HOW KNOWLEDGE BECOMES A PUBLIC GOOD: PERMANENCY, PATENTS AND SECRECY

A master's thesis by

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Submitted to

School of Public Policy

Central European University

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Written and submitted in

Budapest, Hungary

June 2018

Author's Declaration

I, Šimon Trlifaj, hereby declare that I am the sole author of this thesis.

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Date June 15th, 2018

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Abstract

Knowledge is often considered to be a public good, and many policy proposals take lessons from public goods management and apply them to knowledge creation. I argue that this is an oversimplification. Knowledge can be partially rival and excludable, and companies routinely use secrecy to mitigate the risk of knowledge disclosure. The path of an invention from an inventor to general knowledge is far from straightforward, influenced by many factors including institutional interventions such as patents. I introduce a new property of permanency—the inability to reverse transactions with a good—to analyze how knowledge becomes a public good. To show the effects of permanency empirically, I use assignment data on over four million US patents to test the hypothesis that patents on relatively less reverse-engineerable inventions will more likely be reassigned sooner after the application date. The results of a logistic and survival regression support this hypothesis, which suggests that permanency plays a role in motivations of inventors and companies to patent. Future research on knowledge creation and disclosure and policy proposals for patent reforms thus should employ a more nuanced conceptualization of knowledge, in which permanency plays a role.

Acknowledgments

I would like to thank Cristina Corduneanu-Huci, my thesis supervisor, for a helping me navigate through my thoughts and for pushing me to test their validity. I could not have wished for a better combination of challenges and support. I would also like to thank Ludmila Tydlitátová for her invaluable personal and technical support, Viktor Mak for feedback on stylistics and clarity and all friends and family members who helped and encouraged me. Thank you!

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Introduction

In February 2016, researchers from a technical university in Ostrava, Czech Republic, sold a patent on an invention that improved a heat exchanger to a private company. The invention was not a breakthrough, but according to the university's press release, hopes were it would "help increase energy sustainability and decrease environmental effects of [heat] production."(VŠB-TUO 2016)[1] Let me pose three speculative questions. 1) If the invention would have been developed not by the university researchers, but by the company, would it still be patented, or would the company rely on secrecy (and lead time) to make a profit from it? 2) If the invention consisted of a production method of the heat exchanger, and not the heat exchanger itself, would it be less likely patented, because it would be harder to reverse engineer by competition? 3) Would the invention become part of general knowledge sooner when patented, or when kept a secret by the company?

These questions are relevant beyond heat exchangers. Economists, policymakers and politicians often say that we increasingly live in knowledge-based economies, in which "the proportion of knowledge-intensive jobs is high, the economic weight of information sectors is a determining factor, and the share of intangible capital is greater than that of tangible capital in the overall stock of real capital."(Foray 2004, ix) Intellectual property protections and patents, in particular, are one of the key regulations that shape how knowledge is produced and dispersed. At the United States Patent Office (USPTO), the number of patents granted per year tripled between 2000 and 2015, and almost doubled between 2008 and 2017 at the European Patent Office.(USPTO 2015; EPO 2018) But in contrast to the increasing importance of knowledge and role of intellectual property, policy understanding of knowledge creation and disclosure lacks behind, and patents remain to be a controversial yet under-researched topic.

The economic literature on knowledge frequently considers it a public good, which is characterized as non-excludable and non-rivalrous (see section 1.2 for a thorough discussion). Patents are then described as an institution that makes knowledge a private good, creating a legal right to exclude

[1] Author's translation from the original: "[výměník] přispěje ke zvýšení energetické soběstačnosti a snížení ekologických dopadů produkce [tepla]" (Czech).(VŠB-TUO 2016)

others from its usage, effectively creating a monopoly. The status-quo consensus is that there is an inevitable tradeoff between knowledge creation and access to knowledge: who would invest in knowledge creation if anyone could free ride on its results? The status-quo policy pursued by both the European Union and the United States is to strengthen intellectual property rights and encourage companies to apply for patents, as that is argued to lead to more innovation and make companies more competitive—even at the costs of monopolies.(Arundel 2001; Mankiw 2011)

At least two alternative policy approaches challenge this status-quo: one arguing for stronger government intervention in the creation of knowledge, the other arguing for a weaker intervention. Stiglitz et al. (2017) argue that because knowledge is a (global) public good, mainly because of its non-rivalrousness, it should be provided by the public sector, and not privatized with patents. Inspired by issues in access to medicines—where patent-based monopolies make life-saving medicines cost thousands of U.S. dollars when their production price is below one hundred dollars—the authors propose several alternatives to patent-based financing of innovation: direct financing through centralized systems, tax credits or another form of "decentralized" funding mechanisms or prize financing system. The main benefit of these alternatives is that, like other public goods, public-sector-financed knowledge would hopefully be much more accessible. The problem of knowledge creation in this approach becomes a classical problem of public goods provision.(J. Stiglitz, Jayadev, and Baker 2017; J. E. Stiglitz 1999; Arrow 1962)

Second, some argue that knowledge is closer to a private good and public policies should better reflect that. For example, Boldrin and Lavine (2008) argue that inventors are free to choose to exclude others from their knowledge, and if an invention is truly innovative, there will most of the time be enough reward in lead time of the first inventor to introduce a product to the market. In fact, the authors argue, patents harm not only access to knowledge but also innovation by discouraging follow-up inventions and creating transaction costs. Recently, two auto-makers, Tesla and Toyota, decided to open up significant parts of their patent portfolios in hopes to facilitate innovation in the industry.(Sheridan 2014) Elon Musk, the founder of Tesla, expressed his skepticism about the patent system in a blog post in 2014, stating that while patents might have been a good thing, today, they "merely […] stifle progress, entrench the positions of giant corporations and enrich those in the legal profession, rather than the actual inventors."(Musk 2014) The policy advocated by in this approach is to significantly limit intellectual property rights, which would not only lead to better access to knowledge but would also help to create it.

Aside from these two alternative approaches to knowledge, some economists look for ways in which the status quo could be adjusted or improved. For example, Gilbert and Shapiro (1990) calculate optimal patent policy in terms of patent length and breath, arriving at the conclusion that in homogeneous-good market, an optimal length of patent is infinite; Roin (2014) proposes that the time it takes to introduce inventions to the market should determine patent strength; Encaoua et al. (2006) argue for self-selection of strength of patent protection based on fees for the patent regimes. These proposals are usually based on microeconomic models and are limited by strong assumptions about knowledge markets.

In this thesis, I wish to complicate the view that knowledge can be analyzed in the classical categories of private and public goods. I distinguish between general knowledge, which is widely accessible and fulfills the properties of a public good, and particular knowledge, which can be to some extent excludable and rivalrous. As will be discussed in section 1.2.6, there is strong evidence that patents are not the only means of making particular knowledge excludable. Many companies consider secrecy and lead time as significantly more important means of exclusion than patents. That directly contradicts the concept of knowledge as a public good, at least when applied to inventions.(Hall et al. 2014)

How does particular knowledge become general knowledge? In section 1.3, I argue that the property which guides this process is permanency: the inability to exclude someone from a good that they had been previously provided. Permanency changes how knowledge can be transferred on the market. For example, it makes it harder for inventors to investigate what is the market price of their invention if by offering it to buyers, they risk being copied. New knowledge is excludable with secrecy. However, transactions of knowledge are permanent: there is no way back when knowledge is sold, disclosed or reverse-engineered. When those transactions accumulate, knowledge becomes less and less excludable, until it eventually might become a public good, a part of general knowledge.

To some extent and in some industries, secrecy can slow down or stop this process, but the extent to which this is possible depends on many factors, such as the ease of reverse-engineerability of knowledge from products, or the market position of the inventor. Unlike secrecy, patents make the usage of knowledge not only excludable but also non-permanent. Patents make it possible to perform transactions of knowledge that are reversible, at least until the patent expires (usually 20 years from its grant date). For example, it is possible to offer patent to a buyer without risking they would copy it.

To clarify the abstract argument, let me discuss the three questions from the opening paragraph. 1) I argue that sometimes, the motivations to patent are not to make inventions excludable, but rather to make them non-permanent. Thus, it is more likely that if the company (rather than the university researchers) had invented the heat exchanger improvement, it would have used secrecy as means of exclusion. 2) I argue that reverse-engineerability plays a role in the motivations to patent. Inventors and companies will more likely patent inventions that are easier to reverse engineer, regardless on whether they are capable of monetizing them by selling the patent or by producing and selling a product (in this case, a heat exchanger). If a company invents a less reverse-engineerable invention, it will more likely keep it a secret. 3) I argue that the process of inventions becoming part of general knowledge is a far from straightforward. On the one hand, if an invention is easy to reverse engineer, it would more likely become part of general knowledge sooner without patents. On the other hand, if an invention is less reverse-engineerable, it would more likely be kept a secret—and those inventions might never become a public good. In this case, patents may lead to early disclosures and inventions becoming part of general knowledge sooner.

On a policy level, this thesis hopes to contribute to the understanding of how knowledge is created and disclosed, and what would be the effects of different policy approaches towards knowledge. Company representatives report that patents are significantly more important in some industries than in others. The theoretical concept of permanency should deepen our understanding of the motivations of companies to patent and the alternatives they seek if they cannot patent. For example, in some industries and for some inventions, approaches based on the public provision of knowledge might be effective, because inventions are easily reverse-engineerable and secrecy is not a very good option. In this context, knowledge is close to a public good. But in other industries, secrecy makes knowledge excludable, and alternatives to patent might lead to less knowledge disclosure and disclosure. In this context, knowledge is a permanent private good.

Chapter 1 discusses the theoretical argument outlined above. It starts with defining theoretical building blocks, discusses the literature on economic properties of knowledge and introduces permanency of knowledge. To test theoretical arguments introduced in Chapter 1, Chapter 2 uses patent data from the USPTO to investigate whether permanency can be empirically observed in inventors' behavior. It looks for evidence that patents with lower reverse-engineerability are traded sooner. While the results of the empirical analysis are limited, they support the theoretical argument. The final section discusses limitations and opportunities for future research on the permanency of knowledge and open questions around how knowledge becomes a public good. With its limited yet novel inquiry into knowledge creation and disclosure, this thesis should be viewed as a proposal for a new analytical framework, which could hopefully eventually be developed into a coherent and formalized theory.

Chapter 1 Theory

In this chapter, I discuss the properties of knowledge in the theoretical framework of public sector economics. In the next section, I start by defining and discussing theoretical building blocks with which this thesis operates. In section 1.2, I discuss whether knowledge can be considered a public good and the limits of knowledge non-rivalrousness and non-excludability. In section 1.3, I introduce permanency of knowledge as a property that can explain the dynamics in which knowledge is created and disclosed. Section 1.4 links permanency to observable inventors' patenting behavior as an introduction to Chapter 2. Analysis of public goods is often at the core of arguments over public sector involvement in the economy: what are the origins of those concepts and how does knowledge play into that?

1.1 Building blocks

Three building blocks will be needed to discuss public good properties of knowledge and its implications on patents. First, I define public and private goods and discuss the normativity of those concepts. Second, I define intellectual property, patents, secrecy, and reverse-engineering. Finally, I define knowledge, inventions, and disclosure of knowledge.

1.1.1 Public goods

Concepts of public and private goods are at the foundations of economic analysis of public policies. They are defined by two properties: rivalrousness and excludability, which were first conceptualized by Samuelson (1954), further developed by Ostrom and Ostrom (1977) and today appear in virtually every economic textbook (e.g., Mankiw 2011).[2] A good is *rival* if one person's consumption of it diminishes other person's consumption (for example, one person using a bike diminishes the

[2] The terminology evolved over time, Samuelson wrote about "collective consumption goods" (instead of public goods) and Ostrom and Ostrom about "joint" or "alternative" use (instead of rivalrousness), for example.(P. A. Samuelson 1954; Ostrom and Ostrom 1977)

possibility of another person using the same bike).[3] A good is *excludable* if it is possible to exclude persons from using it (for example, it is possible to exclude others from using one's bike).

