Complementary Assets, Patent Thickets and Hold-up Threats -
Do Transcation Costs Undermine Division of Labour in Innovation?

Franz Schwiebacher*

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Abstract

Empirical evidence for hold-up and transaction costs in patent thickets, empirical evidence is rare. I investigate whether specific investments to commercialize new technology is affected by fragmentation and heterogeneous capital stocks among owners of complementary technology. In order to verify the transactional character, the effect of these technological characteristics on non-specific investments is clarified. I find that a lack of coordination within patent thickets results in transaction costs, while hold-up does not appear to cause transaction costs. On the contrary, heterogeneous capital stocks among patent applicants increase propensities to invest in complementary assets. This suggests that efficiency gains from division of labour in innovation exceed potential transaction costs.†

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*ZEW Centre for European Economic Research, Mannheim and Department of Management, Strategy and Innovation, KU Leuven. Correspondence: ZEW, Industrial Economics and International Management, P.O. Box 103443, D–68034 Mannheim, email: schwiebacher@zew.de.

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1 Introduction

Does access to complementary assets necessarily imply a privileged share in the distribution of rents from innovative activity? At first glance, Teece's (1986) seminal work regarding the impact of appropriability regimes and complementary assets on the distribution of innovation rents seems to imply this conclusion. However, Teece (1986) and Gans and Stern (2003) focus their discussion on a unilateral dependence of technology suppliers on complementary assets owned by an established downstream innovating firm. These complementary assets thereby serve as gatekeepers to a successful commercialization of technologies. In this case, inventors are held-up from commercializing their technology, because they lack complementary assets such as distribution networks, manufacturing equipment, or brand-name reputation.[1][2] On the other hand, imperfections in the market for technology (Gans and Stern 2010) may also lead to situations where the owner of complementary assets is held-up by technology suppliers that own relevant patents. In this case, downstream innovators may find themselves unilaterally dependent on access to single intellectual property rights (e. g. Shapiro 2001). A prominent example is the case of the Blackberry producer Research in Motion (RIM). In the year 2000, when RIM was already producing its devices, the patent-holding company NTP (which was founded in 1992) sent notice of infringed patents to RIM. Although doubts have been raised on the validity of NTP's patents, the threat of shutting down their operations induced RIM to agree on a settlement payment of $ 612.5 million. This study aims to investigate, whether firms perceive such hold-up threats in the German market for technology when deciding about investments into cospecialized assets.

During the last two decades, firms have increasingly been turning to external markets for technology developments (Arora et al. 2001, Chesbrough 2003). In parallel, investments in small, research-intensive start-up firms have accelerated (Kortum and Lerner, 2000). These developments point to a more pronounced division of labour between the creation of new technology and its downstream commercialization in innovative products and processes. In order to reap the benefits from such a division of labour, however, transactional challenges have to be overcome. The literature on technology markets has primarily focused on the expropriation risks that inventors face (Arrow, 1962, Mowery, 1983). This is surprising, since regarding the primarily considered case of cospecialized complementary

[1]In his original article, Teece (1986) already mentioned the possibility that the dependence may not be solely unilateral in the form that the technology supplier is dependent on access to complementary assets owned by incumbent innovators. He already indicated that the owner of specialized assets may equally well be dependent on technology of others. However, the discussion in the literature of mediating effects from access to specialized assets focuses to the best of my knowledge on the former case.

[2]A prominent example is the lost innovation race of EMI that developed the first tomographic scanner. Only after EMI lost its independence and incumbents took over the market with imitative innovations, they were granted damages for patent infringements.

assets, technology suppliers depend on access to them, as well as downstream innovators depend on access to the technology. As technology generates economic value only when commercialized, the former needs access to the necessary complementary assets. However, when these assets are already adapted to specific technological input (as the term 'cospecialized' indicates), the downstream innovators becomes as well dependent on the upstream technology supplier. Thus, in the case of cospecialized assets, a mutual dependence is present. The distribution of profits from innovation then largely depend on the relative degree of dependence: Is the inventor more dependent on the innovating firm's assets or vice versa? The answer to this question is largely determined by the point in time negotiations take place. When the innovating firm has already sunk its investments in assets specialized to a certain technology, it is likely that the patent-owning technology supplier finds itself in an improved bargaining situation, since failure of negotiations would leave the downstream innovator with the incurred costs of adapting its equipment. On the other side, if licensing negotiations take place *before* the owner of complementary assets adapted it to a specific technology, we find ourselves in the classical case of an inventor facing the risk of expropriation by an incumbent owner of complementary assets.

This study contributes to a growing literature that analyzes the mediating role of complementary assets in boundaries of firm decisions.[3] The literature largely focuses on the effects of complementary assets on propensities to collaborate or license from the perspective of the technology supplier (e. g. Arora and Ceccagnoli 2006, Gans et al. 2002). Whether the demand-side for specialized technology is affected by expropriation risks is still an unanswered question. Ziedonis (2004) demonstrated that capital-intensive owners of complementary assets safeguard their access to the underlying technology more aggressively, when transaction costs in the market for technology are high. But whether the diffusion process of new technological knowledge into innovations of economic value is actually affected is still an open question. Empirical evidence regarding this question is the more warranted, since transaction costs in the market for technologies are presumed to hamper diffusion of technological knowledge into innovative goods (Heller and Eisenberg 1998). Whether such transaction costs actually impede the innovation process is still subject to an intense debate (Padilla et al. 2007, Geradin et al. 2008).

I investigate whether innovative investments are affected by the distribution of capital stocks among potential technology suppliers, since a lower amount of sunk investments by technology suppliers (compared to downstream manufacturers) is a necessary condition for hold-up threats to be credible. I do not find that the German market for technology

[3]For a general overview of the empirical literature on the boundaries of the firm (i. e. whether parts of the value chain, like e. g. R&D, are organizationally independent or integrated) see Lafontaine and Slade (2007).

creates major transaction costs from hold-up threats. On the contrary, I find that dispersion of capital stocks among patent applicants increases investments in complementary assets. This result indicates that efficiency gains from divisions of labour in innovation outweigh transaction costs from hold-up threats. Nevertheless, transaction costs may also originate from fragmented ownership on technologies (Shapiro 2001, Ziedonis 2004). Indeed, I find that fragmentation within technologies negatively affects investments in complementary assets.

