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Endogenous sharing of knowledge

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SUMMARY

This thesis investigates the willingness of firms to cooperate on Research and Development (R&D). I present three papers concerning incentives to share/exchange knowledge created by the firms' own R&D. It is my hope that this thesis can give some clues of how sharing and exchange of knowledge can contribute to an already large literature on Research and Development.

It is commonly believed that in order to sustain future growth and secure increased living standards, R&D is one of the few and most important ways to achieve this goal. R&D conducted by firms and universities create a lot of knowledge which has the possibility to be turned into innovation. Innovation creates new products and processes, products that replaces old ones and processes that increase efficiency and reduce cost. As a testimony to the perceived importance of R&D, the European Union has set a goal that a certain fraction of each country's GDP should be committed to R&D. Public polices have also been changed to foster more R&D. For example, the National Cooperation Act was enacted in the U.S in 1984, with the aim of fostering R&D by allowing firms to cooperate on R&D. Prior to this Act, firms were not allowed to conduct R&D together, because it was feared to lead to collusion in the product market.

To investigate this topic, this thesis employs economic laboratory experiments. A typical economic Industrial Organization (IO) laboratory experiment has subjects conduct choices in a computer lab, where each participant takes on the role as one firm. An important role of IO experiments is to bridge theoretical modeling and empirical work done on real life data. Some of the benefits of using such experiments include control over the environment within which the firms interact. Collecting data from real firms have several issues that make inference problematic. A major problem is the potential for reverse causality. Does competition affect

innovation or does innovation affect competition? Another issue is related to measurement. For example, how can one accurately measure competition? A laboratory experiment tries to address some of these issues by allowing for human behavior rather than economic man behavior. Experimenters may control the information and parameters as they wish. In principle, varying one variable between different treatments, a change in the outcome variable they are measuring should be attributed to the variable the experimenter is manipulating. In other words, a causal effect. However, laboratory experiments do come with some drawbacks. Since mostly students are recruited as participants, the field is criticized for lack of representativeness. That is, how can public policy be based on the decision of students sitting in front of a computer? Experiments does not paint the whole picture. They can however, provide evidence and valuable links for the theoretical modeling and empirical work based on economics and field data.

Let me summarize some of the main findings of this thesis. I find that firms are less willing to cooperate on R&D when the firms face tough market competition. It is not just competition that plays a role but also initial asymmetry between firms. If one firm is ahead of the others in terms of technology or knowledge, the leading firm will be less willing to agree to cooperate on R&D. Allowing for a side payment being transferred from the lagging firm to the leading one makes the leading firm more willing to cooperate. One way that seems to lead to both high R&D and incentive to cooperate, is to prevent firms from entering into R&D exchange before investment in R&D has taken place. The threat of one firm "out running" the other, keep both investing, and as long as the firms invested fairly equally, they wished to cooperate by agreeing ex post to share their knowledge.

Contents

LIST OF PAPERS

Paper I:

Roelofs, M. R., Østbye, S.E. & Heen, E. E. (2017). "Asymmetric Firms, Technology Sharing and R & D Investment." *Experimental Economics*.

Paper II:

Heen, E. E. (2017). "Does endogenous R&D sharing lead to an inverted U relation between investment and competition? An experimental approach."

Paper III:

Heen, E. E. & Østbye, S.E. (2017). "Should anti-trust legislation allow R&D information sharing? A simple experiment."

1. INTRODUCTION

The modern neoclassical view on macroeconomic growth dates back to the 1950s. The Solow (1956) model tries to explain the development in per capita income growth over time. The model shows how capital accumulation makes each worker more productive. If this model was correct, growth would stop as the marginal productivity of workers equals the marginal depreciation of capital. Growth has not stopped and the Solow model does not explain why the Western world had about 2% GDP growth per year for the last century (Jones and Vollrath 2013, p. 97). Solow attributed this residual to technological progress, but this was left unexplained in his model. Paul Romer endogenized the technology process in the late 1980s, incorporating R&D into the model. Now many consider Research and Development (R&D) and innovation to be the engine of growth (Gilbert 2006a). Understanding the underlying mechanisms of how to stimulate R&D and transform it into innovation is important in order to sustain continued improvement of living standards (Tang 2006). R&D has received a lot of attention. For instance, with the countries of the European Union having set a target for the share of GDP that should be spent on R&D and implementing policies that encourage firms to engage in R&D.