Goods that are rivalrous and excludable are classified as *private goods* (e.g., bikes, cups of coffee). In contrast, goods that are non-rivalrous and non-excludable are *public goods*: one's consumption does not diminish the consumption by another person, and it is impossible to exclude persons from using the good. Classical examples of public goods include public defense, flood protection, public radio broadcasting. Between private and public goods, two other categories are defined. *Club goods* are non-rivalrous but excludable (e.g., private park, cellphone network). *Common-pool resources* are rivalrous but non-excludable (e.g., fish in the sea, a city park).

Public goods and common-pool resources had traditionally been of main interest in public policy. Because they are non-excludable and individuals can free-ride, they are likely to be undersupplied without public intervention. For example, who would pay for public broadcasting, if no one can be excluded for not paying—and who would broadcast if no one pays? Who would limit their fishing if no one can be excluded from accessing the sea—and how do we maintain a stable fish population if no one limits fishing? Paying for public broadcasting through taxation or creating systems for limiting fishing are some of the examples of interventions which are justified by providing a public good or managing a common-pool resource, respectively.

1.1.2 Normativity of public goods

Most goods are on a spectrum between those classifications and can change their properties with technological and institutional changes. For example, a road can be turned from public good to a club good when the government installs toll payment machines and makes it excludable.[4] Malkin and Wildavsky (1991) point out that these changes in good properties are not external to the public

[3] In other words, a good is non-rival if the marginal cost of an additional person using it is zero.

[4] Such technological changes are often costly and that limits their use. For example, for most roads, toll payment machines are too expensive to build. This is assuming that the road is close to being non-rivalrous (one extra car driving it does not diminish other car using it), which holds to only some extent.

policy and that "what is a public good is not determined by a fixed criteria, [but] constructed by society."(Malkin and Wildavsky 1991, 355) The question of whether a good is public or private, they point out, is to a large degree a normative one, not only descriptive.

For example, even if installing toll payment machines on a road might be technologically possible, a decision could be made not to do that and keep roads non-excludable. One of the arguments for doing so could be to keep roads accessible for people that could not afford to pay the fee because that would raise inequality. On the other hand, even if installing toll payment machines on a road might be very expensive, a decision could be made to install them and make roads excludable. One of the arguments for doing so could be that only those who use roads should be paying for them, even if that raises the overall costs. Both arguments have a normative component in them, the first perhaps arguing for greater equity, the second for greater individual responsibility. In this thesis, I will assume that properties of goods are a combination of their *technical properties* and (formal and informal) *institutions* societies build around them.[5]

1.1.3 Knowledge and inventions

As defined by Foray (2004), *knowledge* is a cognitive capacity, which "empowers its possessors with the capacity for intellectual or physical action."(Foray 2004, 4) My knowledge of English language gives me the capacity to write this text; knowledge of bike mechanics gives the capacity to build bikes, for example. *Information*, on the other hand, is "structured or formatted data that remain passive and inert until used by those with the knowledge needed to interpret and process them."(Foray 2004, 4)[6] An English dictionary contains information about the English language,

[5] I understand formal and informal institutions as used in institutional economics, defined broadly as "the humanly devised constraints that shape human interaction."(North 1990, 4) Informal institutions include conventions and codes of behavior, formal institutions include laws and other codified rules. Most of the time, institutions will refer to formal institutions, specifically laws and international agreements.

[6] Foray (2004) contrasts this to the interchangeable and broad definition of knowledge and information, used in earlier literature.

but it is required of me to engage with it to improve my knowledge of English; a manual for a bike needs educated interpretation to be useful when building a bike.

While knowledge and information are often used interchangeably in economics, this is a mistake, according to Foray. In contrast to information, which can be copied easily, knowledge needs a high mobilization of cognitive resources to be reproduced or transferred: teaching and learning, physically engaging with the subject, working or otherwise interacting with experts. Additionally, knowledge can be disclosed to a limited group of people. For example, the staff of a bike-producing company has specific knowledge about bikes.

Sometimes, knowledge is used in a broad sense of all knowledge publicly available on the internet, in libraries or textbooks. I will refer to this broader meaning as to *general knowledge*, and to underline the difference, *particular knowledge* to a cognitive capacity as described in the previous paragraph. For example, the basics of bike's mechanics are part of the *general knowledge* (anyone can look it up easily), but details of the mechanics of bike brakes from a certain manufacturer are a particular knowledge (which only the manufacturer might know). If not specified otherwise, knowledge refers to particular knowledge.(Mankiw 2011)

I define *invention* as a specific piece of new human-invented knowledge, which typically empowers its possessors with the capacity to produce a commercial product. Additionally, *knowledge disclosure* is a conscious or unconscious process which allows others to obtain someone's knowledge. Disclosure can happen through different means, which differ in how easy it is to obtain knowledge through them: patents, academic publications, conference presentations, production process descriptions, manuals, products, etc. Knowledge disclosure may be intended only for a limited group of people and combined with secrecy. For example, a bike company outsourcing production of wheels discloses knowledge about the production process, but might limit this disclosure by trade secret contracts and other tools.

1.1.4 Intellectual property rights and secrecy

Intellectual property rights are examples of formal institutions. *Intellectual property rights* are a set of formal institutions that assign rights over specific assets created as a result of an intellectual activity.[7] Precise legal definitions of intellectual property differ by the type of asset in question and by national legislation. Three basic intellectual property institutions are patent law, copyright law, and trademark law. For example, a text of a book is an intellectual property treated under the copyright law, which grants rights on the reproduction, attribution of rights, etc., up to 100 years from authors death—given, given legally-defined conditions are met.(Dutfield, Graham Suthersanen 2008)

A *Patent* is an intellectual property institution that grants exclusive rights over the utilization of a technological invention (specifically its manufacture, use, sell and import) typically up to 20 years.[8] While the details of patent systems differ in different countries, their basic properties are laid out in the Agreement on Trade-Related Aspects of Intellectual Property Rights (TRIPS) agreement negotiated under the World Trade Organization (WTO). Such products and processes are patentable if they meet the criteria of usefulness (must have useful applications in the industry), non-obviousness (must introduce a novel idea, compared to what is known) and an innovative step (must be non-obvious to a person who has ordinary skills in the field). Additionally, the applicant must disclose the invention enough to be "carried out by a person skilled in the art."(WIPO 2004, 21) Patents are applied for at and published by national patent offices, and the application can take several years and considerable financial resources to process.(Dutfield, Graham Suthersanen 2008; WIPO 2004)

[7] In different words, "An intellectual property right is a right: (i) that can be treated as property; (ii) to control particular uses; (iii) of a specified type of intangible asset. In addition, intellectual property rights normally share the characteristics that they are: (i) only granted when the particular intangible asset can be attributed to an individual creator or identifiable group of creators, the creator(s) being presumptively entitled to the right; and (ii) enforced by both the civil and criminal law."(Spence 2007, 12–13)

[8] Patents usually do not automatically remain valid for 20 years, but need to be periodically maintained with fee to the patent. At the European Patent Office, about 20 percent of patents are maintained 20 years from grant; at the USPTO, this is the case for about 40 percent of patents.(Ollier 2008)

As will be discussed in section 1.1.4, from an economic perspective, patents make aspects of an invention excludable and thus give it private (or club) good properties for a limited period.[9] Patents make it possible to exclude others from the utilization of the invention, and owners of patents can sell these rights to another person. When a patent expires, the properties change and the invention becomes close to a public good: being published in by the patent office and without any legal means of excluding from their utilization. Patents are thus used by companies to privatize profits from inventions and protect their business against competition for a limited time while making the invention public.[10]

Secrecy is often cited as an alternative business strategy to patenting. If a company develops a new product or a method of production, it can choose to keep it undisclosed and use a variety of management tools to prevent competition from utilizing the invention. These include encryption of key documents such as business plans or manufacturing processes, trade secret contracts with sub-contractors, non-disclosure agreements with employers, keeping knowledgeable employees in a company, setting security systems around research centers, etc.[11] Unlike intellectual property, trade secrets rely on common law contracts between individuals: they do not provide exclusive property rights on information or an invention. This makes trade secrets a weaker legal instrument in the case an invention is copied (which, however, has other advantages, as will be discussed later).(Friedman, Landes, and Posner 1991; Holgersson and Wallin 2017)

[9] By using the word "aspects" of an invention, I mean that it is the manufacture, use, sell and import of the products and processes described in the patent—not the invention itself—that is protected by the patent. The invention itself, on the contrary, is made public when a patent is published by the patent office (but cannot be freely manufactured, used, sold or imported). It is for example possible to reproduce the patent or work on improving the invention it covers (as far as the restrictions on manufacture, use, sell and import are not violated).

[10] Patents don not necessarily create a monopoly: the patent holder can licence or not to enforce their rights and thus allow competition in the manufacture, use, sell and import the invention. However, it is a frequent practice that patent holders enforce their rights in a way that restricts competition and creates a monopoly.(WIPO 2004)

[11] Trade secrets are used on information and knowledge beyond patentable inventions, but including them.(Friedman, Landes, and Posner 1991)

Reverse engineering is "the process of extracting know-how or knowledge from a human-made artifact."(P. Samuelson and Scotchmer 2002, 1577)[12] Most legal systems had traditionally recognized reverse engineering as a legal way to obtain know-how or knowledge from a manufactured product, even if that leads to the creation of a competing product, as long as they are not protected as intellectual property. Unlike with patents, there is usually no legal remedy "if through accident the secret leaks out, or if a competitor unmasks it by reverse engineering."(Friedman, Landes, and Posner 1991, 62)[13] I define *reverse-engineerability* as the inverse of costs associated with reverse-engineering a particular invention: the higher the reverse-engineerability, the lower the costs of reverse engineering an invention. Finally, *lead time* is the period between an introduction of a product containing an invention by one company and the entry of other products containing the same or competitive invention by other companies. Using secrecy, and relying on low reverse-engineerability, companies can prolong lead time and gain a market advantage.(Holgersson and Wallin 2017; Hall et al. 2014)

Patents are thus designed to make disclosure easy, but limit the utilization of inventions; whereas secrecy and reverse engineering make disclosure costlier, but don't limit utilization of inventions. The next section discusses how this relates to knowledge rivalrousness and excludability.

[12] Human-made artefacts are defined as "objects that embody knowledge or know-how previously discovered by other people."(P. Samuelson and Scotchmer 2002, 1577)

[13] Some restrictions on the use of reverse engineering had been introduced or proposed in recent decades. Most importantly, in the semiconductor chip industry in the U.S., the 1984 Semiconductor Chip Protection act requires the follow-up invention to include forward engineering step compared to the reverse-engineered invention. In the computer software industry, decompilation of computer programs had been discussed as a possible breach of copyright, but the practice remains to be widely accepted. In the entertainment industry, attempts were made to restrict reverse encoded digital content, but these do not affect knowledge as much as entertainment products such as movies, books etc. Overall, these exceptions are limited to very specific uses and patents remain to be the main institution of legal protection of an invention.(P. Samuelson and Scotchmer 2002)

1.2 Is knowledge a public good?

Knowledge is often categorized as a public good. While the statement is relatively straightforward for general knowledge, it is sometimes unproblematically extended to particular knowledge and inventions. In the textbook *Principles of Economics*, Mankiw lists knowledge as one of the "important" public goods, stating that "the creation of knowledge is a public good. If a mathematician proves a new theorem, the theorem enters the general pool of knowledge that anyone can use without charge."(2011, 228) Stiglitz states that knowledge is a "pure public good […] in the sense that giving knowledge to another individual does not detract from that which the others [have]".(J. E. Stiglitz 1987, 9) Under a closer examination, however, these statements have nuances in definitions and normative components that make them more complicated than they might seem. To analyze those nuances, the following sections explore the two properties of public goods in detail and then turn to the normative components.

