllable rigidity (from hard to soft).

We also documented how a shower brush was inspired by a car wash brush; a mouse pad arm rest was combined with an office chair after an individual had been inspired by some classroom furniture; a controllable sled was inspired in part by the movements of ice skates; a production shop for a new type of baby bag was inspired by the division of labor in a restaurant kitchen; a device to conduct time studies drew on ideas from chess clocks, stop watches and computers, among others; and a pulp and paper mill machine was partly inspired by a meat grinder.

4.3. On the importance of local economic diversity for Jacobs spillovers

While we documented a large number of otherwise 'invisible' new combinations, assessing the specific impact of the large metropolitan areas in which they took place is not as straightforward as identifying the uniqueness of highly specialized industrial districts. Indeed, in most cases, these new combinations could probably have been developed in many other large urban agglomerations. This was certainly the case when individuals were inspired while traveling or watching television. Another problem is the wide discrepancy we observed in terms of the geographical (local versus regional) and time (rapid transfer or long development process) scales involved in various cases. In terms of geographical space, different individuals have obviously different perception of space, with inhabitants of rural areas (especially if they were born there) being much more inclined to travel long distances to interact with other individuals than urbanites (although in many cases repeated long distance commutes took their toll and resulted in the termination of projects). While most cases of Jacobs spillovers occurred at the metropolitan level, some involved collaborative efforts at what can only be described as the regional level (a couple hundred of kilometers). The amount of time required to develop new products or Jacobs spillovers also obviously depended on the level of technical difficulty involved and on contingent circumstances, such as the death of a collaborator, the bankruptcy of a firm, the enactment of new regulations affecting directly the product under development or other, more lucrative, opportunities.

Because this article is limited to theory-building, we limit our discussion to the non-contingent factors that underlie Jacobs spillovers. This will be done in two ways. The first will be through a much more detailed description of a specific case in order to give a better sense of the complexity of the realities we documented. The second will be, once again, by identifying broad patterns that will be further illustrated through short descriptions of other cases.

4.4. Jacobs spillovers at the firm level: a case study

Our more detailed case is that of an experienced entrepreneur/inventor who spent his working life in Jacobs' adoptive hometown of Toronto, but who had by the time of our interview sold his business, been retired for eight years and was living in a (mainly) resort area located a 3 h drive north of the Greater Toronto Metropolitan area.[9] A chemical engineer by training, he first worked for the oil refining industry in the late 1940s, but soon struck out on his own as he felt that that this would give him more freedom to use his creative capabilities. His first business was in plastic molding, where he constantly developed new products such as bottle openers, sophisticated key holders, travel mugs and acrylic wine goblets. While describing the genesis and development of all these inventions is beyond our scope, it is interesting to note that the inspiration for that last item came as a result of his meeting some glass-makers in trade shows and of immediately seeing the advantages of using acrylic for some segments of this market. Acrylic was strong, safe and much more versatile than glass in terms of using colors, attachments and printed text or figures. After much trial and error which involved other creative individuals within and outside his firm, the product turned out to be a commercial success in the US market, but not in Europe.

9 This was, of course, under the best conditions as winter driving in this part of Canada is often arduous.

This invention in time led the inventor/entrepreneur to increasingly switch his product line towards the glass ware industry where, after more research, he was able to build on technologies similar to those used in windshield production to create a compound that drastically improved the resistance of glass ware. While learning and experimenting, sometimes in collaboration with people involved in Southern Ontario's large auto parts industry (therefore involving collaboration at the regional as opposed to the metropolitan scale), he had observed the difficulties involved in decorating glass and learned about safety issues related to the use of lead in the process. To overcome these problems, he developed, again in collaboration with specialists possessing complementary expertise, a plastic coating for glass ware on which ink could be spray printed.

He further refined his ideas after seeing a demonstration of digital ink jet printing in a graphics show in Toronto. He looked for a specialist in this area and, at the time of our interview, was jointly developing the product with a digital inkjet printing company. According to him, digital printing will make the production faster and less costly than through traditional methods, while the resulting product will be durable, non-toxic and visually much more spectacular.