This study integrates insights from managerial strategy literature of innovation with a transaction cost and property rights perspective of technology markets. Section 2 discusses the role of complementary assets in technology transactions and why market imperfections may arise in technology markets. Subsequent sections delineate the different kinds of transaction costs that could hamper the diffusion of technological knowledge into innovative products and processes. Such transaction costs can emerge when market participants make sequential irreversible actions that are adapted to specific uses. Section 2.1 discusses why and when investments in complementary assets could result in a risk of expropriation rather than creating competitive advantage. Section 2.1.1 discusses expropriative risks originating from opportunistic players in the market for technology. Section 2.2 describes why the sequential and cumulative invention process could create transaction costs. Section 3 shows the empirical findings of this study. Section 3.1 describes the data sources I use. Section 3.2 provides the descriptive statistics of the sample and discusses the empirical operationalization of the research question. Section 3.3 presents my econometric evidence and section 4 concludes.

2 Hypothesis development

The resource and competence based view of the firm in the strategic management literature largely regards downstream complementary assets as source of competitive advantage. Their adaptation to specific uses makes them hard to imitate for inventive entrants. (Dierickx and Cool 1989, Barney 1986). Complementary assets are, however, only a source of competitive advantage when they are specialized, i. e. are not easily tradeable and are therefore associated with a certain amount of sunk, non-recoverable expenditures. Because these assets serve as effective gatekeepers for the commercialization of technologies when they are specialized, it is frequently argued that their ownership allows incumbents to master waves of competence-destroying technological change (e. g. Tripsas 1997, Rothaermel and Hill 2005). Having established assets necessary for a successful commercialization of technological breakthrough inventions mitigates competitive threats from inventors of new technology, because incumbent's assets serves as effective barrier to entry the final product market. This reflects the traditional supply-side focus since Arrow (1962) regarding expropriation risks in the market for technology. The installation of an intellectual property regime and the associated provision of exclusion rights to the inventor shall induce inventors to disclose their generated knowledge to other inventors and potential 'commercializers of technologies'. Since disclosure of inventions is necessary to value the invention and to allow technology transactions to take place, intellectual property rights serve as insurance against expropriation and therefore are regarded as necessary condition for a market for technology to emerge.[4] An (efficient) market for technology creates economic benefits from realizing comparative advantages and scale and learning economies. However, recent evidence suggests that transaction costs still restrict a broader market for technologies to emerge (Gambardella et al., 2007) and therefore further economic benefits to be realized.

The existence of an intellectual property regime is, however, not sufficient for a market for technology to emerge, since patents are varyingly effective as appropriation mechanism (Cohen et al. 1996). This ineffectiveness is grounded in the fact that patents are only property-*like* rights. Patents solely provide a right to exclude others from usage of the protected technology, but do not (and cannot) confer rights to use and rights to the fruits from its usage. Property to tangible goods grant the owner all three sorts of rights. This imperfection of intellectual property rights becomes a transaction cost concern when innovative products and process become increasingly complex and of multi-technology nature (Gambardella and Torrisi 1997). In this case, congruence between technological exclusion rights and value-creating innovations vanishes. This lack of congruence between legal rights and economic rents is further amplified by the fact that single technologies frequently cannot be captured by a limited number of patent rights. In some technologies, like e. g. the pharmaceutical industry, it is relatively easy to codify invented technological knowledge into patented claims. Patenting a certain molecular structure in the pharmaceutical industry excludes effectively imitators from the rent-generating product. However, patents protect technology and not innovative product concepts, that ultimately generate economic rents. This distinction becomes especially important in complex technologies. Here, innovative product designs cannot effectively been captured by limited amount of patent rights. Levin et al. (1987) phrase this lack of distinct codifyability of the R&D outcome as 'difficulty to determine whether comparable components of two complex systems ‚do the same work in substantially the same way'. This inability of patents to capture new complex technology may result a variety of patent rights, so-called patent

[4]When the inventor is able to threat the downstream manufacturer to renege expropriative behaviour by disclosing the technology to manufacturer's competitors, Anton and Yao (1994) have shown that division of labour in innovation is also possible when the invention is only protected by secrecy. Alternatively, the prospect of future interactions may induce the downstream manufacturer to establish a reputation for honesty (Teece 1989, Baker et al. 2002).

thickets (Shapiro 2001), that protect a restricted part of the technology space and overlap mutually.

Empirical evidence regarding technology transactions largely considers the effects of weak appropriability regimes and transaction costs on the supply-side. For instance, Gans et al. (2002) show that start-up technology suppliers are more likely to collaborate with established firms, when their intellectual property is an effective exclusion mechanism and sunk costs of market entry are high. Much literature also investigated the form of collaboration between technology suppliers and 'commercializers of technologies': Arora and Ceccagnoli (2006) show that patent effectiveness increases licensing predominately for firms that lack commercialization capabilities. Rothaermel (2001a, b) shows that incumbents can leverage their complementary assets also via strategic alliances with providers of new technology. Bloningen and Taylor (2001) report a negative correlation between own R&D intensity and the propensity to acquire other firms in high-technology industries. Less is known regarding the demand side of external technology acquisitions. This literature largely examines complementarities between internal R&D and external technology acquisitions (Arora and Gambardella 1990, Cassiman and Veugelers 2006). Only few studies investigate to what degree the demand side of the market for technology is affected by market imperfections and transaction costs. Pisano (1990) studied the „make-or-buy" decision of established firms with respect to R&D expertise when small-numbers bargaining hazards and appropriability concerns are present. Ceccagnoli et al. (2010) also focus on the role of internal R&D capabilities and find that firms endowed with relatively more cospecialized assets have a lower propensity to source outside technology. However, whether the demand side of the technology market is subject to expropriation risks due to the specifity of complementary assets has not yet been investigated in the literature. The next subsections will therefore discuss the different kinds of transactions costs that could hamper the diffusion of new technologies into innovative products and processes.

2.1 Hold-up Expectations

Transaction costs can emerge when unprogrammed adaptation, lock-in and appropriable quasi-rents, that could be haggled over are present (Joskow, 1991). In other words, preconditions for transaction costs are sequential and irreversible actions that are targeted to specific outcomes but cannot be fully contracted upon ex-ante. In the case of technology transactions, these sequential, irreversible actions refer to sunk investments of both market sides: The technology supplier sunk expenditures in R&D[5] and the 'commercializer of technology' sunk expenditures in the adaption of its assets to become complementary.