Before discussing the question of whether knowledge can be considered a *public good*, one more note should be made. It may seem strange to consider knowledge as a *good* in an economic sense at all. Knowledge appears to be rather different from tangible economic goods, such as roads, bikes or lakes, and classifying it in the same theoretical framework might appear unfitting. However, economic goods can server as imperfect models (or metaphors) for understanding knowledge in the context of an economy. The motivation to do that is to be able to use economic models to analyze the creation of knowledge—while knowing the limits of such usage. In other words, considering knowledge as a good is a model for better understanding its creation, disclosure and utilization—and the discussion on its nature should facilitate this. With that in mind, the next two sections discuss the ways in which knowledge is non-rival and non-excludable and the limits of those metaphors.

1.2.1 Non-rivalrousness of knowledge

Non-rivalrousness is an uncomplicated property of general knowledge: if someone possesses knowledge of bike mechanics, that does not diminish anyone else's ability to have the same knowledge. Stiglitz (1999) clarifies that even though there is a non-zero cost of knowledge transfer (etc., obtaining a relevant source, learning), it remains non-rivalrous because these are costs of accessing knowledge, not of producing an extra unit of it. For particular knowledge, however, complications arise.[14] Archibugi and Filippetti (2015) point out that while the usage of knowledge is usually non-rivalrous, there might be some rivalrousness "in the generation and upgrade of knowledge."(Archibugi and Filippetti 2015, 6) Gaining a better understanding of bike mechanics, for example, might allow a manufacturer to gain a temporary competitive advantage, and make extra profit by selling better bikes. The process of inventing can often be competitive, the authors argue, because the commercial benefit from inventions is temporarily rivalrous. While the authors call this somewhat confusingly rivalrousness in generation and upgrade of knowledge (while rejecting rivalrousness in usage), it is a factor that shapes how economic actors approach knowledge and its creation.[15]

Another way to describe this temporary rivalrousness of knowledge is by using the concept of negative network externalities. The introduction of better bikes thanks to a better understanding of bike mechanics, might create negative externalities for other producers. In other words, the commercialization of new knowledge by one producer creates differences between producers that put some producers into a disadvantage. It should be noted that this also rests on the assumption that knowledge can be temporarily excludable (otherwise, there would be no competitive edge), which is discussed in the next section.

In contrast, Foray (2004) describes positive externalities of transferring knowledge as a property of cumulativeness, meaning that its "externalities enhance not only consumers' enjoyment but also, and above all, the accumulation of knowledge and collective progress; it is the possibility for some to 'stand on the shoulders of giants.'"(Foray 2004, 94) Similarly, Archibugi and Filippetti (2015)

[14] This includes the clarification made by Stiglitz, which assumes these costs of knowledge transfer are fixed. For particular knowledge, however, I will later argue that secrecy can be used to manipulate these costs to achieve exclusion. In connection to that, Archibugi and Filippetti (2015) make the argument that because of this non-zero costs of knowledge transfer, knowledge free-riding is less likely.

[15] For a more radical formulation of this argument, see Boldrin and Levine (2008).

argue that many types of knowledge have positive network externalities as “its value can escalate with increased use.”(Archibugi and Filippetti 2015, 160)[16] For example, my knowledge of English language not only allows me to write this text but also your knowledge of it allows me to communicate my ideas to you. As discussed in the introduction, this logic is also expressed in recent decisions by two automakers, Tesla and Toyota, to make significant parts of their patented inventions freely available in hopes for positive network externalities in the industry.(Sheridan 2014)[17] It seems to be the case (at least form the arguments found in the literature) that the negative network externalities are mostly temporary (and can be a property of particular knowledge), positive externalities can be permanent (and can also be a property of general knowledge).

1.2.2 Non-excludability of knowledge

Non-excludability, too, is a property that is more complicated for particular than for general knowledge. Because general knowledge is widely available on the internet, in libraries and textbooks, it is very hard to exclude someone from using it.[18] For particular knowledge, there are usually two tools for exclusion discussed in the literature: secrecy, as a technical possibility and intellectual property rights (the first being closer to a technical property, the second being an institution, in the distinction developed in section 1.1.2). While there are some who argue that knowledge is fully excludable through secrecy or some form of coding, when it comes to knowledge which is commercially utilized, most authors hold that excludability is only temporary if any. Foray (2004), for example, states that while knowledge can be kept a secret, it is “difficult to make it exclusive or to control it privately [because] as soon as it is revealed it slips out of one’s grasp.”(Foray 2004, 91) Archibugi and Filippetti (2015) differentiate between secrecy and access

[16] The authors are one of many who use information and knowledge interchangeably, including in this discussion.
[17] While the motivations for the decision and its business logic would require a separate investigation, Tesla at least rhetorically justifies it as an attempt to improve the whole industry of electric cars.(Musk 2014)
[18] Verschraegen and Schiltz (2007) complicate this claim by pointing out the options digital technologies bring to controlling information such as DRM protections of audio files (using it interchangeably with knowledge). One such usage of digital technologies is the wide censorship of the internet by the Chinese government (and others). Discussion of this phenomena is beyond the scope of this text, and is linked to topics of information manipulation and education, but it should be noted that it takes significant resources to censor the internet and make general knowledge excludable.

codes, which both provide only partial protections and can be broken. Stiglitz (1999, 2014) argues that while secrecy is an option in some technological industries, such as metallurgy, it is fundamentally inconsequential, as "there is no way that rivals can be excluded from knowledge of the chemical composition and the properties of the alloy."(1999, 310; see also Arrow 1962)

There are exceptions to this assessment. Callon (1994), for example, argues that scientific knowledge is fully excludable. His argument, however, is an abstract one: scientists can keep their knowledge for themselves, which makes it excludable. This is true, but it does not say much about scientific knowledge which is commercially utilized. Boldrin and Levine (2008) assess that while abstract ideas are non-excludable, copies of ideas are fully excludable. In fact, they argue, it is harder to force someone to give you their copy of an idea than a cup of coffee. This makes ideas closer to private goods than to public goods (such as national defense, where exclusion is much harder). However, their argument does not discuss ideas slipping from the grasp once they are revealed, which makes the excludability temporary—unlike classical private goods.(Foray 2004)

Intellectual property rights (and patents in particular) are institutions that make the utilization of knowledge excludable. For example, Mankiw (2011) states, "the patent system makes specific, technological knowledge excludable, whereas general knowledge is not excludable."(Mankiw 2011, 229) Stiglitz (2014) puts a lot of emphasis on intellectual property and patents as the principal tool of exclusion, arguing that it "provides a way of appropriating the returns to investments in knowledge, but in doing so, effectively privatizes a public good. [...] Patents inevitably enclose what would otherwise have been in the public domain."(J. E. Stiglitz 2014, 14) Archibugi and Filippetti (2015) point out that as this form of exclusion dependents heavily on the design of institutions, which are too large extent arbitrary, and this raises an important policy question: "what is the suitable level of excludability that governments should guarantee to inventors and innovators?"(Archibugi and Filippetti 2015, 8) Disputes over this question go to the normative components of discussions on the nature of knowledge as an economic good.

1.2.3 Other relevant properties of knowledge

There are several other properties of knowledge as an economic good that are discussed in the literature. Importantly, Foray (2004) identifies three properties of knowledge that will be relevant for discussion in section 1.3: knowledge is acquired definitively, as "the seller—by selling knowledge—does not lose anything"; "the buyer does not need to buy the same knowledge several times, even if it is to be used several times"; and "the buyer cannot really assess the value of knowledge without actually acquiring it."(Foray 2004, 12) The author connects the two properties to non-rivalrousness of knowledge, but, as I will argue in the next section, all the three properties also have strong implications for the excludability and permanency of knowledge.

While most policies regarding knowledge are implemented on a country level, the scope of the discussion is much broader. Many argue that knowledge is a global public good. Focusing for now on the word "global," the argument is that while other goods are provided locally (such as national defense, lighthouse, park, road or a bike), knowledge is the same everywhere. If useful, knowledge created in one country often spreads to other countries. The scale of problems with its provision is thus often global. If one country invests public funds in R&D, other countries can benefit from it. If one country has weak intellectual property protections, this can affect businesses in other countries. That is why international agreements such as the TRIPS, and organizations such as Drugs for Neglected Diseases initiative try to coordinate international policies towards knowledge creation and management—and many authors argue more of global coordination is needed. The discussion on global public goods is beyond the scope of this thesis, but the discussion on its properties and provision surely has a global reach. (Verschraegen and Schiltz 2007; Archibugi and Filippetti 2015; J. E. Stiglitz 1999)

1.2.4 Normative arguments and technical properties

While in the classical interpretation, properties of goods are external to political decisions about their provision, knowledge is an example of a case where they are not. As discussed earlier, Malkin and Wildavsky (1991) argue that the question of whether a good is public or private is necessarily a normative one, dependent on institutions in given society. In the case of knowledge, the discussion about its economic properties contains a combination of technical properties and normative arguments and assumptions (sometimes hidden in unreasonably generalized technical properties). Fundamentally, these can be analyzed using the following questions: What would happen—and what should happen—if there were no intellectual property rights? There are (at least) three different traditions of answers, each emphasizing some technical properties of knowledge while resting on different normative premises.

First, *public-interventionists* argue that knowledge is by nature a pure public good. Without some form of intervention, there would be very little new knowledge created; and while intellectual property rights are one form of intervention, public investment in knowledge is a superior option. They put emphasis on the long-term non-rivalrousness of knowledge, arguing that because of that, the public sector should provide knowledge for free to maximize social welfare: "[even if] one could exclude someone from enjoying the benefits of knowledge, it would be undesirable to do so because there is no marginal cost to sharing its benefits."(J. E. Stiglitz 1999, 310) In a more policy-oriented work, the argument goes, "knowledge is a good that is inherently non-rival. A very simple but powerful result follows from this. In order to maximize global social welfare, policymakers should strongly encourage global knowledge diffusion from developed to developing countries when similar technology is appropriate for both types of countries."(J. Stiglitz, Jayadev, and Baker 2017, 29) In other words, Stiglitz and others argue that, because of non-rivalrousness, every new invention should become part of the general knowledge as soon as possible and it is the government's role to make this happen.(See also Richard R. Nelson 1959)

Second, *intellectual-property-interventionists* argue that technically, knowledge is close to a public good, but should be turned into a private good through institutions. Without intellectual property rights, the argument goes, there would be a significant injustice to knowledge creators, and there would be much less new knowledge created. On the one hand, intellectual property rights are a question of natural rights and moral deserves. The philosophical roots of these arguments are based on works of such names as Emanuel Kant or John Locke, but since these arguments are explicitly normative, they are of lesser interest in this thesis (and this summary likely does not do them justice). On the other hand, individual property rights are fundamentally highly efficient instruments of economic transactions and the privatization of knowledge is necessary for incentivizing its creation and disclosure. Specifically, patents create individual incentives which are a much more flexible and efficient way of providing knowledge than any form of public funding. Patents also make knowledge more accessible, incentivizing disclosure, and even though their utilization is monopolized, this monopoly expires and the knowledge eventually becomes part of general knowledge.(Merges 2011; Binns 2014)

Finally, *non-interventionists* argue that knowledge is close to a private good, significantly so that there would be no problem with its provision without intellectual property rights. Without patents, they argue, there would be as much of knowledge created as today, likely even more. Intellectual property rights create arbitrary monopolies, excluding competition from the utilization of inventions that their authors voluntarily disclose when they decide to introduce a new product to the market. Their arguments are based on emphasizing the role of the temporary rivalrousness and excludability of knowledge, which provide strong enough incentives to avoid the underprovision of knowledge. Philosophically, they argue, property rights cannot be easily extended from tangible goods such as cars or apples to intangible goods such as knowledge. Limiting positive network externalities of knowledge (such as follow-up innovations) and significant transaction costs (such as litigation, administrative fees, and monitoring) make patents not only ineffective in incentivizing knowledge creation but even harmful.(Boldrin and Levine 2008)

Regardless of which normative arguments one agrees with, each of these answers emphasizes some technical properties of knowledge while disregarding others. Public-interventionists arguments rest on the assumption that excludability is mainly a matter of intellectual property rights, and without them, it would be effectively impossible to exclude from knowledge. Specifically, the argument assumes that secrecy as a mean of exclusion is not significant and that, consequently, if the public sector provides knowledge instead of privatizing it via intellectual property rights, there would be little exclusion. A public intervention should provide general knowledge. However, this is a danger in a potential oversimplification of the properties of knowledge. As will be discussed in the next section, even in countries with strong intellectual property rights, secrecy is still an option that companies in many industries consider to be a more important tool of exclusion than intellectual property rights.