Interestingly, the inventor-entrepreneur was conducting these activities from his retirement home and was then collaborating with a firm located in the American Mid West. This arrangement, in our opinion, can mainly be understood in the context of its 'retirement project' nature, at least inasmuch the inventor (and his wife) enjoyed his scenic surroundings and was under no short-term financial pressure. Indeed, the entrepreneur-inventor was adamant that his past business activities and operations could never have been located where he was then living and that being based in Canada's metropolis always provided him with, among other things, easy access to suppliers and specialized workers of all kinds who had themselves customers and experiences in a large array of industries. Of course, being based in the Greater Toronto Area also provided him with numerous opportunities to being exposed to countless lines of work.

From this and several other cases, we will now identify a few broad patterns that we deem especially relevant to better understand the importance of large and diverse urban agglomerations in facilitating inter-industrial knowledge spillovers.

4.5. Importance of agglomeration economies

Our first observation is that Jacobs spillovers are only one facet of the economic importance of large and diverse agglomerations. Indeed, in all our cases, the importance of traditional or 'static' urbanization economies was judged crucial by inventors, as benefiting from a proximate and diverse supply of components of all kinds obviously saved them much time and effort. Individuals who had lived in both a large urban agglomeration and a highly specialized (and typically smaller) one were especially adamant on this point. As Thomas Edison reportedly said, genius is 1% inspiration and 99% perspiration, meaning that an idea for a new marketable device is but the genesis of a lengthy process, much of which is entrepreneurial in nature, from which marketable products are eventually created. In the spirit of Edison, we suggest that agglomeration economies save inventors a lot of perspiration and that contributors to the localized knowledge spillovers literature should keep his dictum in mind in terms of the overall importance of inspiration.

4.6. Face-to-face interactions

The greater facility of face-to-face interaction has long been emphasized in the literature on agglomeration economies. Not surprisingly, the fact that physical proximity greatly facilitated collaborations between individuals possessing different expertise in the development (if not necessarily commercial success) of new inventions was made abundantly clear to us. The reasons given in this respect ranged from traditional ones, such as establishing trust and jointly addressing innumerable hurdles in development phases, to one that is more specific to Jacobs spillovers, i.e. making sure that individuals with different expertise truly understood each other and that the final product reflected the vision of the project leader.[10] Among other cases, an electrical engineer working for Quebec's largest public utility company spent his week-end perfecting the production processes of his uncle's window and door-making factory while a technical staff recruiter collaborated with his wife, a chemical engineer by training, to develop a wine-related technology.

To look at one case in more detail, the new type of denture acrylic mentioned earlier had, like most new materials, many different potential applications. Among other things, it is consistency controllable, thermo-elastic and has 'memory' (i.e. it returns to its original shape after cooling). According to the inventor, no other acrylic in the world did these three things simultaneously when it was developed. Furthermore, the product can be used as a quick and easy way of repairing and attaching things. The inventor had thought of more than 60 potential new applications, ranging from moldable handles and hearing aid devices to ski boot insoles and as replacement for plastic casts for broken limbs. At the time of our interview, this last application was being explored in collaboration with medical researchers of a nearby academic institution.

Another interesting case is a bicycle rack for domestic use. The individual interviewed originally got the idea from a friend, who pointed out that no such thing existed yet. The reasons for this soon became obvious as the inventor began researching the topic. The rack needed to be light enough to be carried, heavy enough to hold the bicycles and prevent thefts, have a nice design, be maintenance-free, and suitable for at least four bicycles (two adult and two children's bicycles), be they racing or mountain bikes. Finally, its price should be affordable. A metallic structure would have met most of these requirements, but would have been too heavy to carry. Aluminum was a lighter option, but was too expensive. The inventor then thought of using plastic, but realized quickly that it would be too light. He contacted an industrial draughtsman with whom he had worked with in the past on a specially designed water container for long-distance running. His former collaborator suggested that the rack should be made by blowing rather than casting (i.e. filling a plastic mold) plastic. That way it would be empty inside, which would make it light enough to carry, but heavy enough to hold the bicycles in place after it was filled with water. This solution would finally prove the best one. Interestingly enough, although this solution could be seen *post facto* as a direct implementation of the main principle involved in their previous collaboration, the inventor still needed his previous collaborator to think of this approach.