[5]R&D expenditures consist mainly of labour costs are therefore not recoverable.

These sunk investments create a lock-in situation. However, a successful transaction creates quasi-rents, i. e. rents that do not arise in other factor combinations, but only in those when *specific* technology is matched with *specific* assets. The degree to which contractual incompleteness (that may lead to unforeseen contingencies and unprogrammed adaptations) is present in technology transactions depends on the strength of intellectual property rights. The subsequent sections will verify that these preconditions for transaction costs are met within a division of labour in innovation context.

Transaction costs can emerge between upstream technology supplier and downstream innovator, when one party has sunk investments targeted to the generation of quasi-rents. Quasi-rents only arise in conjunction with specific factor input of the respective other party. Usually, R&D expenditures by technology suppliers are considered as the respective sunk investments. When negotiating the licensing terms, the degree of expropriation by the downstream innovator depends on the specifity of supplier's technology. When the technology is very specific, the dependence to a *certain* owner of complementary assets is very high. Only in conjunction with her assets, a high economic value from innovations is generated. When the technology is not very specific, the supplier could also turn to alternative downstream manufacturers and high economic value from innovations is however generated. In the former case, the amount of quasi-rents is high whereas it is low in the latter case. The degree of expropriation is therefore determined by the amount of supplier's investments that is specific to a certain downstream assets. The higher the associated quasi-rents, the lower the value of supplier's technology in alternative uses and the worse her threat point in negotiations. This is the classical transaction cost argument of Williamson (1985) and Klein et al. (1978). The threat point determines payoffs when no agreement is reached. In such cases, the supplier still has to incur its sunk investments and is rewarded less by alternative downstream innovators when technology is specific. In the extreme case, the supplier has still to incur sunk expenditures without any reward, when the value of alternative use is zero. In this case, the downstream innovator can expropriate rents up to the amount of sunk investments.

However, the hold-up potential depends not only on sunk investments of one market side as the transaction costs literature predicts. Complementary assets are *also* adapted to use specific technology. Thus, there may be a mutual instead of a unilateral dependence between technology supplier and downstream innovator. This reveals the implicit assumption in a resource-based view of complementary assets that the technology supplier is more dependent on access to complementary assets than the owner of the latter is dependent on access to technology. It is assumed that incumbent downstream firms can still use traditional technology, which makes their assets less specific to new technological input. This perspective takes complementary assets necessary to commercialize technologies as already established. Nevertheless, downstream innovators have to take into account expropriation risks from the mutual dependence to technology suppliers, too. Assets needed to commercialize innovative products and processes may be to a certain degree 'locked-in', when they are adapted to specific technology input, since the machinery and equipment or distribution network cannot be easily redeployed to other uses without incurring non-recoverable switching and further adaptation costs. When deciding to invest in specific complementary assets, the downstream innovator has to take into account the possibility that a technology supplier may extract innovation rents up to the amount of sunk investments minus assets' value in alternative uses. This maximum amount of expropriation occurs when the technology supplier has not incurred specific investments. In case the supplier has incurred specific investments on her part, too, the expropriation potential declines by that amount (cf. Acemoglu et al., 2010). Thus, the *difference* in threat-points or differences in the amount of sunk investments, respectively, determine on which market side the expropriation risk lies. The case of RIM being held-up by NTP illustrates this point. RIM already invested in its capital-intensive production facilities and was already producing its devices when NTP claimed patent infringement. NTP's patent portfolio, on the other hand, was of low technological value. Associated R&D was therefore lower as sunk investments in machinery and equipment incurred by RIM. This difference in threat points explains why RIM agreed to a licensing deal that presumably overvalued the intrinsic economic value of NTP's patents. This study investigates whether innovators perceive such hold-up threats in the German market for technology, when deciding to invest in machinery and equipment that aims at commercializing technological knowledge into innovative products and processes.

Specifity of investments itself does not yet justify economic efficiency concerns. Transaction cost concerns come only into play when contractual incompleteness is present that could cause unprogrammed adaptations. Of course, downstream innovators has strong incentives to secure their technology access before they sink investments to adapt assets to specific technologies. However, innovators cannot be sure ex ante whether they have access to the relevant technology and they do not have the opportunity to contractually ensure access with certainty. Only if such contractual incompleteness is present, downstream innovators can be held-up. If the innovator knows ex ante that she will be held-up ex post (i. e. after specific investments have been sunk), she would license-in the respective exclusion right. Ex ante, there is no hold-up threat, because they arise only when specific investments have already been sunk. The contractual uncertainty may be either a result of the unpredictability of the innovation process or, alternatively, may be a result of the imperfect property characteristics of intellectual property. The latter may be due to the fact that sourcing of external intellectual property within arms-lenghts contracts only transfers rights to exclude. In complex technologies, these exclusion rights frequently do not coincide with the right to use the technology. Within patent thickets, exclusion rights protecting minor technological facets may be able to hold-up owners of major inventions, when their claims partly overlap with the major invention. Thus, the distinction between exclusion and usage rights may become relevant to commercializers of technologies even when they secured access to core inventions before starting adaptations of assets into complementary assets. Even if transferred patent rights are sufficiently strong, the recursive nature of the innovation process (Kline and Rosenberg 1986) may still make unprogrammed adaptations necessary. During the innovation process, new information regarding actual customer needs may arise. This is associated with altering the technical specifications of innovations and may require adaptations of downstream assets with the associated need to access further technology. Consequently, not all necessary technological inputs can be anticipated at the outset (Rosenberg, 1998).

The transaction cost literature concludes that vertical integration should be more prevalent when specific investments are more common and the cost of market transactions increase. The hierarchical relationship to the technology supplier within a vertically integrated firm should eliminate the hold-up potential. In our case, which is characterized by contractual incompleteness originating from imperfect property characteristics of intellectual property, vertical backward integration is unlikely to resolve hold-up threats. This is because the residual control rights cannot be captured by 'owning' the entire technology, since the boundaries of intellectual property are fuzzy and the mapping of specific technology to certain property rights remains unclear and can finally only be determined by courts (Lemley and Shapiro, 2005). When the scope and validity of patent rights is uncertain, unless brought to court, identifying a distinct set of patents that capture a specific technology is a mere insurmountable task (Lemley, 2001). Ownership structure of technologies is unclear, so that the downstream innovator can identify all patent-holding entities. The same is true when during the process of adaptation of assets the need for further external technology emerges. Here too, the technology supplier that could hold up is not known ex ante. If vertical integration is not a feasible option, under-investing in specific assets is the only feasible option (Williamson, 1985). This is also the prediction of the diffuse entitlement theory (Heller and Eisenberg, 1998).