Directly measuring R&D and innovation can be difficult. This thesis focuses on R&D cooperation and its effect on investment in R&D and the formation of research alliances. I have employed economic experiments to explore this phenomenon. Much theoretical and empirical work connected to innovation research has been done already. However, experimental methods in industrial organization have been given a small role (Sorensen et al. 2010). Factors influencing innovation and cooperation in R&D may be related to market conditions such as the intensity of competition. On the other hand, factors relating to the agents themselves may play a role, like whether they are similar or asymmetric with respect to initial starting positions. A third set of factors affecting R&D cooperation relates to the actual sharing arrangement, whether contracts are entered into before or after R&D takes place. Should firms be allowed to commit upfront to exchange of R&D, or should only cross-licensing and similar arrangements after conducting R&D be allowed?

This thesis looks at how asymmetry in initial knowledge, competition intensity or timing of R&D exchange affect the amount of R&D and firms willingness to share their knowledge.

2. R&D AND INNOVATION

Innovation is the process that includes, but is not limited to, the search for new ideas and the discovery, development and commercialization of new processes or new products. It may also be improvement in organizational structures or procedures. It is a process that is characterized as "*dry holes and blind alleys are the rule, not the exception*" meaning that even if firms are engaged in innovative activities, being successful in R&D is far from certain (Jorde and Teece 1990).

Innovation is generally either inventing new products or improving existing ones (product innovation), or improving the productivity of existing products (process innovation). Most R&D conducted by private firms is focused on commercializing new products rather than cost-reducing processes (Tang 2006).

Firms' incentives to conduct R&D are many. The main focus of this thesis is on firms' ability to gain market power and/or avoid losing market power. Through process innovation, firms can reduce their marginal unit cost. In the case of an oligopoly, this will give the innovating firm a competitive advantage compared to the other firm(s). If every firm innovates equally, no firm will increase their market power or market share, though all firms' profitability will be increased due to lower cost of production and higher quantity sold. If a firm is the first to innovate a new product they may secure the patent right for several years. This leads to market power and the firm may reap monopoly profit. Other reasons for conducting R&D can be to differentiate one firm's product from the product of other firms', which will soften substitutability and lower competition.

As I have stated, R&D is the engine of growth, so it comes as no surprise that governments wish to encourage R&D. They may do it in several ways. The most direct ways are through subsidies and tax credits, such as funding university or research laboratories or allowing firms to deduct R&D costs from their taxes. It is important to note that funding universities generally does not lead to process or product innovation, these type of institutions usually conduct basic research.[1] There are two main arguments against subsidies. First, they are not

[1] Basic research is*: "research directed toward increases in knowledge or understanding of fundamental aspects of phenomena and of observable facts without specific application towards processes of products in mind."* (Martin, 2008, p.473). Hence basic research does not incorporate any entrepreneurial l aspects. It is the role of applied research (usually carried out by private industries) to use the knowledge gained by basic research to turn it into something that will stand the test of the market (Nelson and Rosenberg 1993)

necessarily the most efficient[2]; second, an overwhelming part of R&D is conducted within the industry sector, not the public sector (Martin 2008, p. 472). Governments may also use different public policies to stimulate R&D, such as patent protection and/or fostering R&D cooperation (Cabral 2000, p. 303). Patent protection allows innovating firms to be the single user of a new product or technology.

The knowledge created through R&D has the main characteristics of a public good. This is because if one firm uses knowledge it does not reduce the utility of another firm using that knowledge (non-rivals). Further, if one firm uses the knowledge, it does not prevent another firm from using it (non-excludable). Therefore, without institutional mechanics like patent-protection, individual firms have little incentive to do research because of the risk of failing will incur large cost, while the risk of quick and easy imitation leads to little additional profit (Martin 2008). Even if patents protect innovations, Mansfield, Schwartz and Wagner (1981) find that 60% of all patents were imitated after 4 years. Patents have the goal of protecting the innovating firm against free riding firms. A problem with innovation is that without protection, a firm might not be able to fully appropriate the social benefits from a discovery, removing the firm's potential monopoly profit. In the case of rival firms being able to appropriate the innovating firm's innovation, this would lead to lower private return of the innovating firm, in turn reducing the incentive to conduct R&D (Martin 2008). Firms may be able to appropriate rival firms' R&D through poor patent protection or through investing in absorptive capacity. The more rivals invest in absorptive capacity, the more they profit from rivals' R&D, again reducing the incentive to conduct R&D (Cohen and Levinthal 1989). There is however, reason to believe that a firms interest in investing in absorptive capacity depends on the type of R&D (Martin 2008). Hence, changing patent law in length or scope may change the perceived amount of competition in the product market.

The theoretical literature on innovation and R&D models in industrial organization fall mainly in to two categories, tournament and non-tournament models (Cantner and Guerzoni 2011). Tournament models usually have only one winner or innovator. Because of the one/few winners, firms' R&D efforts increase their own chance of winning, though if one firm increases it's chance of winning it reduces other firm(s) chance of innovating.