10 Of course, the importance of face-to-face interaction for people possessing similar expertise has long been a mainstay of the economic geography literature.

4.7. Local diversity as offering more creative opportunities

Another recurring theme in many interviews was, not surprisingly, that a large urban agglomeration provides many unplanned learning opportunities by spontaneously allowing creative individuals to observe processes and ways of doing things by people working in different contexts. They could, as discussed earlier, either borrow ideas and incorporate them in their own work or else contribute their expertise in a new line of work, thus resulting in countless 'spontaneous' (if undocumented) new combinations. The main channel in this respect, at least in terms of the actual development of innovations, seems to be job mobility between different lines of work, a process that is obviously facilitated by the fact that a large and diverse metropolitan area gives creative individuals the possibility to do so without having to relocate their family or lose their friends and social networks. Admittedly, the expertise and capacities possessed by an individual influence the number of possible job opportunities available to him. But while many companies are limited to a specific sector or a few end products, many industrial capacities are generic in nature and can be applied in many different contexts.

4.8. Local networks

The importance of local networks for regional development has long been a mainstay of the economic geography and related literatures. Not surprisingly, the individuals we interviewed all belonged to various networks, some of which were obviously more specialized than others such as, for instance, the contacts that were developed by a plastic molder who had been active in this line of work for a long time and who had worked for several employers. Some networks, however, were especially conducive to Jacobs spillovers, chief among which were the inventors associations themselves. In short, since each individual member's background is limited in various ways, belonging to an association whose members have diverse and complementary expertise typically proves valuable. While opening up to other individuals often proves difficult for inventors, as the limits of their know-how became apparent during the development phase of their invention, they typically became more willing to discuss their ideas as they came to understand the trade-offs between secrecy and the sharing of insights and expertise with individuals whose own know-how was often complementary to theirs. Besides networking with other inventors in order to tap into different skill sets, intellectual stimulation and friendship, an important aspect of these associations is the support their members can provide to each other in terms of locating manufacturers for the supply or fabrication of specific parts, sources of capital and help with marketing and distribution, business and activities that are typically of a more generic nature.

5. Jacobs spillovers and the related variety controversy

One of the spillover effects of the MAR–Porter–Jacobs debate has been the development of the concept of 'related variety' (Frenken and Boschma, 2007; Frenken et al., 2007), a topic now controversial enough to warrant further attention and on which our work can shed additional light. As we see it, its most important aspect is its reliance and emphasis on the notion that sufficient 'cognitive proximity' (Noteboom, 2000) is required to actually facilitate innovative advances. In other words, large differences in expertise and jargon between individuals will prevent them from communicating effectively and will therefore hinder the creation of useful and commercially valuable new combinations. Our evidence suggests a number of rebuttals to this line of thought: (i) the significant internal diversity of large firms does not prevent individuals with very different backgrounds to collaborate towards a common goal; (ii) individuals working for firms that are unrelated in terms of final products might nonetheless be using similar 'generic' technologies and thus benefit from learning from each others; (iii) while 'cognitive distance' can indeed be a challenge, it can most easily be addressed through the frequent face-to-face interactions of diverse individuals, which is obviously facilitated if they are all located in close geographical proximity.

The theoretical contribution of related variety and its proponents' less aggregated approach to study the effects of diversity is welcomed, but its reliance on industrial classifications remains debatable in our opinion. While one can plausibly argue that a pig farmer is unlikely to learn anything from a microchip company (Boschma and Iammarino, 2008), similar examples could doubtless be given using firms within the same two-digit level industrial classifications. Besides, while large-scale pig and microchip producers handle very different commodities, it doesn't seem implausible that some useful exchange of ideas might occur in terms of, say, controlling temperature or air quality in production facilities or workforce management. Besides, we did document Jacobs spillovers between sectors that seem equally implausible (such as production arrangement transfers between a restaurant and a baby accessory manufacturer).