There are not only downsides of vertical disintegration between inventive technology suppliers and innovators that commercialize new technologies into innovative products and processes (Arora and Merges, 2004; Whinston, 2002). This is formalized by the property-rights theory of Grossman, Hart and Moore (GHM).[6] The provision of property-like rights to the inventor of new technological knowledge gives him the right to exclude others from its usage, and eventually to hold-up. But on the other side, ownership rights to the in-

[6] Grossman and Hart (1986); Hart and Moore (1990) and Hart (1995)

vention provide the technology supplier strong incentives to enhance the economic value of the R&D outcome compared to being employed as a researcher within a vertically integrated organization. His effort and R&D investments in the inventive process will be more pronounced in the vertically disintegrated case, since he gets reimbursed by selling the outcome of the R&D process. Contrarily, being employed in a vertically integrated organization reduces technology supplier's effort due to the input-related reimbursement from fixed wages. Vertical disintegration between inventive and innovative activities allows these units to realize their comparative advantages. Thus, in a dynamic view, learning and scale economies can be realized. And in view of units' more homogeneous activities, administrative and bureaucratic burdens should be reduced. For the chemical industry, Arora et al. (2004) provide evidence for the innovation-encouraging effect of the presence of specialized technology suppliers. Thus, when deciding whether to invest in technology-specific assets, the downstream innovator has to balance hold-up threats and transaction costs against improved quality characteristics of externally sourced technology.

The empirical section will search for evidence whether innovating firm's investment in complementary assets is affected by hold-up threats. We have seen that such hold-up threats arise when technology suppliers have less investments sunk than the downstream innovating firm. In order to empirically operationalize these considerations, I will construct measures for the dispersion of capital stocks among technology suppliers. Patenting-owning firms are potential residual IP-holders that could hold up innovating firms. The lower the average capital stock of patent holders, the higher is the potential for the small patent-owners to hold-up the larger ones, when the latter aim at commercialize the technology. However, we have seen that the provision of exclusion rights to inventors also provide them strong incentives to increase the economic value of his R&D activity. Thus, efficiency considerations have to be balanced against transaction-costs from threat point differentials. Depending on the relative strength of the effects, the following hypotheses emerge:

H1a: The propensity to invest in innovation-specific complementary assets decreases with capital stock dispersion among relevant patent owners, when anticipated hold-up threats outweigh the higher quality provided by independent upstream suppliers.

H1b: The propensity to invest in innovation-specific complementary assets increases with capital stock dispersion among relevant patent owners, when quality advantages of independent upstream suppliers outweigh anticipated hold-up threats.

2.1.1 Patent Trolls

A special kind of non-practicing technology suppliers has evoked attention with regard to effectiveness considerations of markets for technologies. So-called patent trolls are small firms that are accused to deliberately manoeuvre capital-intensive innovators into hold-up situations of inadvertently infringing their intellectual property (e. g. Henkel and Reitzig, 2008). Patent trolls' business model is described as hiding their (often simplistic) exclusion rights in patent system's lack of transparency respectively abstain their rights from being enforced for a long time, but enforce their exclusion rights when innovators invested in capital-intensive assets. This kind of non-practicing entities are considered as not primarily interested in broadening the stock of technological knowledge, but solely in the associated exclusion rights in order to generate supra-normal returns on their patented technology. Such returns could be reaped, since licensing negotiations between patent trolls and established firms are one-shot transactions. They will not engage in future licensing negotiations that offer downstream firms the opportunity to retaliate expropriative behaviour. Reitzig et al. (2007) have shown that for owners of patented technology that is of low commercial value in ex-ante licensing negotiations and therefore easy to invent around ex ante, the dominant strategy is to trap downstream innovators in hold-up situations. This is because courts do not consider these invent-around costs when determining a reasonable compensation rate for infringement. However, these invent-around costs determine the extent of licensing revenues the technology supplier could have earned in ex-ante negotiations. It is argued, that this systematic overcompensation should make patent troll business sustainable. Reitzig et al. (2007) argue further that Germany should be an especial fertile ground for the patent shark business, because infringed patent owners can choose among various types of compensation, inter alia compensation due to unjust enrichment. Here, compensation is based on the legal fiction that the infringer undertook the business on behalf of the patent owner, although, in the case of patent trolls, they lack the necessary complementary assets. Thus, if downstream 'commercializers of technologies' in Germany are aware of such an increased hold-up threat from patent trolls, they should be more reluctant to invest in innovation-specific assets. However, patent troll business is not easily categorized, since they consist of firms with prior R&D background (whose inventive activities may have failed), law firms and professional patent exploitation firms (Reitzig et al. 2010). I therefore restrict my empirical investigation of threats from patent trolls to a minimum requirement of their business model, viz. that they must be small compared to infringing innovator, since we have seen in the previous section that hold-up threats are the more credible the larger the difference of sunk investments between technology supplier and downstream innovator. This results in the following hypothesis:

H2: If innovative firms anticipate hold-up threat from patent trolls, then the propensity to invest in innovation-specific complementary assets decreases with the presence of small patenting entities.