[2] Efficiency in R&D is most often made through aligning the effort of R&D and the returns on conducting R&D. Subsidies given for conducting R&D are disconnect to the firms success in R&D. Hence a firm receiving subsidies for conducting R&D may have very different incentives than a firm conducting R&D to stay competitive (or invent a new product).

Tournament models have clear winners and losers. Non-tournament models allow several or all firms' to receive some sort of positive pay off from their innovative activates. Depending on the nature of the relationships between the firms, they may benefit from the R&D conducted by the other firms. Hence, the non-tournament innovation models may see all firms being better off by R&D.

The non-tournament theoretical models following the work of d'Asprémond and Jacqemin (1988) are deterministic innovation models. All of these models have an underlying production of R&D that has a deterministic effect on the marginal cost of production (Clark et al. 2009). Non-tournament models link to the case of continuously upgraded technologies and allow for multiple stages of R&D (Caloghirou et al. 2004).

While d'Asprémond and Jacqemin investigated the effects of spillovers between firms conducting R&D, later work allowed for endogenizing the rate of spillover depending on the agreement between firms (Kamien et al. 1992; Katsoulacos and Ulph 1998; Kultti and Takalo 1998; Piga and Poyago-Theotoky 2005).

The strengths of tournament models are the explicit role of uncertainty and their ability to handle both product and process innovations. One important weakness of tournament models is the lack of continuous improvement of production technology. Knowledge in firms usually accumulates over time, and there are usually more than one "winner". Usually R&D races have more than one winner, since at least part of the R&D conducted and dispersed benefits the other firms (Caloghirou et al. 2004).

2.1. Research alliances/cooperation

Prior to the EU regulation enabling R&D Block Exemption since 1971 and the US National Cooperative Research Act of 1984, firms were not allowed to cooperate on R&D. The reason for this is that historically, allowing firms to cooperate has been viewed with suspicion, since firms who have cooperated on price or quantity (or other dimensions) usually have misused their market power to reduce competition. Governments have normally been suspicious of firms' agreements or cooperation between firms because of the fear of softening the market competition (Cabral 2000). Such cartels are in the firms' best interest, but not the interest of consumers. Firms were not allowed this form of cooperation on R&D, even if it could be beneficial for the firms and/or society (Bhattacharya et al. 2012). Prior to the Act, the relationship between market competitions and innovation, regardless of the nature of model, usually leads to a suboptimal level of R&D from a social welfare point of view.

After these changes in legislation, firms have not only been allowed to cooperate, but also in later years governments have changes polices to foster firm clustering. Ways in which firms were allowed to cooperate were binding agreement on amount of R&D (d'Asprémont and Jacquemin 1988); Exchange of all knowledge created through R&D; or funding of joint research labs (Kamien et al. 1992), allowing firms to share all costs and results of R&D. Cost sharing leads rival firms who benefits from one firm's R&D efforts to share the costs of efforts. This type of cooperation will no longer lead to negative externalities (since the rival firms are co-funding the efforts) for firms of conducting R&D and in turn will stimulate to more R&D being conducted.

When allowing firms to cooperate, the type of cooperation matters, both for the firms and from the social planer points of view. Kamien, Muller and Zang (Kamien et al. 1992), investigated how coordination and formation of Research Joint Ventures (RJV) between firms effect R&D and product market prices. They investigated four possible scenarios by changing the two conditions, coordinating R&D efforts and/or creating RJV. Allowing firms to cooperate by choosing a level of R&D that maximized joint profit but assuming no knowledge spillover between the firms, leads to both firms wishing to reduces investment, since coordination meant they avoided the prisoners' dilemma off high investment in R&D just because the rival firms had a high investment. Both firms choosing to invest low levels in R&D lead to high product prices, which leads to lower consumer surplus and higher firm profits. Investigating firms entering in to RJV, they found that if firms could not coordinate on effort in R&D, the free-rider problem dominated the firms' decision and none would be willing to invest a lot, leading to the worst possible outcome of all the four scenarios. However, when firms created RJV and could coordinate R&D efforts to maximize joint profit, the firms had the highest profit and the lowest product price. Kamien et al. (Kamien et al. 1992) found that firms should be allowed to cooperate and the best type of cooperation would be to set up joint research labs. A possible problem with allowing firms to cooperate this closely is the risk of coordination on price or quantity in the product market. Although Kamiens paper does not address this problem, there is evidence from lab experiments that coordination in R&D may lead to product market coordination (Suetens 2008).

Though Kamien does show that these ex-ante cooperative agreement may be beneficial for everybody, Kultti and Takalo (Kultti and Takalo 1998) show that forward-looking firms being only allowed ex-post agreements to exchange R&D after the investment were sunk, would still have an incentive to do exchange. The implication of their work is that there is no need to allow firms to make upfront commitments since cross licensing solves the problem of low spillovers between firms.