We therefore suggest that it is probably more constructive to analyze creativity in terms of individual skills and know-how, a reality not well reflected in industrial classification schemes, and to consider the essence of innovation to be about making connections between previously unrelated things. While the ultimate goal of the relatedness approach is to separate the diversification benefits (unrelated variety) from Jacobs externalities (related variety), industrial classifications alone are probably not sufficient in this respect as they do not always reflect the correlation between the demand for outputs or the various ways in which ideas are used and transferred between industries (again, see the much earlier comments to that effect in Jacobs, 1969, 61). In fact, while this approach highlights the benefits of a more disaggregated method and gives an opportunity to study these effects on different time scales (Saviotti and Frenken, 2008), it also shows that diversity is a complex and heterogeneous phenomenon (Bishop and Gripaios, 2010). As such, while it can yield a more comprehensive understanding of the phenomenon when coupled with studies on individual inventors and other experts, it might still assume away too much.

6. Reflective conclusion

Shedding additional light on the intra- and inter-industrial localized knowledge spillovers controversy requires methods that are complementary to the statistical approaches used in previous studies on the topic. In particular, proving and assessing the existence and importance of Jacobs spillovers requires a more fundamental understanding of the processes by which people actually come up with new combinations and the relative importance of local economic diversity on facilitating or promoting these processes. We attempted to provide a better theoretical understanding of this issue by identifying relevant insights from the creativity and other relevant literatures and by conducting semi-structured interviews with several Canadian individual inventors.

While determining the frequency of Jacobs spillovers and their relative importance to other factors could not be measured satisfactorily with our approach, we believe that it has given us the opportunity to identify the main types of stylized processes through which knowledge was actually transmitted between different lines of work: (i) adding to, switching or adapting specific know-how to other product lines; (ii) observing something and incorporating it in a new environment; and (iii) formal or informal collaboration between individuals possessing different skills and backgrounds. Local economic diversity was found to facilitate these processes in several ways, ranging from frequent face-to-face interactions between people possessing different backgrounds and otherwise unlikely to understand each other to facilitating job mobility between different lines of work. We cannot claim on our evidence alone that these mechanisms are present in all technical lines of work, but because new combinations are at the roots of all creative processes we are confident that these basic patterns will be observed in all industrial sectors.

With these considerations in mind, we would now like to venture a few additional thoughts on two controversies that have sprung from the work of MAR–Porter–Jacobs literature. The first is that the notion of a 'creative class' (Florida, 2002) should at the very least be broadened to recognize the contribution of technically creative individuals who might not possess a university education and be working in unglamorous lines of work, but nonetheless contribute much to the economic vitality of their communities. As such there is a significant difference in terms of regarding 'creativity' as a 'type' (e.g. education or occupation) as opposed to an ability to create new things or ideas by recombining older ones (Weitzman, 1998), a distinction which should be kept in mind when these literatures are merged.

The second is Breschi and Lissoni's (2009, 465) argument that it is not geographical distance as such that is crucial for knowledge flows, but that 'the main reason why geography really matters is that mobility of technologists across organizations, either as employees or consultants, is bounded in space'. These authors have a point to the extent that two of our three Jacobs spillovers mechanisms, 'adding to...' and multidisciplinary collaborations, are clearly dependent on social and personal ties. These ties are also typically more or less local, even if not necessarily so. In our opinion, however, social proximity, while undoubtedly important, should not be unduly emphasized at the expense of geographical proximity since in the absence of such ties it is much more convenient for individuals looking for vaguely defined potential solutions—especially if they work alone or for small firms—to first contact nearby individuals that are beyond the confines of their 'epistemic community' (Lissoni, 2001) and possess different and potentially complementary skills. In addition, one spillover mechanism, observing something elsewhere and incorporating it in someone's own line of work, doesn't seem reducible to social proximity, as there do not need to be any social ties present in order for this channel to work, while closer geographical proximity between different types of work do, in our opinion, provide better opportunities of observing something useful. Through observational learning, individual or corporate inventors can observe novel ideas being developed in particular circumstances and learn spontaneously without searching for new knowledge (Malmberg and Maskell, 2002).

In the end, no matter which spillovers are studied, their analysis should not be limited to why people innovate, but it should also explain *how* they go about it. We hope that the preliminary analysis presented in this article has moved the understanding of this issue one step closer to that goal.

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