2.2 Royality Stacking

The provision of intellectual property rights to inventors lays the ground for a division of innovative labour, since the inventor is obliged to disclose the new technological information, but maintains legal exclusion rights to claimed inventions. So far, we have considered imperfections in the market for technologies due to differences in sunk costs between technology suppliers and downstream innovators. However, the provision of patent rights does not only facilitate technology transactions. The disclosure of technology associated to the provision of these rights also serves as basis for others active in the R&D process. They can build upon this knowledge in cumulative way to further develop the technology and avoids them to bear duplicative R&D expenditures (Scotchmer 1991). This may lead to situations of having follow-on inventors been granted exclusion rights, who have at the same time not the right to use the follow-on technology, because the initial patent-holder blocks its usage. Blocking patent rights may therefore not only result from difficulties to codify the developments and discoveries into patented claims but may also reflect the division of labour with respect to *inventive* activity and its sequential and cumulative nature. We have discussed that sequential irreversible actions are a necessary precondition for transaction costs to emerge. However, with respect to the cumulative nature of the invention process, transaction costs do not emerge from having already invested in complementary without having full access to the employed technology, but from sequential patent applications referring to the same technology (in different stages). In this case, transaction costs do not originate from coordination between the innovating firm and a single residual IP-holders, but from coordination among the several patent owners of a distinct technology. When several parties have contributed to the development of the technology and therefore own exclusion rights, commercialization of such a technology requires access to the complete bundle of intellectual property. Thus, the single patent rights are perfect complements, since single exclusion rights have no economic value. The economic value of the technology is only created, when the patent rights are comprehensively provided. However, when the ownership of the technology lies in the hands of various parties, each IP holder has the incentive to skim off the complementarity gain from access to the complete bundle. Each patent holder therefore induces a negative externality on other parties in the bargaining process. Compared to a situation when a single inventor developed the entire technology (Shapiro 2001, Lerner and Tirole 2004), the charged licensing fees increase with the number of parties that have exclusion rights

on the technology. This specific reincarnation of double marginalization within vertical chains when ownership on a technology is fragmented is called royality stacking.
Müller et al. (2010) found such evidence for licensing expenditures of downstream innovators to be increasing with fragmentation of intellectual property.[7] Nevertheless, there is still a heated debate to what degree the innovation process is actually affected by fragmented exclusion rights. Since the answer to this question depends on the size of arising transaction costs, quantifiable empirically evidence is warranted. Case-study evidence for the US Biotech sector suggests that these concerns may be exaggerated (Walsh et al., 2004). Murray and Stern (2005) find evidence for a modest anti-common effect for dual knowledge that diffuses within academia as well as within the commercial intellectual property sphere. Von Graevenitz et al. (2008) show that thickets exist in nine out of thirty technology areas within European patents. Graff et al. (2003) document a dramatic restructuring of the plant breeding and seed industry (from a diffuse to a tightly vertically integrated industry structure) in order to exploit complementarities between intellectual property of breakthrough technologies. Noel and Schankerman (2007) find that firms active in more fragmented technologies have lower market valuations. Like Noel and Schankerman (2007), many theoretical and empirical studies of patent thickets focus on their impact on ex-ante R&D incentives (e. g. Clark and Konrad, 2008). Contrarily, this study aims at investigating innovators' propensity to lock themselves in by specific investments. Under the assumption that innovative firms anticipate potential transaction costs from fragmented technology ownership[8], the following hypothesis emerges:

H3: The propensity to invest in innovation-specific complementary assets decreases with the degree of fragmentation of the respective technology.

[7]This study draws on and continues work by Müller et al. (2010). Based on the same database, they found evidence for a stifling effect of upstream fragmentation of intellectual property on the innovative output from downstream commercialization. They find that fragmentation of patent rights reduces the probability to introduce innovative products for firms with very small patent portfolios. However, whether this exclusion of small firms from the innovation process reflects the original purpose of an intellectual property regime (to give exclusion rights to inventors) or whether small firms are excluded due to transaction costs in patent thickets remains unclear. Therefore, this paper further investigates the nature and degree of transaction costs within a division of innovative labour.

[8]Walsh et al. (2004) have documented that US biotech firms anticipate potential transaction costs and redirect their R&D efforts accordingly. This is possible, since biotechnology is an emerging market with many commercial applications yet unexploited (cf. Von Graevenitz et al. (2008))

3 Empirical Section

3.1 The Data

My sample is constructed from three different data sources: the Mannheim Enterprise Panel (MUP), the Mannheim Innovation Panel (MIP) and patent data from OECD's PATSTAT database. The MUP is a firm-level database collected by Creditreform, the largest creditrating agency in Germany. Since 1999, the Center for European Economic Research (ZEW) receives twice a year a full copy of Creditreform's data-warehouse of firm level data and constructs the MUP thereof. In the preceding years, ZEW received a subsample of Creditreform's data. This subsample consisted of two parts: ZEW received Creditreform's entire firm-level data on newly established firms. Furthermore, ZEW received a stratified random sample of the stock of German firms.[9] From 1999 onwards, it can be assumed that the MUP covers nearly all firms economically active in Germany. The comprehensive firm-level data of the MUP forms the sampling basis for several surveys conducted by ZEW, including the Mannheim Innovation Panel (MIP). The MIP survey is conducted annually by the ZEW since 1993 on behalf the German Federal Ministry of Education and Research. The survey is based on the concepts and definitions of OECD's Oslo Manual (2005) for collecting data on innovation processes. It is also the German contribution to the European-wide Community Innovation Survey. These databases regarding German innovation activities (MIP) and data on general firm characteristics (MUP) were linked to data on patent applications at the European Patent Office (EPO), obtained from OECD's PATSTAT database. My sample refers to firm-level information for the years 1994 to 2006. Due to lacking information on some explanatory variables, data referring to 1997, 1999 and 2000 does not enter the sample. Since characteristics of the patent landscape are my main variables of interest, naturally, only firms that had applied for patent protection enter the sample. I investigate the influence of technological characteristics on the propensity to invest in innovation-specific machinery and equipment. The characteristics of the patent landscape refer to the degree of sunk investments by patent applicants in certain technologies. This would best be captured by information regarding real capital investments within industries and technologies. Unfortunately, this information is rare in the MUP database. I will proxy investments in real capital by the invested equity. This has proven to be a more reliable source to generate capital stock characteristics on a sectoral and technology level, since German corporations are obliged to publish this information. Correspondingly, I restrict my estimation sample to corporations and neglect information on partnerships in order to ensure comparability between capital stock characteristics and firm-level information. Furthermore, I exclude pure R&D service companies from the sample in order to avoid a likely bias, as these

[9]See Almus et al. (2000) for a more detailed description of the Mannheim Enterprise Panel.

firms should have a very low propensity to invest in innovation-specific machinery and equipment owing to their specialization on performing R&D activities only. Other service sectors, like e. g. ICT or financial intermediation (that are frequently subject to hold-up concerns), remain nevertheless in the sample besides the manufacturing industries. This leaves me with a sample of 2142 observations.