Intellectual-property-interventionists, on the other hand, might admit that secrecy is an alternative to intellectual property rights, but use that to justify them. Thanks to patents, for example, there is more knowledge disclosure, even though only after some time. In contrast, the two other traditions of thought deemphasize his point. On the other hand, they tend to disregard the negative effects of this form of excludability on knowledge creation: many inventions rest on previous ones, and intellectual property rights significantly complicate subsequent innovation. The systems for managing those also create significant transaction costs, including costs of litigation, administrative costs, negotiation costs. Non-interventionists emphasize the temporary nature of excludability, which on the one hand creates incentives for knowledge creation, but does not complicate subsequent innovation. However, they tend to disregard that in many industries, the temporary excludability might be too short to provide socially-optimal incentives for knowledge creation and disclosure.(Scotchmer 1991)

1.2.5 The importance of technical properties

Different institutions can make knowledge closer to private or a public good, with different problems associated with one or the other. While the discussions whether it should be the first or the second are, to a large degree, normative, many technical questions need to be clarified to inform the normative discussion. What are the problems of making knowledge a public good (as proposed by public-interventionists)? Would there still be secrecy? If there are no patents (as proposed by non-interventionists), would there be no new inventions in some technological areas? Would there be more secrecy? What kind of knowledge would be kept secret and why? Do companies consider secrecy an important tool? How does particular knowledge become general knowledge and what policies can facilitate this process?

Many of those questions circle around the property of excludability. Is knowledge, in practice, excludable? Before moving towards discussing the theoretical contribution of this thesis on the topic in the next chapter, the next section discusses the role of patenting in knowledge excludability: are inventions patented or kept secret, and why?

1.2.6 Non-excludability of knowledge revisited

As summarized by Hall et al. (2014), there is a substantive empirical and theoretical literature exploring companies' choice between technical exclusion (e.g., secrecy, lead-time) and institutional exclusion (patents) of inventions.[19] The main empirical finding is that "[on average], patents are not the most important mechanism of [intellectual property] appropriation, while secrecy and lead time are, regardless of whether product or process innovations are concerned,"(Hall et al. 2014, 380)[20] but there is variation for specific kinds of inventions and industries. For example, Mansfield (1986) surveyed United States companies about the importance of patents, asking what percentage of inventions would not have been developed or introduced to the market without them. He found that in pharmaceuticals and chemicals, the percentage was 30 percent, in petroleum, machinery, and fabricated metals, 20 percent, and in seven other industries, there was no reported reliance on patents.[21] There is also variation in the kinds of inventions: product inventions are more likely to be patented then process inventions, because processes "may not be patentable; if patentable, they are more likely to disclose too much information to competitors and they are seen to be easy to invent around."(Hall et al. 2014, 380)[22]

The findings are largely consistent over time and across countries. According to a study of Western European companies by Arundel (2001), secrecy, lead time and keeping qualified people in the company are often considered more important than patents, with "50 percent of firms [ranking]

[19] The authors consider secrecy and lead time an informal intellectual property protection tool, and what they mean specifically is secrecy using trade secrets, confidential agreements etc.; and patents a formal intellectual property protection tool.(Hall et al. 2014)

[20] The authors use intellectual property appropriation in the broad sense of privatizing the benefits of invention, that is exclusion of invention utilization.

[21] Electrical equipment, office equipment, motor vehicles, instruments, primary metals, rubber, and textiles.(Mansfield 1986)

[22] Most of empirical research has been done on a company level or national level, which has been criticized as too broad: companies often operate with many different inventions.

lead time as the most important mechanism to appropriate returns to their innovation," compared to only 10 percent for patents.(Hall et al. 2014, 383) The reported advantages of secrecy and lead time are numerous: some inventions are not patentable or might be later invalidated in a court; potentially, they can cover an invention indefinitely; there might be lower transaction costs associated with them (including monitoring and administrative costs); patents require disclosure; and secrecy and lead time can cover work-in-progress and not only finished inventions.(Hall et al. 2014)

Theoretical models that analyze the decision of companies between patenting and secrecy support these findings. For example, Zaby (2010) and Schneider (2008) model a market situation between two companies: a lead innovator and a potential follower. The decision of the innovator whether to patent an invention or not will, to a large extent, depend on its ability to keep a leading position using secrecy, meaning that "if the inventor's [lead time] is large, the negative effect of patenting – the required disclosure of enabling information – outweighs its positive effect: the inventor will choose secrecy."(Zaby 2010, 159)[23] The technical properties of the invention, most importantly reverse-engineerability, play one of the important roles in most of the analyses of incentives to patent, suggesting that in industries where reverse-engineerability is higher, lead time is lower, and patents should be used more.(Zaby 2010; Hall et al. 2014)

In sum, existing research shows that there is significant variation between industries in terms of what kind of exclusion tools they use: patenting or secrecy and lead time. The finding that patents are unimportant in many innovative industries, and only somewhat important in most, suggests that excludability of knowledge is more complicated than discussed earlier. But if knowledge were a pure public good, secrecy as a form of excludability would be an insignificant factor in its provision, because public goods are by definition non-excludable. If intellectual property rights would effectively make knowledge private, companies would consider them more important. However, these empirical findings have been very weakly recognized in the discussion on economic properties of knowledge and their policy implications. In other words, the variation in business

[23] The author uses the term "head stars" with the same meaning as "lead time."

practices has not been linked to the variation in the deviation of knowledge from the concept of public good. Explaining these links is the goal of the next section.

1.3 Permanency of knowledge

It looks like a paradox. On the one hand, in policy discussions, knowledge is argued to be non-excludable, and close to a public good. But many companies exclude others from knowledge using secrecy and patents (the first often being a more important tool than the second). A way to avoid this paradox is to focus on general knowledge as a public good, which is close to non-excludable. But even then, it is far from straightforward to understand how particular knowledge becomes general knowledge and to analyze the ways knowledge would be provided effectively. In other words, there is variation in knowledge excludability. In what ways is knowledge excludable and how can this variation be explained?

I propose a new analytical tool for explaining the variation in the excludability of knowledge which goes beyond the classical distinction between public and private goods. I define a property of *permanency*: the inability to reverse transactions with a good, specifically to exclude those who had been provided with the good. When knowledge is leaked, intentionally disclosed, or traded, these actions cannot be taken back. Most classical private and public goods are non-permanent: it is possible to buy back a bike, tear down a lighthouse, let a road deteriorate, stop providing public defense. In contrast, knowledge is permanent: once someone gains knowledge in a market context, it is impossible to take it from them.

To a degree, of course, this is a simplification: knowledge contained in a book can be destroyed, and knowledge once learned can be forgotten. Cognitive scientists and historians would hardly agree that knowledge is permanent. However, when limited to the context of technical inventions exchanged in a competitive market, the simplification is not vast. Knowledge—earlier defined as a cognitive capacity (as opposed to just information)—can hardly be made non-permanent in market transactions.(See section 1.1.3 and Foray 2004) While people might forget what they once learned, actors in a competitive market will likely not forget invention that had been disclosed to them. At the very least, the risk of knowledge permanency is very high and will have an impact on the behavior of inventors and companies.

In a competitive market, permanency is the guiding principle of knowledge excludability. Technically, knowledge is excludable: one can easily keep an invention a secret. However, in the absence of intellectual property rights, the more knowledge is disclosed, the more non-excludable it becomes. An invention described in an academic paper becomes a part of general knowledge that is non-excludable and fulfills the properties of a public good. But an invention that is kept secret (say, in a company production plant) is much closer to a private or a club good. It might once be disclosed and become part of general knowledge, too, but its current excludability plays an important role in its provision.

Permanency makes excludability one-directional: it can be made non-excludable, but not the other way around. More generally, both non-permanent and permanent goods can be turned from being excludable to being non-excludable. One can make a park entrance free of cost or disclose an invention in bike mechanics. But while non-permanent goods can be made excludable, but that is not the case for permanent goods. Once knowledge is disclosed to others (or even becomes a public good), it is virtually impossible to take that back.[24]

This one-directional change in excludability is also what differentiates intellectual property rights from secrecy as tools of knowledge exclusion. Patents make it not only possible to exclude others from knowledge, but also make knowledge non-permanent (for the duration of the patent, that is). A patent license can be withdrawn, the patent itself can be offered on the market and traded. Patents can be treated as private non-permanent goods, and in effect, patents change the nature of particular knowledge so that it is no longer permanent. In contrast, secrecy allows exclusion, but

[24] This is focusing on the technical properties of knowledge and not on institutional interventions, i.e., assuming there are no intellectual property rights.

permanency bounds it. A company can exclude others form knowledge using secrecy, but once a production secret gets leaked, or once it is reverse-engineered, it is impossible to reverse that.[25]

The introduction of permanency also makes it possible to analyze differences in the technical properties of knowledge in different technological areas. In some technological areas, it is very hard to avoid disclosing knowledge—if a business wants to sell products which utilize an innovation, it is often relatively easy to reverse-engineer the knowledge contained in the innovation. Consequently, companies in these technological areas would be more likely to patent, even if they only want to produce the invention. In other areas, however, it is possible to exclude competition from knowledge using secrecy—perhaps because of lower reverse-engineerability. Companies in those areas would be less likely to patent—and if they do, that might be because they want to license out or sell an invention. With secrets, it is possible to keep knowledge excludable even when producing.

How then, does particular knowledge become general knowledge—in other words, how does knowledge become a public good? Figure 1 shows a schematic visualization of this process on a hypothetical example of five inventions.[26] Each invention shows the level of excludability of the invention itself (dotted line) and its utilization (solid line). Each invention starts as fully-excludable (in a research site of a company, in the computer of an inventor). Inventions A, D and E are not patented. Invention A (yellow) is disclosed shortly after the invention, and becomes quickly non-excludable; its utilization follows with a lag as it takes time for others to acquire the knowledge. Invention D (orange) is partially disclosed several times (say, in an outsourcing agreement or as part of a trade secret; or in reverse-engineering). Invention E (red) is successfully kept secret for a long time (say, as part of production know-how of a factory).

[25] This links permanency to the point made earlier by Foray (2004), who identified three properties of knowledge: knowledge is acquired definitively, as "the seller—by selling knowledge—does not lose anything"; "the buyer does not need to buy the same knowledge several times, even if it is to be used several times"; and "the buyer cannot really assess the value of knowledge without actually acquiring it."(Foray 2004, 12)

[26] I focus here on inventions as particular pieces of knowledge, as defined earlier, and not on products. One product can include (and often does include) more than one invention and is protected by more than one patent.