Other reasons for allowing firms to cooperate in R&D is as stated by John Kenneth Galbraith (1952, pp. 91–92), that the era of cheap invention was over, sine "*development is costly, it follows that it can be carried out only by a firm that has the resources associated with considerable size. In the more recent past it has been asserted that even very large firms do not have adequate resources to undertake unilateral development of some new technologies and, therefore, that numbers of them should conduct development jointly*". Simply said, all the small simple innovation advances are already found and only huge research projects can find the remaining innovations.

Many papers assume full appropriability and zero transaction cost for transfer of technology. One of the potential benefits of research alliances is the elimination of duplicate technologies. This is especially true for developmental activity when the knowledge has a high tacit component (Jorde and Teece 1990).

There are also arguments against allowing firms to cooperate in R&D. Nalebuff and Stiglitz (1983) show that R&D cooperation may lead to a loss of diversity. In the case where private enterprises are allowed horizontal cooperation, their joint research efforts may converge towards one product application, rather than several different products if these firms would compete in R&D (Jorde and Teece 1990).

2.2. Market structure

How market structure and competition intensity affects innovation is an old topic in economics (Martin 2008), and one of the most tested in empirical IO (Aghion and Tirole 1994). However, how the level of innovation is affected by product market competition is not clear. Schumpeter (1943) argues for a negative relation, as monopolies and large scale is conducive to a firm's willingness to conduct R&D. With higher market share, more of the benefits of innovation will befall the firm. Arrow (1962) argues for a positive relation between competition and innovation. The argument is that under tough competition, small firms benefit more from innovating than under soft competition.

Most of the theoretical discussions on R&D and competition within the tradition of non—tournament models is an extension of the work done by d'Asprémont and Jacquemin (d'Asprémont and Jacquemin 1988)[3]. In this model, firms first conduct R&D to lower their unit cost, then compete in the product market. In general, the findings are that with high spillovers (i.e. one firm's R&D reduces the unit cost of the other firm), firm profit and social welfare is higher if the firms cooperate on R&D. However, if spillovers are low, R&D competition yields higher social welfare (Suetens 2005).

Aghion et al. (2005) argues that for an inverted U-shape, this was suggested by Scherer (1967).[4] This relationship is empirically tested by e.g. Tingvall and Poldahl (2006), who find support for an inverted U when measuring the competition intensity with the Herfindal index. There is uncertainty to this type of empirical testing since it can be difficult to quantify what the level of completion or the level of innovation is (Ostbye and Roelofs 2013; Tingvall and Poldahl 2006).

Non-experimental empirical studies have shown that cooperation in R&D can lead to cooperation in the product market (Duso, Röller, and Seldeslachts 2014; Gugler and Siebert 2007). Experimental studies have found similar results where cooperation in R&D or joint profit maximizing behavior in R&D leads to collusion in the product market (Suetens and Potters 2007; Suetens 2008). One of the first papers to innovation and R&D in experimental economics was Isaac and Reynolds (2008).[5]
The relationship between competition and innovation might not be clear, as innovation may be affected by the particular type of competition and general relationship between them can be ambiguous (Schmutzler 2010a). The empirical literature has neither arrived at a clear conclusion, and it might be no surprise that distinguished scholars are lead to quite different conclusions (Schmutzler 2010b).

[3] Other notable work in the field include (Kamien et al. 1992; Petit and Tolwinski 1999)
[4] In the paper by Østbye and Roelofs (Ostbye and Roelofs 2013), they show that an inverted U shape can emerge naturally if firms are endogenously allowed to cooperate in R&D in an product innovation setting.
[5] For further literature on experimental I-O I recommend Sorensen, Mattssson and Sunbo (Sorensen et al. 2010) and Potters and Suetens (2013).

3. METHODOLOGY

This thesis employs the methodology of experimental economics and theory to investigate endogenous sharing in R&D. A major part of the analysis is done based on experiments. Experimental economics is one of the fastest growing fields in economics (Normann and Ruffle 2011). There are few fields in economics that has not been affected by the development in this new field, and industrial organization is no exception. The International Journal of Industrial Organization has to date had two special issues dedicated to experiments in industrial organization, the first being in 2000 and the second in 2011.

Economics is a field based on models with assumptions such as fully rational consumers, stable preferences, generally only self-interested, time consistent preferences (and the list goes on) (Grubb 2015). Evidence that these assumption are not always valid have begun to show, and new models were developed, giving birth to the field of behavioral economics (Grubb 2015). The idea that subjects does not always follow these assumptions is not a new one, and economists have long recognized concepts from psychology (see Rabin 1997). However, as late as 1985, Samuelson and Nordhaus (1985, pp. 8–9), argued that economists cannot perform the type of controlled experiments of chemists or biologists, because we cannot control important factors. The work of Vernon Smith, Charles Plott and Reinhard Selten has become more known in the later decades, an economists have opened their eyes to behavioral and experimental economics (Friedman and Sunder 1994, pp. 1–2).