3.2 Variable Definitions and Descriptive Statistics

This study aims to shed light on the influence of technology characteristics on the propensity to invest in innovation-specific machinery and equipment. Therefore, fragmentation and diversity in capital intensities among patent applicants have to be operationalized. With regard to the former, this study follows Müller et al. (2009): Ziedonis (2004) proposed a fragmentation index on the company level. Her measure captures the ownership dispersion among backward citations in company's patent portfolio. Since fragmentation of exclusion rights is a (time-specific)[10] feature of technologies, Müller et al. (2009) proposed a technology-specific measure as weighted average of firm-specific fragmentations according to the formula:

$$\text{Fragmentation}_j = \frac{1}{N}\sum_{i=1}^{N}\{[1-\sum_{k=1}^{K}(\frac{\text{references}_{ijk}}{\text{references}_{ij}})^2(\frac{\text{references}_{ij}}{\text{references}_{ij}-1})]\} \qquad (1)$$

In this formula, references_{ijk} refers to the number of backward citations in company i's subportfolio of patent applications in technology j that refer to patents hold by company k. References_{ij} refer to the total number of backward citations in company i's patent portfolio in technology j. N refers to the total number of companies active in the respective technology and the last term within the summation refers to Hall's (2005) bias correction of Herfindahl-type measures. For my estimations, I will use a firm-level fragmentation index that is generated as weighted average of the above technological fragmentation according on a 4-digit IPC technology-class level.

In order to empirically operationalize varying intensities of sunk capital among patent holders, some type of Herfindahl-type concentration measure of sunk capital associated among holders of backward-cited patents would be needed. Unfortunately, backward citations usually do not exclusively refer to patents of single jurisdictions. For instance, from the German population of firms that apply for patent protection at the EPO, these patents frequently refer to patents not issued at the EPO. In addition, also non-German

[10]For clarity, the time index is omitted in the formula.

firms or individual inventors may hold the cited patent. Therefore, Herfindahl-type measures of capital heterogeneity among backward citations would be unreliable. Although my database is extraordinarily comprehensive with regard to characteristics of patent applicants, concentration measures of capital stock heterogeneity would require information on capital endowments of international corporations that apply for patent protection at the EPO. To the best of my knowledge, such comprehensive data is unlikely to exist. This lack of information makes technology-based measures for the degree of capital dispersion among patent holders little reliable. Instead, I will focus on the (time-specific) capital endowments of German firms applying for patent protection at a 2-digit-NACE sectoral level. Information of capital endowments of German patent applicants at the EPO is available from the MUP. From 1999 onwards, this merge captures presumably nearly all active German firms that patent at the EPO. Before 1999, only a random sample of the stock of German firms in combination with the stock of newly established firms is available.[11] Thus, capital stock characteristics of patent applicants before 1999 are subject to measurement error. However, these measures rely on a random sample of the German company stock. Furthermore, since patenting activity is mainly explained by firm size (Hall and Ziedonis, 2001) and pure R&D service companies are excluded from my estimation sample, the overrepresentation of newly established firms should not bias my capital stock characteristics. Several statistics were calculated at this sectoral level to characterize the capital distribution among patent applicants: I calculated their mean capital intensity, the standard deviation of capital endowment among them and the share of small firms applying for patent protection. The latter refers to firms with capital endowments less than the year- and sector-specific 10 per cent quantile or to firms with less than 100000 Euro invested equity. Their low degree of sunk capital would create an especially favourable bargaining position within ex-post licensing negotiations in the industry, if the threat point reasoning within hold-up considerations is evident. However, there are frequently two-digit sectors in which only one company is an active patenter at the EPO. Therefore, the share of small-patenting entities is calculated at a 21-sectors-level.[12]

Table 1 shows the descriptive statistics of my sample. Since having at least once applied for patent protection is a necessary prerequisite for observations to be included in the sample, average innovation-specific investment activity is very high in my sample: 82 per

[11]Especially for these periods, a minimum criterion of at least 10 observations per 2-digit sector is imposed in create meaningful statistics. If this is not the case, the corresponding 2-digit statistic is replaced by its counterpart calculated on a 21-sector-level.

[12]These 21 sectors are: food/beverages/tobacco, textiles/clothing/leather, wood/paper/printing/publish, chemicals/pharmaceuticals/oil, rubber/plastics, glass/clay/mineral products, metal production/processing, mechanical engineering, electrical engineering/electronics, transport equipment, furniture/toys/recycling, electricity/gas/water supply, wholesale trade, transport/post, motion picture/broadcasting, financial intermediation, computer activities/telecommunicaiton, consultancy/advertising, technical services, other business services.

Table 1: Descriptive Statistics

	Full Sample				
	Mean	Median	Stand.dev.	Minimum	Maximum
Innovation-Specific Investments	0.82	1	0.39	0	1
Non-Specific Investments	0.86	1	0.35	0	1
Innovation-Specific Investment Intensity	0.01	0.003	0.03	0	0.48
Non-Specific Investment Intensity	0.02	0.01	0.06	0	1.75
Occasional R&D activities	0.12	0	0.33	0	1
Continuous R&D activities	0.69	1	0.46	0	1
Sales	850.05	100	5000.93	0.04	92168.5
Planned Product Innovation Activities	0.42	0	0.49	0	1
Planned Process Innovation Activities	0.37	0	0.48	0	1
Fragmentation Index	0.88	0.88	0.02	0.80	0.91
Share Small Entities	0.29	0.21	0.22	0.10	1
Mean Industry Equity Invested	86.12	21.95	164.47	0.025	976.90
Standard Dev. Equity Invested	116.17	39.31	196.24	0.007	863.63
Part of Conglomerate	0.64	1	0.48	0	1
Invested Equity Intensity	0.46	0.03	2.02	0	38.03
Capital Asset Intensity	0.24	0.10	0.43	0	14.93
Material Cost Intensity	0.24	0.23	0.13	0	2.94
Labour Cost Intensity	0.16	0.15	0.14	0	4.25
Location in Eastern Germany	0.12	0	0.33	0	1
Low-Tech Manufacturing	0.35	0	0.48	0	1
Medium High-Tech Manufacturing	0.43	0	0.50	0	1
High-Tech Manufacturing .	0.16	0	0.37	0	1
Distributive Services	0.003	0	0.05	0	1
Knowledge-intensive Services	0.01	0	0.11	0	1
Technological Services	0.04	0	0.19	0	1
No. of Observations			2229		