Inventions B and C are patented. The inventions themselves become non-excludable quickly, as they are published in the patent database. However, their utilization is excludable because of patents. Invention C (light blue) is covered by one patent, and its utilization becomes non-excludable right after the patent expires. Invention B (darker blue) is covered by three consecutive patents that the company issues in attempts to keep it excludable for a longer period.[27] Some of these patents are weaker and provide only partial protection (maybe on the production process or specific utilization of the invention) or may be invalidated by a court, which makes excludability lower. After some time, all three patents expire, too.

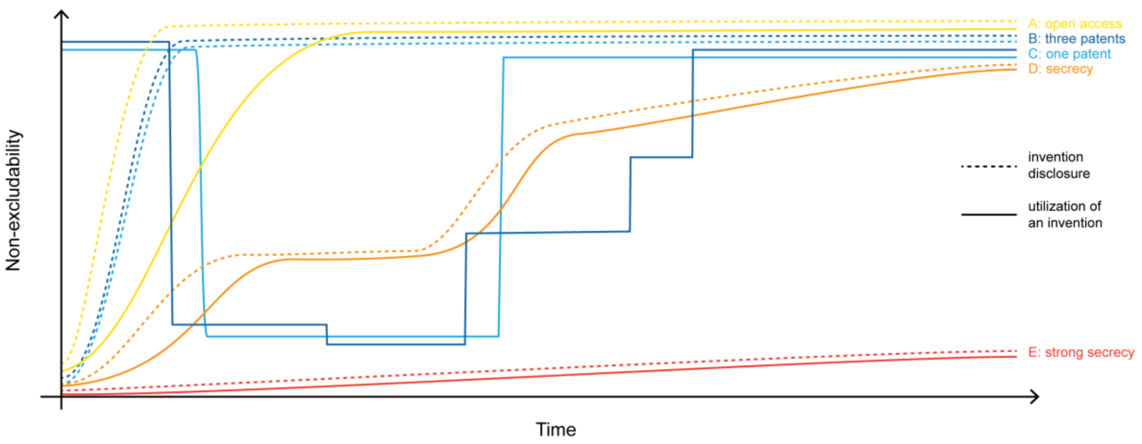

Figure 1 Schematic visualization of how knowledge becomes a public good. On the vertical axis is non-excludability, which, without patents, increases in time. This shows the effect of knowledge permanency. On the vertical axis is time, with the patent grant as the null point for patented inventions and invention event for non-patented inventions. We observe a difference in the amount of excludability in time for different strategies and kinds of inventions.

It should be noted that the level of non-excludability of all those inventions is increasing over time. The only exception is the utilization of patent-protected inventions, which is temporarily made excludable, and becomes non-excludable once patents expire. This reflects the property of

[27] This is a common practice in pharmaceuticals, where patents on variations of medicines are issued to prolong protection even after the patent on the main substance had expired.

permanency: knowledge is only becoming less excludable over time, except when patented, which allow its utilization to become temporarily excludable.

Two implications follow, which will be discussed in the following sections or chapters. On a policy level, this complicates the way one should think about knowledge creation. If a policy objective is to make knowledge a public good (and therefore non-excludable), patents might sometimes be a good tool for that (even disregarding incentives to innovate)—unlike what is traditionally argued. For inventions for which secrecy is an option, patents may, in fact, encourage disclosure. For example, if invention C on Figure 1 would become invention E in the absence of patents, it would become a public good later. As discussed in the previous chapter, secrecy plays an important role in companies' management of knowledge. More generally, for industries with different secrecy options, different policies might be optimal regarding public-goods creation (including intellectual property rights).

On an empirical level, if knowledge is permanent, this should be reflected in the way companies treat it. Is it possible to observe permanency and does it affect how companies and inventors approach inventions? How important is permanency? For example, companies and inventors in industries with lower reverse-engineerability might choose to patent, not because of production (for that, secrecy might be a better option), but because they might want to sell the invention. The next section will analyze these questions in more detail.

1.4 Incentives to patent

What are the factors that determine whether companies and inventors choose to patent (as opposed to relying on secrecy or open access)?[28] The literature on incentives to patent analyzes various considerations, some of which have a link to permanency. The most straight-forward set of considerations is related to excludability. For example, products inventions are more likely to be

[28] This is assuming that an invention is patentable. Additionally, many authors point out, the choice between patents and secrecy might not be mutually excludable. However, this is beyond the scope of this thesis.(See e.g., Arundel 2001)

patented than process innovations. This is often explained by the ease with which those inventions can be reverse engineered or imitated by competition: processes are harder to reverse engineer and can be kept a secret. On the other hand, "the role of secrecy is not as evident for product innovations since once the product is on the market, it can be reverse-engineered by competitors."(Arundel 2001, 613) This is also used to examine differences between industries: those with higher reverse-engineerability rely more on patents out of fires of knowledge disclosure.(Arundel 2001, 613; Arundel and Kabla 1998; Harabi 1995)

Legal institutions and transaction costs are two other considerations that influence excludability. If costs of enforcing a patent are high (i.e., costs of enforcing excludability), this would lead to less patenting. The relatively high transaction and monitoring costs for small companies and inventors had been used as an explanation for why "patenting has been found to be relatively difficult for small firms to benefit from."(Holgersson and Wallin 2017, 1088; Davis 2006) Similarly, the strength of the patent system is argued to play a role, particularly disclosure requirements. Patent institutions less strict on disclosure will lead to more patenting, as companies try to avoid giving knowledge about ways to "innovate around" a patent and competition after the expiry date of the patent.(Harabi 1995)

The second set of considerations is linked to permanency. When inventors want to sell an invention, they will more likely patent. If a company creates an invention but is not able to utilize it for the production and selling of products (maybe because they lack the production capacity to do that), patents make the invention easier to sell than secrecy. This might be the case of small companies, "could find patents to be more effective than secrecy, [because they] frequently lack the manufacturing capacity or marketing networks to be able to rapidly recoup their investment in innovation through the sales of their own products"(Arundel 2001, 613).[29] Thus, even inventions that could be kept excludable as a secret might be patented in order to make them non-permanent. Additionally, in contrast to secrecy, patents provide what Holgersson (2017) describes the dynamic

[29] The small size od a company thus cuts both ways: on the one hand, they might find it hard to enforce a patent, on the other hand, they might find it hard to utilize invention on their own.

freedom to operate: the ability to adapt to the market situation as new technologies emerge. A company with a strong patent portfolio, for example, might be able to maintain its position "[…] through cross-licensing agreements and various grant-back and assign-back license clauses."(Holgersson and Wallin 2017, 1092) Again, even inventions that could be kept excludable as a secret might be patented to be licensed or traded in the future.

Related to that, the third set of considerations, which is only of a minor interest in this thesis, is related to the strategic reasons to patent. For example, if inventions are very complex, and patents overlap or relate to each other heavily, and if patent requirements are low, then "firms build "thickets" of patents, especially incumbent firms in mature industries."(Bessen 2002) This is arguably the case of technology companies such as Google, Apple or Microsoft, and others, who develop significant patent portfolios to strengthen their position in case of legal disputes. As put by Harabi (1995), patents generally strengthen negotiation position towards other companies or governments. Additionally, patents might not be necessary if a company is in a monopoly position for other reasons; or patents (or open competition) might be applied for to prevent competitors from patenting—without an intention to enforce them at all.(Holgersson and Wallin 2017) Thus, in certain market contexts, incentives to the patent can exist even without the intention to exclude others from utilization or without making utilization reversible.

Those three sets of considerations represent overlapping, but analytically distinct incentives to patent. Even inventions that could be very efficiently excludable through secrecy (and have low reverse-engineerability) could be patented to make them reversible. For example, a small inventor without the capacity to produce an innovative, non-reverse-engineerable product might choose to patent not to exclude others from the invention, but to sell the invention to a large company. This represents an example of how permanency affects how knowledge creation and disclosure in ways that should be observable. Incentives to patent should be traceable on patent data. If inventions are not patented because of excludability (i.e., they are not easily reverse-engineerable), are they more likely to be patented to make them non-permanent (and sell them)?

This chapter introduced basic concepts of public sector economics and economics of knowledge, analyzed the limits of public good properties of knowledge and the normative arguments surrounding it, investigated the ways businesses use secrecy and patenting, and introduced the property of permanency as a new analytical tool for analyzing knowledge creation and disclosure. The following chapter will use USPTO patent data to observe inventor and company behavior that is shaped by permanency using proxy variables for reverse-engineerability of inventions and incentives to patent.

Chapter 2 Empirics

In Chapter 1, I argued that permanency is an important property of knowledge which has implications on how inventors and companies behave. In this chapter, I wish to trace down these behaviors empirically, in inventors' and companies' invention-level decisions. Because inventions that are kept secret are hard to observe, I use a patent database and a survival regression analysis. The results show that the reverse-engineerability of inventions affects changes in patent ownership, even when controlled for industry and year fixed effects, as well as the economic and social value of patents. This effect can be explained using permanency.

2.1 The empirical strategy: observing permanency

As I argued in Chapter 2, knowledge has the property of permanency: the inability to exclude someone from an invention they had been previously provided. Knowledge is also (temporarily) excludable: others can be excluded from an invention either through secrecy or intellectual property rights. But there is an important difference between these two means of exclusion. Permanency bounds exclusion which was achieved through secrecy. Once a secret invention is revealed (maybe through a leak or through reverse engineering), it cannot be made excludable again. Exclusion achieved through patenting, on the other hand, is not bounded by permanency. Competition can not utilize reverse-engineered invention because of the patent monopoly, patent sold to another person can be bought back, or the license can be withdrawn. Unlike secrecy, patents thus not only make knowledge excludable but also non-permanent (or make the utilization of knowledge non-permanent).

Different inventors and companies treat inventions differently. For some industries, secrecy is used as the main means of exclusion, but in others, patents are more important. Does permanency affect these different behaviors?

The problem with investigating this question is that secrecy is hard to observe. The ideal empirical analysis of the theoretical arguments in Chapter 1 would include analyzing data on the decision to patent and the time lag between invention and patent application—including on inventions that were never patented. In this imaginary ideal setting, one could observe whether more reverse-engineerable inventions would be more likely patented because of the risk of disclosure, whether entities in certain market positions would more likely be to patent, and what would be the secrecy strategies for non-patented intentions. But records of inventions for which the inventor chooses secrecy over patenting are usually not publicly available, and it appears that the most comprehensive means of observing secrecy is through surveys (discussed above). This significantly limits the ability to compare inventions which are kept as a secret to patented inventions.

Patenting, on the other hand, is a highly public process, recorded by patent offices from the application to changes in ownership and patent expiry. Patent offices keep these records in databases which are becoming increasingly more available for research.(e.g., Fierro 2014; Marco et al. 2015; Squicciarini, Dernis, and Criscuolo 2013) Even though patented inventions represent only a self-selected subsample of all inventions, different motivations to patent might be to some degree observable on these limited observations. In this chapter, I develop an empirical strategy that uses these public patent records. The use of patent data creates a limitation, as it only contains inventions that were patented. However, particularly for smaller inventors, I speculate there are differences between patented inventions in the motivations of why were they patented. I exploit differences in the complexity of patented inventions to explain different behaviors of those who invented them.

Figure 1 visualizes how permanency influences to how knowledge becomes a public good. Inventions that are easier to reverse engineer have technical properties that make them less excludable and inventors of such inventions have the option to choose only between strategies A, B and C. Inventions that are harder to reverse engineer have technical properties that make them more excludable and inventors of such inventions have the option to choose between strategies A, B, C, D, E. This has two implications. First, in industries with higher reverse-engineerability, patents will be used more, because exclusion through secrecy is effectively available. This is supported by anecdotal evidence from the literature, as discussed earlier.