Laboratory experiments can help us study a wide range of economic questions, some experiments generate data that might influence a specific decision (Friedman and Sunder 1994), studying the effects of incentives, to classifying cognitive biased, to testing economic models. They can be employed to investigate changes in institutes, changing in incentives, the decisions of consumers, voters and managers, generating data that others vises would be difficult or impossible to measure, observe, or obtain, these are just some of the possible uses.

Experimental economics presents the tools needed to, among other things; test theory predictions, investigate behavioral phenomena or irregularities, and illuminating and supporting policy-making (Guala and Mittone 2005). Through experimental economics, it is possible to construct experiments that engage only a small piece of the world, thereby allowing the restriction of effects that might affect the theoretical models (Smith 1989).

Two of the main benefits of using experiments to investigate questions in industrial organization is controllability and replicability (Brandts and Potters 2016; Falk and Heckman 2009). Experiments allow for a very high level of control, where all the relevant game-theoretic equilibria are known. Since the experimenters have the possibility to only change one variable between treatments and keep everything else constant, it is easy to make ceteris paribus comparisons. Such ceteris paribus comparison permits researcher to make clear-cut causal interpretations. Experiments allow for a high degree of replicability. Experimental economics papers usually clearly outlines how the experiment was conducted, in addition to often giving out the experimental code and instruction to other researchers. This gives sceptics to a certain paper the possibility to replicate studies (Brandts and Potters 2016). In addition, variables that are hard to observe or measure in the "real world" can be change exogenously in the lab, with no degrees of uncertainty (Brandts and Potters 2016). Such "unobservable" could be degree of reciprocity, social approval, decision based on information social parties have (Falk and Heckman 2009), or firms interests in TSC or firms direct investment in R&D.

There might be raised questions of using students as the subject pool, as they are not "real-people" and hence the experiment would lack representativeness. This however, is not a problem since economic theory drive prediction are independent of the subjects (Falk and Heckman 2009). The hypothesis about behavioral differences between subjects used in experiments and "real businessmen" is the call for more experiments (Plott 1982). Several experiment do not find any reliable result of difference in stacks or employment (Fehr et al. 2014; Slonim and Roth 1998) and may more. The rejection rate in Ultimatum games even lead Cameron (1999) argue: "the persistence of rejections at high stakes does however raise the question of how high the stakes need to be to complete the reversion to Nash equilibrium". There are some instances where there are differences between cultures or social background affects behavior, Gächter and Herrmann (2011) found higher level of cooperation among rural residents in Russia than urban residents in Russia. However, the result of same behavior within same culture is quite robust.

Even if laboratory experiments is now a widely used methodology, there remains considerable resistance among some social scientists who argue for the lack of "realism" in experiments (Falk and Heckman 2009). Laboratory experiments are generally simple in comparison to naturally occurring processes, they do engage real processes in the sense that participants are incentivized by profits and real rules, and engage with real people. General theories must apply to special cases, if experiments employ the mechanics of general models they should hold in and experimental lab as well. If theories do not apply to special cases they are not general and may not be portrait as such (Plott 1982).

For the field of experimental industrial organization, lab experiments give a clean and direct way of measuring casual effects in IO. Using field data to measure effects such as how competition effects innovation, it is not clear if competition effects innovation or innovation effects competition (also known as revers causality). In addition, measuring exact levels of investment by a firm, or competition in a market, may also prove difficult. Firms may invest in diversified research for different aspect of their frim. Market competition may be hard to measure with firms who are not in direct competition. An experiment solves all these problems as it allows for the experimenter to determine them a-priori. Experimental IO can provide complementary information from both the empirical field and the theoretical one (Falk and Heckman 2009). It is important to note that experiments do not paint the whole picture, but does shed light on some aspects of this field, and may help us to where to look next for answers.

It is beyond the scope of this thesis to defend the field of experimental industrial organization. I have provided some arguments for the use and strength of experiments. For more discussion on reliability and external validity of experimental economics, I refer interested readers to Falk and Heckman (2009), Guala and Mittone (2005) and Fréchette and Schotter (2015).

4. SUMMARY OF PAPERS

All three papers focus on what has been called ‘coopetition’(Brandenburger and Nalebuff 1995), the situation where firms compete in some dimensions and may cooperate in others. Here, the firms compete in the product market but may cooperate (or compete) in innovation. All papers also share a common methodological framework by using theoretical models within the non-tournament IO tradition, as well as controlled laboratory experiments.