cent of observations invested in innovation-specific machinery and equipment. However, investment activity that is not related to innovative activity is still higher with a share of 86 per cent. The higher weight on non-specific investments is also reflected in the respective intensities, constructed as expenditures relative to sales. On average, one per cent of sales are innovation-specifically invested. An additional per cent point of sales is invested not related to innovation activities. Nevertheless, the prerequisite of having already generated new technological knowledge reflects itself also in R&D activity of my sample observations. Nearly 70 per cent are continuously engaged in R&D; only 12 per cent conduct R&D on a irregular basis. Similarly, the average size of sample observations seems very high with mean sales of 850 Mio. Euro. Correspondingly, 64 per cent of the sample are part of a conglomerate. However, this also originates from the highly skewed size distribution, since the median sales are 100 Mio. Euro. Thus, large parts of my sample are companies from the chemical industry, electrical and mechanical engineering. Unobserved productivity expectations often raise endogeneity problems, especially with regard to investment decisions. The MIP collects data on planned product or process innovation activities forthcoming two years. 41 per cent of firms plan to conduct product innovation acitivities, 37 per cent plan process innovation activitiess. On the firm-level, the sample firms show a mean equity intensity (relative to sales) of 46 per cent. Survey information on real capital stocks indicate that they invested 24 per cent of sales tangibly.

Several measures were constructed on a sectoral level to capture dispersion of sunk capital among patent applicants. At first, the mean capital endowment of patent applicants has been calculated. Conditional on observational unit's own capital endowment, an increase in the degree of sunk capital of other companies within the same industry should increase the potential for hold-up and extraction of innovation rents, if threat point considerations are evident. Since industry wide information on real capital stocks is rare, the degree of sunk investments will be proxied by invested equities. The mean invested equity of patent applicants on a sectoral level is 86 Mio. Euro with a standard deviation of 165 Mio. Euro. The maximum average capital endowment of patent applicants on a sectoral level reaches its maximum hold-up potential with 977 Mio. Euro invested equity. A further operationalization of the hold-up potential is given by the standard deviation of capital stocks among patent applicants within sectors. On average, capital stocks vary by 116 Mio. Euro among patent applicants within industry sectors. Thus, this standard deviation can be considered as a measure for the average hold-up potential. Furthermore, a measure for the prevalence of small patenting entities that downstream innovators face is constructed. On average, 29 per cent of patents originate from applicants with an capital endowment less than the 10 per cent industry quantile or that are smaller than 100000 Euro, respectively.

3.3 Econometric Results

Specifity of investments and contractual uncertainty are the main prerequisites for transaction costs to be relevant. We have discussed the prevalence of the latter in the division of innovative labour context in section 2. Such contractual uncertainty within the division of labour between inventive and innovative activities can arise from the incomplete property characteristics of intellectual property and from the uncertainties inherent in the innovation process. Despite the fact that transaction costs should not arise in the absence of specific investments, this is rarely taken into account in empirical investigations of transaction cost phenomena (Lafontaine and Slade, 2007). In order to discern transaction costs phenomena from other spurious effects, the influence of technological characteristics on the propensity to invest in innovation-specific and non-specific machinery and equipment is investigated. Therefore, simple Logit and lower-bounded Tobit regressions on the probability and intensity, respectively, of investments are conducted. I differentiate whether these investments were associated to the introduction of innovative products or processes or not. Intensities to invest innovation- and not-innovation relatedly increase with the relative size of present physical capital assets and the importance of material and labour costs. The strategic orientation of companies with respect to R&D and its expectations with respect to innovation success have a significant effect on innovation-related investments. Firms continuously, as well as occasionally, active in R&D have a significantly higher probability and intensity of investments in innovation-related machinery and equipment. The same is true, when firms expect to introduce product or process innovations. Thus, expectations concerning innovation success are well captured by my regressions. Conditional on these expectations, I find that the degree of fragmentation among technologies, in which the observational units are active, has a significant negative effect on the propensity to invest specifically in the commercialization of new technologies. Conditionally on having invested in innovation, the investment intensity is not significantly affected. This appears to be a pure transaction cost effect, since the probabilities and intensities of non-specific investments are not negatively affected by fragmented technologies. Of course the explanatory power of the non-specific investment regressions are highly reduced, since explanatory variables are dedicated to explain innovation-specific investments. Besides fragmentation, hold-up considerations could affect investment decisions. Therefore, statistics of capital endowments of patent applicants are included as explanatory variables. *Conditional* on observational unit's own capital assets and invested equity, hold-up reasoning would imply that with increasing average capital endowment of players in the market for technology the threat of being locked-in to be decreasing. Thus, due to reduced hold-up threats, propensities to invest in specific assets are expected to increase with sectoral capital endowments. However, I find that increasing sectoral capital stocks *reduce* the propensity to invest in complementary assets, conditional on own capital stocks. This rather points to barrier to entry in innovative markets than to the prevalence of hold-up threats. In order to verifiy this transaction cost interpretation of this effect of mean capital endowments, their impact on non-innovation related investments is investigated. The propensity to invest in non-innovation-related assets remains unaffected the average sectoral equity stocks. The intensity to invest in innovation-specific capital is also significantly negatively affected by the mean equity level of patent applicants. However, the intensity to invest in general assets is positively affected by mean capital assets of patent applicants. Thus, barriers to entry to innovation markets could lead firms to substitute their funds to investments in general assets. Thus, if hold-up considerations play only a minor role, then the benefits of a vertical division of innovative labour should dominate associated transaction costs. The positive and significant effect of an increased dispersion of capital endowments among patent applicants on the propensity to invest in innovation-specific complementary assets points into that directions. However, associated intensities in innovation-related investments remain unaffected by the capital dispersion among patent applicants. There is no such effect of the standard deviation of capital assets among patent applicants on the propensity to invest in general assets. Intensities to invest in general capital are, however, significantly negatively affected by the capital dispersion among patent applicants. This could indicate that general investments leave comparative advantages between patent-holding, small technology suppliers and patent-holding, large innovating firms unreaped. This potential of comparative advantages within a division of innovative labour will be further discussed in the context of small technology suppliers.