Second, as discussed in section 1.4, companies and inventors patent because of different incentives: to make inventions excludable, to make them non-permanent (or for strategic purposes).[30] Following the argument developed by Arundel (2001) and others, more reverse-engineerable inventions will more likely be patented, because otherwise, there is no option to keep them excludable while producing. In this case, patents are mainly used to make an invention excludable (for the same reason secrecy would be used if it were an option). Consequently, I expect less reverse-engineerable inventions to be less likely patented because keeping those inventions excludable is possible using secrecy. Crucially, if patented, these inventions will be more likely traded soon after the patent had been issued. This is because—especially for inventors and companies which might not have the capacity to monetize inventions by producing and selling products—patenting provides an opportunity to make the invention non-permanent, which allows them to offer and sell it to a company who can monetize it. That is, selling those inventions and making them non-permanent had been the reason for patenting in the first place.

This should be observable on patent data. Less complicated, more reverse-engineerable patents will change owner longer after patent grant. In this case, patents serve as means of excludability. More complicated, less reverse-engineerable patents will change owner sooner after patent grant. In this case, patents serve as means of making inventions non-permanent.

[30] I will now disregard these strategic reasons, assuming they do not have strong effects on the variables used in the empirical analysis.

2.1.1 The hypothesis and the basic model

Based on the reasoning in the previous section, I formulate the following hypothesis.

H_1: Patents on relatively less reverse-engineerable inventions will more likely change owner sooner after the application date.

With the corresponding null hypothesis:

H_0: Patents on relatively less reverse-engineerable inventions will not more likely change owner sooner after the application date.

As will be discussed in section 2.2, reverse-engineerability is proxied by patent description length. The relation is reversed: the longer the patent description, the less reverse-engineerable the invention is. Change of ownership lag is measured as the number of days since application date and serves as a proxy for the motivation to patent. Patents with shorter lag were more likely patented to sell the invention, patents with linger lag were more likely patented to create products containing the invention.

The basic model to test this hypothesis is (variables will be discussed in the following section):

$$
\begin{aligned}
&\mathit{probability\ of\ early\ reassignment}\\
&\quad = \beta_0 + \beta_1 \mathit{description\ length} + \beta_2 \mathit{forward\ citations}\\
&\quad + \beta_3 \mathit{backward\ citations} + \beta_4 \mathit{scope} + \beta_5 \mathit{priority\ claims} + \beta_6 \mathit{grant\ lag}\\
&\quad + \beta_7 \mathit{priority\ claims} + \beta_8 \mathit{year}\ 1982 + \beta_9 \mathit{year}\ 1983 + \cdots + \beta_{36} \mathit{year}\ 2010\\
&\quad + \beta_{37} \mathit{year}\ 2011 + \beta_{38} \mathit{Electric\ machinery} + \cdots + \beta_{71} \mathit{Civil\ engineering}\\
&\quad + \varepsilon
\end{aligned}
$$

Where the main variable of interest it the description length, and other variables serve as controls, including 30 year and 34 invention field fixed variables, respectively.[31] In line with hypothesis 1, I expect β_1 to be negative, meaning that the longer the patent description (and the less reverse-

[31] Where coefficients on the year 1981 and the field of Transportation are included in the intercept.

engineerable the invention is), the sooner after grant date it will be sold (and the more likely had the patent been applied for with the intention to sell it).

2.2 The Dataset

The dataset used in this analysis is based on USPTO patent database publicly available at the organization's website.[32] The database has been further processed into a SQL database available in the Google BigQuery service.(Wetherbee 2017) It includes information about millions of patent applications filed at the USPTO, such as application date, grant date, description, classification, etc. Using SQL, I queried this database to create a dataset for this analysis. The dataset consists of detailed information about on 4,741,023 patents granted by the USPTO office between January 1st, 1981 and December 31th, 2011. The year 1981 was chosen based on data availability (see further), while the year 2011 was chosen partially based on data availability and because of America Invents Act, which changed legislation regarding patents on that year.(USPTO 2011)[33, 34]

Several variables were used as controls in the models: grant year, grant lag, field, scope, priority claims, and citations. The next section provides their overview. Lag in the change of ownership is used as the dependent variable, while a length of the description is used as the main independent variable—these are discussed in sections 2.2.2 and 2.2.3. Appendix A provides summary statistics for all the variables.

[32] Available at https://bulkdata.uspto.gov/, accessed on Jun 7, 2018.

[33] The law brought some international standards to U.S. legislation, most importantly the first-to-file rule, and was intended to speed up administrative procedures. In principle, the analysis could be performed on post 2011 data as well, and differences could be analyzed. However, this is beyond the scope of the text.(Hurst 2013)

[34] Additionally observations with unavailable description, unavailable field, negative reassignment value and reassignment value greater than maximum patent life were dropped—less than 1.5 percent of observations.

2.2.1 Control variables

Patent application date (or patent filing date) is the date the patent application was filed at the USPTO. It is used to calculate the maximum expiration date of patents for the survival analysis model (see further) and to normalize other variables. *Patent grant date* is the date on which the patent had been granted.

Patent grant lag is the difference between the application date and the grant date (in days). It had been previously used as a proxy variable for expected patent value: the smaller the lag, the higher the expected economic value, because patent applicants try to speed-up application process of patents with higher expected value, and "more controversial claims lead to slower grants, […] whereas well-documented applications are approved faster."(2009, 1969) Well-documented inventions that clearly fulfill the criteria of patentability are thus expected to be granted sooner. As Table 2 shows, the patent granting procedure takes on average about three years, which is one of the reasons to restrict dataset to patents applied for before 2012.(Regibeau and Rockett 2010; Dietmar Harhoff and Stefan Wagner 2009; Squicciarini, Dernis, and Criscuolo 2013)

Based on research by Schmoch (2008) for the World Intellectual Property Organisation, *Patent field* is a variable with 35 possible values, which is assigned to each patent based on its international patent classification (IPC) 4 digit code. If more than one code is available for each patent, the main classification code was taken in line with author's recommendations. Patent fields, for example, include Information technology, Optics, Machine tools or Environmental technology and were designed to be useful in research by being balanced in size and level of abstraction, while being distinct (see Appendix D for a full list). It is mainly used to control for field-fixed effects and to normalize other variables. *Patent scope* is the number of distinct IPC codes per patent. It had been previously used as a proxy for the technological breadth and economic value of a patent: the more fields, the higher the breadth and value. (Lerner 1994; Squicciarini, Dernis, and Criscuolo 2013)

Patent claims are descriptions of what is claimed to be patented (thus being non-obvious, innovative and useful), while *Priority claims* refer to claims in earlier patent applications (even in different countries) by the same actor that had covered the same invention and to show non-obviousness, innovativeness, and usefulness with respect to the filing date of the previous application. Claims are used as a proxy variable for the economic value of a patent, and there is little literature to be found on whether this can be extended to priority claims, too. In the absence of data on patent claims, I use the number of *priority claims* as a control variable for the length of and complexity of the process from invention to patenting.(Squicciarini, Dernis, and Criscuolo 2013)

When a patent is filed and examined, patent citations are used to refer to previous patents on which the patent builds on or relates to. They are both submitted by the applicant and edited by the examining USPTO employee. *Backward citations* are the number of citations to previous patents. They are to indirectly used as a proxy for the novelty of a patent. *Forward citations* are the number of citations from other patents to a patent in question. They are a well-established indicator of patent social value: more important inventions will likely be cited more. By their nature, they are observable only after a period of time, which is another reason to restrict dataset to patents applied for before 2012.(Harhoff, Scherer, and Vopel 2003; Squicciarini, Dernis, and Criscuolo 2013)

2.2.2 The dependent variable

As the dependent variable, I use the lag between patent application date and a first patent assignment. Information on patens assignment events was only recently comprised into one dataset and described by Marco et al. (2015), chief economist at the USPTO. Using a set of analytical methods, they distinguish assignment events between patent assignments that occurred within a company between employee and employer, assignments, corrections, name changes, security interests, government interests, results of mergers, and others. Importantly, about 82,1 percent of assignments are identified as employee to employer assignments, because (prior to the 2012 legislation change), "the patent must issue to a human inventor" and reassignment was needed to transfer the patent to an employer.(Marco et al. 2015, 7)

For each patent, the *reassignment lag* is calculated: the number of days between the patent application and the first new assignment, which is the closest indicator of ownership change (excluding employee to employer assignments). I also code *reassigned* variable indicating whether a patent had been reassigned at all or not for a logit model. I use this as an indicator of the incentives to patent. If a patent changed ownership sooner after application, it had more likely been patented with the intention to sell it. If it changed ownership later or never, it had more likely been patented with the intention to produce a product while excluding competition from the utilization of the invention. While assignment changes had been previously used in patent analyses, I did not find their usage as a proxy for the incentives to patent. About 24 percent of patents in the dataset were reassigned.

The data on ownership assignment has several limitations. Patent holders are not obliged to register assignments, which could result in self-selection bias: only certain changes in assignments could be recorded. However, they are incentivized to do so, because "if an assignment goes unrecorded, the assignor may sell the patent or application to a subsequent purchaser, and that subsequent assignment, if recorded, will take priority."(Marco et al. 2015, 6) Additionally, based on information provided by the USPTO, recording assignment change is important in case of patent enforcement or validity challenge.[35] Based on a recent report on patent non-practicing entities, 95 percent of patent acquisitions of those entities are recorded and 67 percent even within 90 days. This could be due to a high number of litigations non-practicing entities but indicates the data is relatively reliable.(FTC 2016, 144; Ciaramella, Martínez, and Ménière 2017; Marco et al. 2015)

The documents used to record patent assignments are not completely standardized, and the authors used text analysis in a "reasonable attempt" to distinguish between different assignment events.(Marco et al. 2015, 11) The tools used for this purposes included key-words search, analysis of the number of reassignments in one transfer, reassignment execution dates, etc. As a result of this, changes in company ownership and transfers within a corporate structure might show in the data as false ownership changes. The data is also "sufficient for time series analysis" only from 1981, which is the reason for the lower-bound time restriction in the dataset used in this analysis.(Marco et al. 2015, 10)

[35] Partly based on an email exchange with Acting Deputy Chief Economist from the USPTO in April 2018.

2.2.3 The independent variable

As the main independent variable, I use the length of patent description. As stated earlier, each patent filed in the USPTO has a description which discloses the invention so that it can be "carried out by a person skilled in the art."(WIPO 2004, 21) The text *description length*, technically calculated as the number of bytes of the description, is used as a proxy for invention reverse-engineerability.[36] The longer the patent description, the more complex the invention it covers, and the less reverse-engineerable the invention is. While text length is a basic way of measuring its complexity, due to the legal and technical nature of patent descriptions, it should serve as a decent proxy.

2.2.4 Normalization and winsorization

Patent datasets frequently include outliers that could heavily affect results of models, which could be valid observations, but also errors of information processing. Also, regulation changes, time trends, and industry fixed effects could bias values of variables. To control for this, I follow Squicciarini, Dernis, and Criscuolo (2013) and generate standardized and winsorized variables. For each combination of a year (between 1981 and 2011) a field (35 in total) and a variable, the 99 percentile is calculated. All values are then divided by the 99 percentile and values above are changed to the 99 percentile value.[37] Most variables in the following text will be thus used in their normalized form. (Squicciarini, Dernis, and Criscuolo 2013)

[36] Google BigQuery, the source of the dataset, limits the size of description to 9 megabytes. However, these are clearly outliers as less than a hundred of patents have a description of 8 megabytes or more.

[37] For variables with both negative and positive values, this is done separately above and below zero.