The first paper looks at what happens when firms are asymmetric as compared to symmetric in initial conditions, with and without sidepayments that should be sufficient to incentivize a technological leader to give up the initial advantage and share R&D output with initial laggards. Through an experiment, this prediction is tested empirically.

The second paper only considers asymmetric firms without any sidepayment, but introduces different levels of competition intensity in the product market. This makes it possible to analyze within the framework of coopetition, the much studied issue of the relationship between competition and innovation that has in particular been associated with the work of Schumpeter.

In the third paper, the importance of institutional framework on coopetition is studied. Firms are assumed to be symmetric and allowed to cooperate by engaging in a binding agreement on exchange of R&D output before each invest in R&D. This is compared to the baseline case where exchange is only allowed after investments. The two cases are interpreted as reflecting different positions in terms of anti-trust legislation.

4.1 Summary of paper 1: Asymmetric Firms, Technology Sharing and R&D Investment

In the first paper, a duopoly model of a potentially emerging market is presented. The model includes uncertainty about the success of R&D efforts (and therefore of the possibility of the market emerging). Both symmetric firms and leader/laggard asymmetry in terms of initial knowledge are considered. A combination of theory and experiment is used to study the incentives for firms to share knowledge when they engage in research and development (R&D).

The paper studies how differences in starting position (initial knowledge) affect the willingness of firms to share knowledge, when and if firms find R&D cooperation beneficial and how investment in R&D is affected by the sharing outcome.

Multiple empirical approaches are used in the empirical part: experimental methodology, panel data regression techniques, and Quantal Response Equilibrium (QRE) analysis. The experimental design contains both traditional treatments by assignment and more unusual treatments by choice. The design implies comparisons both between-subjects and within-subject. The regression techniques are used to control for possible dependencies in the data. Finally, Quantal Response Equilibrium (QRE) analysis allow for bounded rationality in the empirical model.

More specifically related to the experiment, there are 3 treatments by assignment: Symmetric initial conditions, Asymmetric initial conditions in terms of knowledge (leader and laggard), and finally, the same as the second but with a sidepayment paid by the laggard to the leader if sharing takes place. There is also what can be seen as two treatments by choice: knowledge sharing if both subjects are willing to share (TSC: Technology Sharing Cartel), and no sharing (NO) if not.

Are subjects willing to share new knowledge? The model predicts they should except when in the role of leader without a side payment. The data show that a clear majority of the subjects behave consistent with prediction in the treatments in which they should share. A significantly lower proportion is willing to share in the only treatments where they should not (leader in Asymmetric), but there is still a majority of subjects willing to do so. Notice that a leader under TSC is guaranteed to maintain here initial lead of because sharing of knowledge accrues to both the leader and laggard. By not sharing, however, there is the possibility that the laggard can reduces the competitive edge of the leader and catch up, or even overtake the leader.

Turning to the investment decision, there is a clear distinction in the behavior of leaders depending on whether the outcome of the sharing stage leads to a TSC or not. With a TSC in place, leaders overinvest relative to the Nash prediction and in NO they underinvest. This difference does not exist for laggards who overinvest in both cases. The paper also shows that subjects in the baseline Symmetric treatment without sharing invest according to the Nash prediction, but overinvest when there is sharing (as did the asymmetric subjects). Finally, comparing investment across sharing regimes, holding treatments constant, investment is significantly and substantially lower under TSC than NO in line with the theoretical Nash predictions. Where the Nash equilibrium concept does not fare well is relative to exact numerical predictions. Only symmetric subjects under NO invest according to the Nash prediction. In all other cases subjects exhibit either overinvestment or underinvestment relative to Nash. However, allowing subjects to be less than fully rational via QRE not only explains all qualitative deviations, but also the variability from a quantitative perspective.

Relative to earlier literature, the same pattern in investment across sharing regimes that are found here is also found in Clark et al. (2009) despite the fact that in that paper TSC and NO were exogenous and represented as treatments (by assignment) rather than the endogenous choice used here. Compared to other studies, agreement is more mixed and not easily summarized. The reader is therefore referred to the paper for more details.

Overall, the findings on investment behavior confirm much of what is known from precious theory and existing experimental evidence. For the possibility of sharing knowledge and cooperating in R&D, on the other hand, there is not nearly as much existing literature for comparison. The paper adds to this literature with a model that incorporates the possibility of endogenous R&D, on the other hand, there is not nearly as much existing literature for comparison. The paper adds to this literature with a model that incorporates the possibility of endogenous R&D cooperation and find that the experimental data largely confirms the qualitative predictions of the model. Introducing bounded rationality in the model, even all quantitative prediction are confirmed. The fact that previous findings on investment are confirmed and new evidence to the literature on R&D cooperation is added, all while using a model that endogenizes the sharing decision and incorporates uncertainty and firm asymmetry into the non-tournament framework, is primary contribution of the paper.