2.3 Models

I employ two main models to analyze the effect of patent description length on the first reassignment lag. The *Logit model* (1) examines the probability of a patent being reassigned. The higher the coefficient on a variable, the higher the logarithmized odds that a patent would be reassigned.

$$
\begin{aligned}
logit(reassignment\ probability) \\
&= \beta_{logit,0} + \beta_{logit,1} description\ length + \beta_{logit,2} forward\ citations \\
&+ \beta_{logit,3} backward\ citations + \beta_{logit,4} scope + \beta_{logit,5} priority\ claims \\
&+ \beta_{logit,6} grant\ lag + \beta_{logit,7} priority\ claims\ + \beta_{logit,8} year\ 1982 + \cdots \\
&+ \beta_{logit,37} year\ 2011 + \beta_{logit,38} electric\ machinery + \cdots \\
&+ \beta_{logit,71} civil\ engineering + \varepsilon
\end{aligned}
$$

The expectation is that the coefficient $\beta_{logit,1}$ on description length will be positive and statistically significant: more complicated inventions are hypothesized to be more likely traded, controlling for other variables. The limitation of this model is that it does not take into account the lag in change of ownership, but merely the observation that a patent had or had not changed ownership.

The *Cox survival model* (2) examines the hazard of a patent being traded in time. Survival regression models are designed to work on censored data: some patents were not observed to be reassigned because they had not been granted for a long enough time. The dependent variable, a survival event, is thus coded as the difference between the application date and: the first change of ownership (then, this is also coded as the event of interest in the survival model); 20 years (meaning maximum patent life for patents older than 20 years, this is coded as censored data); or the lag between application date and December 31, 2017 (for patents which were younger than 20 years on this date, this is also coded as censored data).[38] Again, the higher the coefficient on a variable the higher the legitimized odds that a patent will be reassigned.(LaMorte n.d.)

$$\begin{aligned}
&reassignment\ hazard \\
&\qquad = \beta_{survival,0} + \beta_{survival,1} description\ length \\
&\qquad + \beta_{survival,2} forward\ citations + \beta_{survival,3} backward\ citations \\
&\qquad + \beta_{survival,4} scope + \beta_{survival,5} priority\ claims + \beta_{survival,6} grant\ lag \\
&\qquad + \beta_{survival,7} priority\ claims\ + \beta_{survival,8} year\ 1982 + \cdots \\
&\qquad + \beta_{survival,37} year\ 2011 + \beta_{survival,38} electric\ machinery + \cdots \\
&\qquad + \beta_{survival,71} eivil\ engineering + \varepsilon
\end{aligned}$$

The expectation is that the coefficient $\beta_{survival,1}$ on description length will be positive and statistically significant: more complicated inventions are hypothesized to be more likely to be traded sooner. The advantage of the Cox survival model compared to the Logit model is that it can both take into account whether a patent had been traded and how long after application that occurred.(Golub 2007)

In addition to the two main models, a Negative binomial regression was run on a subset of patents which were reassigned. This model shows results that are consistent with the results of the main models, and statistically significant. Its main limitation is that it uses only on about 24 percent of patents, which makes its results less relevant (see Appendix B for full results).[39] Finally, to test for the multicollinearity of independent variables, a correlation matrix and variance inflation factors were calculated, suggesting no multicollinearity (see Appendix C).

[38] Not all patents are valid for all maximum 20 years: they need to be periodically renewed. The decision whether to renew a patent here is taken as part of the decision to reassign it.

[39] Similarly, running the Cox survival model only on the subset of patents that were reassigned produces consistent results, even though only significant on a 10 percent level. The coefficient on normalized description length is 0.018 with standard error of 0.006 (compare to Table 1).

2.4 Results

The results support rejecting the null hypothesis in favor of the hypothesis that less reverse-engineerable patents will be traded earlier, even though the effect is limited compared to other relevant variables, economic and social value. Table 1 column (1) shows the results of the Logit model: the higher the coefficient on a variable, the more likely a patent will be traded. The effect of description length of a patent is positive, suggesting that more complex and less reverse-engineerable patents will be more likely reassigned. Because the variable is normalized, the interpretation is that a patent description length of the 99th quantile (in each year and field combination) increases the odds of the patent being reassigned by a factor of 1.045, compared to a description with zero length (controlling for measures of economic and social value as well as year and field fixed effects).[40] In comparison, the coefficient on grant lag shows that a grant lag of the 99th quantile increases the odds of a patent reassigned by a factor of 1.19, suggesting that patents which were granted quicker after application will be more likely traded sooner.[41] All main results are statistically significant on a 5 percent level.

These results are also supported by the Cox survival model, as Table 1 column (2) shows. Again, the higher the coefficient on a variable, the more likely a patent will be reassigned faster. A patent description length of the 99th quantile (in each year and field combination) increases the odds of a patent being reassigned by the factor of 1.042, compared to a description with zero length. In comparison, the coefficient on forward citations shows that a number of citations of the 99th quantile increases the odds of a patent reassigned by a factor of 1.94.[42] Again, all main results are statistically significant on a 5 percent level.

[40] Calculated as the exponent of the coefficient. For example, in the Transport field in 2005, the 99th quantile corresponds to a description length of 173,350.7 bytes (or about the same number of characters).
[41] For example, in the Transport field in 2005, the 99th quantile corresponds to a grant lag of 3,306 days (or about nine years).
[42] For example, in the Transport field in 2005, the 99th quantile corresponds to 58 forward citations.

Main Models Results		
	Dependent variable:	
	Reassignement odds ratio	*Reassignement hazard ratio*
	Logit	Cox survival
	(1)	(2)
Description length[n]	0.044***	0.041***
	-0.007	-0.006
Forward citations[n]	0.863***	0.663***
	-0.006	-0.005
Backward citations[n]	0.801***	0.654***
	-0.007	-0.005
Scope[n,l]	0.056***	0.048***
	-0.002	-0.002
Priority claims[n]	-0.064***	-0.052***
	-0.007	-0.006
Grant lag[n]	0.175***	0.128***
	-0.006	-0.005
Year fixed effects	Yes	Yes
Omitted year	1981	1981
Field fixed effects	Yes	Yes
Omitted field	Transport	Transport
Observations	4,741,023	4,741,023
R2		0.031
Max. Possible R2		0.999
Log Likelihood	-2,503,671.00	-16,829,044.00
Akaike Inf. Crit.	5,007,485.00	
Wald Test		151,582.300*** (df = 70)
LR Test		147,239.900*** (df = 70)
Score (Logrank) Test		154,660.400*** (df = 70)
Note:	$^{*}p<0.1$; $^{**}p<0.05$; $^{***}p<0.01$	

Table 1 Regression results of the Logit and Cox survival models. Coefficients estimate the effect on logarithmized odds of a patent reassignement. [n] notes normalized variables, [l] notes logarithmized variables.

Figure 2 illustrates this result. Using a Kaplan-Meier survival function estimate, it shows the probability of patents being treated over their maximum lifespan based on their description length. Patents with above average description length (solid line) will be statistically significantly more likely traded. While the visualization does not control for variables such as economic and social value or and field fixed effects, it matches the results of the two models above, which do control for them.

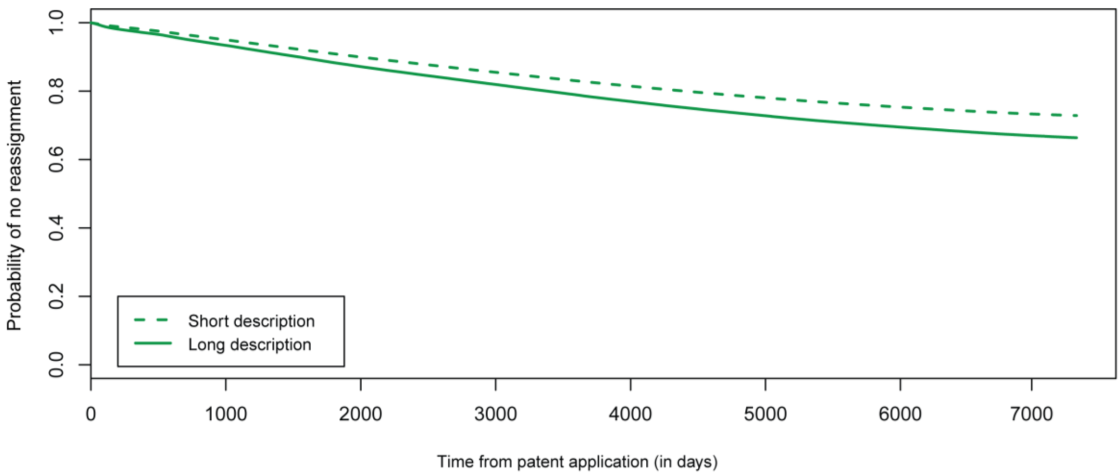

Figure 2 Kaplan-Meier nonparametric analysis of the probability that a patent will be reassigned in time from its grant, by short (below average, dotted) and long (above average, solid) description. The maximum time is a maximum patent term (20 years or 7,305 days from application). No control variables.

Even though these models have some limitations, which will be discussed in the following section, their results show a statistically significant link between two variables in line with the theoretical expectations: the length of patent description and the odds with which it will be traded. This suggests that there is a link between the reverse-engineerability of an invention and the motivation to patent: more complicated inventions are likely traded soon, suggesting that they had been patented to be sold.

2.4.1 Limitations

The empirical analysis shows results consistent with the theoretical argument presented in Chapter 1, but it also has several methodological limitations. I note those limitations in this section and suggest directions for further research. The omitted variable bias might be present, which could result in an incorrect coefficient on the independent variable. The models do not control for many other variables that influence the dependent variable, such as company size, type of invention, etc., which is also supported by the fact that the R2 is relatively low in all models (0.031 for the Cox survival model). Field fixed effects might control for some of this variation, but some of the 35 fields are relatively wide and likely include significant in-field variation. For example, in pharmaceuticals, one medicine is frequently patented multiple times, from patents on the main substance to patents on the production process, dosage, etc. Some of this variation is likely not controlled for, and the results thus do not show definitive proof of a causal effect.

As discussed in section 2.1, this empirical analysis only uses data on inventions that were patented, and not on inventions that were kept secret or published. Observing motivations to patent using a lag in a change of ownership relies on the assumption that reverse engineering plays a significant role in the risk of knowledge disclosure and consequently in the decision to patent. Additionally, it assumes that significant proportion of inventors and companies are not in the position to exploit an invention by producing and selling products (e.g., because of production capacities). This might be the case for small inventors and companies, but maybe less so for big innovative companies. An analysis of patenting motivations of small companies and inventors and an analysis of the effects of reverse-engineerability on the perceived risks of disclosure would be a welcomed addition to test these assumptions.

Both the motivation to patent and patent reverse-engineerability are measured only using proxy variables (first reassignment lag and description length, respectively), which have their limitations. As Marco (2015) points out and as discussed in section 2.2.2, reassignment data only to a limited degree distinguish between different types reassignment events, such as company mergers, reassignments within one ownership structure, etc. For example, a non-practicing-entity, Intellectual Ventures, is famous for managing its patent portfolio by estimated more than twelve hundred shell companies, and patent reassignments within this structure would appear as false changes of ownership.(Feldman and Ewing 2011)[43] Using patent length description also likely captures only some of the reverse-engineerability, as one can imagine patents that have short descriptions of inventions, and are hard to reverse-engineer (e.g., process inventions). But while the usage of both proxy variables would deserve more analysis, their basic logic holds and should

[43] In this concrete example, this would not be a major problem, because non-practicing entities usually do not register new patents. Thus, these assignments would not be recorded as first reassignments.

provide an approximation of the motivation to patent and patent reverse-engineerability, even if imperfect.

The empirical models rest on several other assumptions that might need further analysis. First, in section 2.1, I made the assumption that there are two distinguishable motivations to patent: to make an invention excludable and to make it permanent. The extent to which this is true is a question that I do not directly address in this thesis. However, for statistical analysis, it is sufficient that there is a degree of variations between these two motivations, and the results suggest that this is indeed the case. In the same section, I also made a strong assumption that strategic patenting does not affect the variables used in the empirical analysis. However, strategic patenting is a widely discussed phenomena and could play a role in patent reassignments. Further analysis of the interaction of strategic patenting and knowledge permanency would be an interesting area of research.(FTC 2016)

On a broader level, a qualitative analysis of patenting data has its limitations in showing motivations to patent and rests on many assumptions about company and inventor behavior. In further research that would aim to investigate whether permanency plays a role in inventors' and companies' approach to knowledge and patents, qualitative research might be a suitable method at this point. That could identify possible proxy variables and research strategies for further research. However, quantitative analysis in this thesis has the advantage of not relying on self-reported motivations of behavior and identifying possible further directions interest in research and policy. The conclusion discusses these in more detail.

Conclusion

In Chapter 1, I introduced the property of permanency: the inability to reverse transactions of a good, specifically to exclude those who had been provided with the good. I argued that permanency is a distinct feature of knowledge, which influences the process in which particular knowledge becomes a part of general knowledge. Though sometimes considered a public good, knowledge is partially rivalrous and excludable, and companies engage in excluding competition from knowledge using secrecy and patents. I argued that limiting permanency is a significant motivation of inventors to patent, analytically distinct from excludability. A group of university researchers might patent an invention to sell it, but the same invention might keep a secret if company researchers invent it. In this example, the dominant motivation of researchers might be to make an invention non-permanent (and sell it), while the dominant motivation of the company is to make it excludable (and produce and sell products). In short, permanency influences motivations of inventors and companies to patent and disclose knowledge.

In Chapter 2, I used data on U.S. patent assignments to investigate whether permanency affects motivations of inventors to patent. I hypothesized that patents on relatively less reverse-engineerable inventions would more likely change owner sooner because those inventions had been patented to become non-permanent and be sold in the first place. While the empirical strategy has limitations and different research methods would put more light on the role or permanency, I found evidence in support of this hypothesis. As modeled using proxy variables, patent description length has a positive effect on the probability of earlier patent reassignment, controlling for measures of economic and social value as well as year and field fixed effects.

What are the implications of the arguments from Chapter 1 and findings from Chapter 2? On a research level, permanency is a property that deserves further investigation. Empirical research could investigate whether inventors and companies identify permanency as a factor that influences their patenting practices and how strong of a factor is it. Theoretical research could review microeconomic models of knowledge creation and incentives to patent and analyze how permanency influences their results. Permanency many has implications beyond motivations to patent. Many economic models assume that prices are known, but how does an inventor know how much is their invention worth, if by offering it on the market, they risk disclosure? Finally, the proxy variables for reverse-engineerability and motivations to patent can be further investigated as novel means of analyzing patent data.

On the policy level, it should be recognized that considering knowledge a public good is an oversimplification. If interpreted as a normative statement (in the sense that knowledge should be a public good), the logical question that follows is—how should it be provided? When designing policies that address the creation and disclosure of knowledge, its excludability and permanency play a significant role. Public-interventionist proposals for publicly funded knowledge creation might miss the point that as a result, even more inventors and companies might choose secrecy. Non-interventionist proposals to decrease patent protections might miss the point that patents make knowledge not only excludable but also non-permanent, and decreasing patent protections would limit disclosure and positive network externalities of knowledge.

Designing an effective policy for knowledge creation and disclosure remains to be a challenge. Distinguishing between different fields and inventions—and different motivations to patent, keep an invention a secret or publish it—, should help better understand these challenges. Maybe in industries with high reverse-engineerability, knowledge can be treated as a public good, because secrecy is hard to maintain. But how would potential patent reforms influence industries with high reverse-engineerability? The risk is that inventions based on oversimplifications could make invention disclosure much less likely, which could, in effect, create obstacles to knowledge becoming a public good.

The global economy is increasingly said to be knowledge-based, but our understanding of knowledge creation and disclosure remains to be limited. Fundamental disagreements exist in approaches to knowledge from practical policy decisions to questions about its nature that cut to the basics of economic theory. If one asks policymakers and theorists what would be the effects of dismantling the patent system, answers take on a full range from a complete innovative gridlock to a golden era of knowledge creation. In this thesis, I hoped to introduce concepts that would bring more clarity to our understanding of knowledge, point out to oversimplifications in policy proposals, and suggests several directions in policy analysis and research that would enhance our understanding of knowledge. After all, there is still much we do not know.

Appendices

A. Summary statistics

Summary statistics for control, independent and dependent variables.

	Reassignment lag	Reassigned	Description length	Description length^{n}	Forward citations	Forward citations^{n}	Backward citations
Mean	2543.05	0.24	44727.60	0.21	22.09	0.13	24.94
SD	1776.02	0.42	69694.45	0.17	50.88	0.17	60.46
Median	2222	0	29660	0.17	8	0.07	12
Minimum	1	0	0	0	0	0	0
Maximum	7305	1	9436523	1	9081	1	3948
N	4,741,023	4,741,023	4,741,023	4,741,023	4,741,023	4,741,023	4,741,023

	Backward citations^{n}	Grant lag	Grant lag^{n}	Priority claims	Priority claims^{n}	Scope	Scope^{n}
Mean	0.15	1103.96	0.40	1.82	0.27	1.86	0.34
SD	0.17	644.50	0.19	1.67	0.17	1.16	0.19
Median	0.10	938.96	0.36	1	0.22	2	0.25
Minimum	0	-2533.96	-0.96	0	0	1	0.05
Maximum	1	12650	1	500	1	24	1
N	4,741,023	4,741,023	4,741,023	4,741,023	4,741,023	4,741,023	4,741,023

Table 2 Summary statistics of all variables (with the exception of year and field controls). ^{n} notes normalized variables, ^{l} notes logarithmized variables, SD notes standard deviation, N notes the number of observations.

B. The negative binomial model

In addition to the Cox survival and Logistic regressions, I performed a Negative binomial regression, which shows results which are consistent with the main models. The *Negative binomial regression* (3) examines the duration of time to first patent trade. The higher the coefficient on a variable, the larger the time lag before a first patent trade.

$$\log(first\ reassignment\ lag) = \beta_{nb,0} + \beta_{nb,1} description\ length + \beta_{nb,2} forward\ citations + \beta_{nb,3} backward\ citations + \beta_{nb,4} scope + \beta_{nb,5} priority\ claims + \beta_{nb,6} grant\ lag + \beta_{nb,7} priority\ claims\ + \beta_{nb,8} year\ 1982 + \cdots + \beta_{nb,37} year\ 2011 + \beta_{nb,38} electric\ machinery + \cdots + \beta_{nb,71} civil\ engineering + \varepsilon$$

The expectation is that the coefficient $\beta_{nb,1}$ on description length will be negative and statistically significant: more complicated inventions are hypothesized to be traded sooner. Table 3 shows results of this model, which supports the hypothesis formulated in section 2.1.1: description length results in quicker reassignment of patents, controlling for other variables.

I consider these results supplementary since the Negative binomial regression has several limitations compared to the Cox survival and Logistic regressions. The main limitation of this model is that it only uses data about patents which had been traded (about 24 percent), and for which the description length lag is available. Therefore, it does not take into account patents without data on a change of ownership and does not account for differences in observation times. In contrast, the Survival regression model is designed to incorporate data about patents which had not been traded. Additionally, some of the coefficients on variables other than description length are not statistically significant or show an effect inconsistent with the effect of the main models.[44]

[44] The reason for this inconsistency would deserve further analysis which is beyond the scope of this thesis.

Alternative model results	
	Dependent variable:
	Reassignment lag (log)
	Negative binomial (3)
Description length^{n}	-0.023***
	-0.005
Forward citations^{n}	0.141***
	-0.004
Backward citations^{n}	-0.067***
	-0.004
Scope^{n,l}	-0.002
	-0.002
Priority claims^{n}	-0.022***
	-0.005
Grant lag^{n}	0.154***
	-0.004
Year fixed effects	Yes
Omitted year	1981
Field fixed effects	Yes
Omitted field	Transport
Observations	1,121,236
Log Likelihood	-9,785,517.00
theta	1.613*** (0.002)
Akaike Inf. Crit.	19,571,175.00
Note:	*p<0.1; **p<0.05; ***p<0.01

Table 3 Regression results for the Negative binomial regression. Coefficients estimate the effect on the logarithmized first reassignment lag. ^{n} notes normalized variables, ^{l} notes logarithmized variables.

C. Multicollinearity

This section tests for the presence of multicollinearity between independent variables. First, I calculate the correlation matrix: correlation coefficients between all variables. If close to 1, there might be multicollinearity. The results do not suggest the presence of multicollinearity, with no correlation exceeding 0.4 in absolute terms.

	Reassignment lag^{n}	Description length^{n}	Forward citations^{n}	Backward citations^{n}	Priority claims^{n}	Grant lag^{n}	Scope^{n,l}
Reassignment lag^{n}	1	-0.026	0.001	-0.070	-0.053	0.073	-0.011
Description length^{n}	-0.026	1	0.194	0.271	0.334	0.071	0.128
Forward citations^{n}	0.001	0.194	1	0.219	0.082	-0.163	0.100
Backward citations^{n}	-0.070	0.271	0.219	1	0.248	0.068	0.131
Priority claims^{n}	-0.053	0.334	0.082	0.248	1	-0.006	0.149
Grant lag^{n}	0.073	0.071	-0.163	0.068	-0.006	1	0.057
Scope^{n,l}	-0.011	0.128	0.100	0.131	0.149	0.057	1

Table 4 Correlation matrix of most variables (except for year and field controls). ^{n} notes normalized variables, ^{l} notes logarithmized variables.

Second, I calculate the variance inflation factors for the Logit and Negative binomial models, which measures by how much are variance coefficients inflated. If GVIF is above 4 and close to 10, there is likely multicollinearity, and the variable is inflated. Again, there seems to be no problem with multicollinearity.

Negative binomial	GVIF	Df	**Logit**	GVIF	Df
Description length^{n}	1.256	1	Description length^{n}	1.250	1
Forward citations^{n}	1.142	1	Forward citations^{n}	1.136	1
Backward citations^{n}	1.267	1	Backward citations^{n}	1.267	1
Scope^{n,l}	1.086	1	Scope^{n,l}	1.077	1
Priority claims^{n}	1.227	1	Priority claims^{n}	1.222	1
Grant lag^{n}	1.163	1	Grant lag^{n}	1.186	1
Filling year	1.322	30	Filling year	1.320	30
Field	1.235	34	Field	1.199	34

Table 5 Variance inflation factors for the Negative binomial and Logit models. ^{n} notes normalized variables, ^{l} notes logarithmized variables.

D. Patenting fields

Field	Frequency (%)	Field	Frequency (%)
Electrical machinery, apparatus, energy	5.96	Basic materials chemistry	2.04
Audio-visual technology	5.17	Materials, metallurgy	1.47
Telecommunications	3.43	Surface technology, coating	1.47
Digital communication	4.90	Micro-structural and nano-technology	0.39
Basic communication processes	1.85	Chemical engineering	2.13
Computer technology	9.10	Environmental technology	1.10
IT methods for management	1.15	Handling	2.43
Semiconductors	4.88	Machine tools	2.41
Optics	4.89	Engines, pumps, turbines	2.74
Measurement	4.85	Textile and paper machines	2.19
Analysis of biological materials	0.57	Other special machines	3.03
Control	1.74	Thermal processes and apparatus	1.06
Medical technology	5.22	Mechanical elements	2.73
Organic fine chemistry	3.61	Transport	4.15
Biotechnology	2.34	Furniture, games	2.55
Pharmaceuticals	1.65	Other consumer goods	1.89
Macromolecular chemistry, polymers	1.66	Civil engineering	2.67
Food chemistry	0.59		

Table 6 The 35 fields used to normalize data and to control for fixed effects and their frequency in the dataset. Based on Schmoch (2008).

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