4.2 Summary of paper 2: Does endogenous R&D sharing lead to an inverted U relation between investment and competition? An experimental approach

The second paper applies in principle the same theoretical model as the first paper, but only considers asymmetric firms without any sidepayment and adds different levels of competition intensity in the product market to study the relationship between competition and innovation.

There is a large literature on how competition affects innovation (see Gilbert 2006b; Schmutzler 2010b). Indeed, it has been claimed to be one of the most tested relationships in empirical IO (Aghion and Tirole 1994).

Some studies for a negative relationship between competition and innovation following the late Schumpeter (1943). Other studies argue for a positive relationship, following Arrow (1962). More recently, Aghion et al. (2005) have argued for a non-monotonic relationship and specifically an inverted U shape. Others have offered support for a regular U shape (e.g., Sacco and Schmutzler, 2011).

This paper revisits the relationship between market competition and innovation by allowing for coopetition. Interestingly, this framework implies non-monotonicity in the form of an inverted U if firms play strictly according to Nash and offers a very simple alternative explanation compared to Aghion et al. (2005).

The model allows for 3 different levels of competition intensity in the product market if both firms succeed in their innovation: Tough that corresponds to Bertrand, and Soft that corresponds to collusion. In addition, to allow for non-monotonicity, there is an intermediate case called Moderate. The model predicts that Laggards would always wish to share knowledge, but exchange will only happen if also the Leader agree. The model predicts that the Leader would wish to share when competition intensity is Soft, else not. Hence, prediction is sharing of knowledge only in Soft. Since investment in R&D with sharing is predicted to be low and without sharing high, all else equal, the model predicts low average investment in Soft compared to Moderate and Tough. Without sharing, higher competion intensity implies lower investment in R&D. Hence, average investment is predicted to be lower in Tough than Moderate. Overall, the prediction is therefore flor an inverted U shape between competition intensity and R&D investment. When innovation success on average is increasing in investment, this also implies an inverted U between competition intensity and innovation.

The experimental design reflects the theoretical model by introducing 3 treatments by assignment for each level of competition intensity. For all treatments by assignment, there were also two treatments by choice: If both firms were willing to share knowledge they would create a Technology Sharing Cartel (TSC), if one or no firms were not willing to share there would be no sharing (NO).

The experiment opens up for comparisons both between subjects and between periods for the same subject (within-subject design). Since subjects made multiple decisions across several periods there is a concern of interdependence between periods. Harrison (2007) suggests using panel data regression techniques to take interdependency into account. This is also done in this study and in line with recent literature on experimental IO (see Darai et al. 2010; Sacco and Schmutzler 2011).

The experimental data shows that Laggards clearly wish to share knowledge for all treatments, with their sharing frequency being between 81% and 76%. The results for Leaders on the other hand is less clear. They should only be willing to share knowledge in the Soft treatment, but the evidence suggest that they are also willing to Share in Moderate.

Why leaders are willing to share in Moderate remains unclear, but several behavioral explanations could be possible. Leaders may believe that Laggards will reciprocate if they share knowledge, or Laggards may (negatively) reciprocate by trying to hurt the Leader for not cooperating. Another reason for punishing the Leader could be because the Leader has exogenously been given an advantaged position (Sacco and Schmutzler 2011). The Leader could fear repercussions from aggressive Laggards, and TSC removes the possibility of Laggards overtaking the Leaders (Zizzo 2002).

Turning to the investment decisions the most robust finding is that TSC reduces investment. The aggregate investment should reveal and inverted U shape, however no inverted U shape appears. The results imply falling investment as competition increases. A closer look at data shows that Leaders do not change their wish to exchange between the Soft (56%) and Moderate (55%) treatments. Since TSC leads to less investment, there is lower investment in moderate than predicted. This rejects the theoretical prediction that endogenous cooperation leads to an inverted U shape. There could be several reasons for this. TSC ensures the Leaders the position of being Leader and ensures the lead in knowledge and prevents the lagging firm from being able to overtake the Leader (Halbheer et al. 2009). In the case of NO, the model predicts higher investment for Leaders than for Laggards. This is only the case in the Tough treatment. In the Soft and Moderate treatments, overinvestment by the Laggard and underinvestment by the Leader leads to no difference in investment.

Related to earlier literature, other experimental studies have also found decreasing investment as competition intensity increases. The model in Sacco and Schmutzler (2011), for example, predicts a regular U shape. Their paper focuses on incremental R&D without any form of R&D sharing or spillovers. Overbidding and endogenous R&D sharing leads to falling R&D expenditure as competition increases rather than the theoretically predicted regular U shape. Summarizing what we have learned from the second paper, overall it seems critically important to allow for asymmetry between firms since the position as Leader or Laggard clearly matters for behavior and for how behavior differs from model predictions. In TSC, all firms overinvest. In NO the Leader underinvests while the Laggard still overinvests. The cause of this overinvestment is not clear and should be studied further. Notably, the results support that asymmetric initial condition are important and that firms in an initial favored position may in particular behave differently than simple Nash-play suggests.

4.3 Summary of paper 3: Should anti-trust legislation allow R&D information sharing? A simple experiment

Is it necessary to allow binding agreements on sharing of R&D output between firms before investments in R&D are undertaken (*ex ante* cooperation) in order to align private and social incentives for private R&D, or is it sufficient to rely on possible sharing of R&D output through markets after investments have taken place (*ex post* cooperation)? This paper studies how the sharing of knowledge, before or after conducting R&D affects the willingness to share and the investment level. Is a firm willing to cooperate on R&D when it is beneficial for it to do so, but even more beneficial for other firms? As theoretical framework, the paper employs a simple duopoly model proposed by Kultti and Takalo (1998).

A motivation for the study is the changes made in the anti-trust legislation in EU, enabling R&D Block Exemption since 1971, and in the US, through the National Cooperative Research Act of 1984 and later amendments. These changes should have made firms less reluctant to enter into up front (*ex ante*) binding agreements for R&D sharing in fear of legal prosecution.

Prior to these changes firms were only allowed to buy, sell or cross-license technology or knowledge created through R&D.

In the theoretical model by Kultti and Takalo (1998), the firms have incentives to, ex post, exchange knowledge created through R&D since the investments are sunk. We may think about this as the baseline case reflecting the institutional setting represented by the traditional type of anti-trust legislation. By switching the sequence of decisions, we allow firms to enter into ex ante agreements on exchange before investments take place. We think about this as representing the modern type of legislation. If one firm expect that the other firm will wish to share knowledge, a forward looking firm will wish to invest as much as in the baseline case. Hence, the theoretical predictions for investment in R&D is the same in the two cases.

To investigate whether this is also true empirically, we conduct a simple experiment where the two treatments differ only by the sequence of decisions. The experiment consisted of three stages: the sharing stage, the investment stage, and the profit “stage”. The profit “stage” is not a decision stage, but merely provides information to the subjects about investment level, sharing conditions and profit for both subjects. In the investment stage the subjects decide on how much to invest in cost reduction R&D. Depending on the treatment, the subject would know if they had agreed on sharing with the other subject or they would know that they would be given the opportunity to share knowledge in the next stage. In the sharing stage, there was a simple Yes/No decision to share all knowledge created through R&D. For sharing to take place, both had to say Yes.

Simple non-parametric statistic was used when analyzing the data generated through the experiment: Mann-Whitney U-test for comparisons between subjects and Wilcoxon Signed-Ranks Test for within subject comparisons.

Did the subjects wish to share knowledge? In both treatments, there was a high willingness to share knowledge, between 72% to 85%. There were no statistical differences in sharing between treatments or order of which treatment was played first.

Did the subjects invest the same in the two treatments? Subjects on average tended to choose high R&D investment levels except for when agreeing to share R&D output before investing (ex-ante). The high level is close to the Nash prediction without sharing and the low level close to the Nash prediction with sharing. With the sharing decision made after investing, data are still in accordance with predicted investment for the case when no sharing takes place. However, with sharing we find huge overinvestment compared to Nash play.

How do our results compare to other findings in the literature? For ex post sharing, there are no comparable results. For ex ante sharing, a few experimental papers are relevant for comparison. In all of these, with the exception of Roelofs et al.(2017), sharing or not are treatments by assignment and not treatments by choice as here. The reader is referred to the full version of the third paper for the detailed discussion. Here, we concentrate on the ex ante treatment results from Roelofs et al. that is most comparable: 75 percent of the subjects wish to share, compared to 83 percent here. Hence, a clear majority as predicted in both studies. As for investment, we are in line without sharing: both studies find investment according to Nash. With sharing, Roelofs et al. find overinvestment while our results show investment as predicted.

In summary, we find that allowing ex ante sharing agreements does not affect willingness to share much compared to the baseline treatment, but investment is lower. Although we should be careful not to oversell policy implications based on a single study, this is consistent with what has been observed after the change in anti-trust legislation in the US: not much happened in terms of the number of research alliances being formed (Martin 2008). In addition, our data suggest that the investment level could decrease that would be in conflict with intermediate policy goals related to increasing and not decreasing investment in R&D.

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