The third capital stock statistic of participants in the market for technology also indicates that benefits from a division of innovative labour dominates potential transaction costs. Investment intensities in innovation-related assets increase significantly with the prevalence of small patenting entities. The propensities to invest innovation-relatedly, however, remains unaffected. This indicates that a division of labour in innovation between small technology suppliers and downstream innovators increases the capital-intensity of the latter. This increased degree of sunk assets would indicate a high hold-up potential. However, innovation-related investments do not seem to be affected by the prevalence of small patenting entities. Contrarily, the propensities and intensities of general investments are significantly negatively affected by the presence of small-patenting entities. This could point to a larger hold-up potential for non-specific investments, since potential technology suppliers do not depend on them. Contrarily, technology suppliers are dependent to certain a degree on complementary assets, since their licensing revenues were in the end generated by the innovative products produced by them (cf. Acemoglu et al., 2010). Alternatively, these negative effects could also reflect the unreaped benefits from a division of innovative labour, when investing generally.

Table 2: Marginal threat point effects on propensities to invest

Dependent Variable	Innovation-Specific Investment Propensity		Non-Specific Investment Propensity	
	Marg. Eff.	Std.Err.	Marg. Eff.	Std.Err.
Occasional R&D activities	0.257***	0.019	-0.043	0.028
Continuous R&D activities	0.279***	0.012	-0.012	0.023
Sales	0.0002*	0.000	0.000	0.000
Planned Product Inno. Act.	0.100***	0.028	-0.085**	0.040
Planned Process Inno. Act.	0.104***	0.024	0.017	0.029
Fragmentation Index	-0.775*	0.414	0.541	0.504
Mean Industry Equity Invested	-0.0003***	0.0001	0.0001	0.0002
Standard Dev. Equity Invested	0.0004***	0.0001	0.0001	0.0002
Share Small Entities	0.029	0.052	-0.142**	0.061
Part of Conglomerate	0.010	0.013	0.042***	0.016
Invested Equity Intensity	-0.0004	0.003	0.008	0.007
Capital Asset Intensity	-0.004	0.014	0.044	0.028
Material Cost Intensity	-0.051	0.041	0.172**	0.070
Labour Cost Intensity	0.020	0.052	-0.172***	0.065
Location in Eastern Germany	0.003	0.021	-0.002	0.024
	Time Dummies included			
	Sector Dummies included			
LR $\chi^2(\;)$	880.47***		136.35***	

***, ***, * indicate significance of 1%, 5% or 10%

I therefore investigated whether consideration of the panel the panel dimension of my data could leverage some additional insights. Tables 4 and 5 in the appendix present the random effects estimations of investment propensities and intensities, respectively. These largely confirm the discussed results from the pooled regressions, albeit their explanatory is reduced, since 8 to 47 per cent of the variation are attributed to variation of individual characteristics. In order to control for such individual heterogeneity, Table 7 in the appendix presents the results of fixed effects logit regressions on the investment propensities. One potential source of heterogeneous invest propensities is their (unobserved) embeddedness within a network of technology suppliers. When these observations are part of a division of innovative labour, they should have a higher propensity to invest in complementary assets. In this case, the individual variation of investment propensities should reflect their comparative advantages to specialize in the commercialization of technologies in innovative products and processes. Since fixed effects regressions are conditional on this individual variation, capital stock characteristics of potential technology suppliers should reflect the transaction cost component of vertical divisions of labour. Unfortunately, I suffer the common drawback of the fixed effects approach to lose a majority of my observations. But for the remaining observations, I find that conditional on unobserved comparative advantages in the commercialization of innovations, the propensities to invest in innovation-related assets are significantly negatively affected

Table 3: Marginal Threat point effects on investment intensities

Dependent Variable	Innovation-Specific Investment Intensity		Non-Specific Investment Intensity	
	Coef.	Std.Err.	Coef.	Std.Err.
Occasional R&D activities	0.024***	0.002	-0.010**	0.005
Continuously R&D activities	0.024***	0.002	-0.008**	0.004
Sales	0.000	0.000	-0.000	0.000
Planned Product Inno. Act.	0.014***	0.004	-0.004	0.007
Planned Process Inno. Act.	0.008***	0.003	0.005	0.006
Fragmentation Index	-0.053	0.043	0.099	0.088
Mean Industry Equity Invested	-0.00004**	0.00001	0.0001***	0.00003
Standard Dev. Equity Invested	0.00001	0.0001	-0.0001***	0.00002
Share Small Entities	0.013***	0.005	-0.039***	0.011
Part of Conglomerate	-0.003**	0.001	0.003	0.003
Invested Equity Intensity	-0.0003	0.0003	0.0001	0.0006
Capital Asset Intensity	0.004**	0.001	0.067***	0.003
Material Cost Intensity	0.021***	0.005	0.081***	0.010
Labour Cost Intensity	0.052***	0.005	0.044***	0.010
Location in Eastern Germany	0.009***	0.002	-0.002	0.004
	Time Dummies included			
	Sector Dummies included			
σ	0.027	0.0005	0.057	0.001
LR $\chi^2(\quad)$	575.00***		755.60***	

***, ***, * indicate significance of 1%, 5% or 10%

by the prevalence of small-patenting entities. Thus, this indicates that the presence of small patenting entities induces transaction costs, but these transaction costs are still dominated the benefits of a division of labour. Furthermore, general investments are still significantly negatively affected by their presence. This is consistent with the conclusion that expropriation risks from small players in the market for technology are higher, when investments are more general. On the other hand, the significant positive effect of fragmentation on non-specific investment propensities could indicate a substitution from innovation-specific to non-specific investments due to the presence of transaction costs.

Naturally, the question arises whether unobserved comparative advantages, which are controlled for in the fixed-effects regressions, are correlated with my explanatory variables and bias my baseline results. This seems not to be the case. The Hausman tests cannot reject the hypothesis of consistent and efficient random-effects estimates for both propensity regressions, the innovation-specific and the non-specific one, on a 15% level of significance. Thus, there seems not to be spurious correlations present that bias my baseline results.

4 Conclusion

This study aimed at providing evidence on the nature of transaction costs in a division of innovative labour context. We have seen that imperfect property characteristics of intellectual property in combination with sequential irreversible actions of participants in the market of technologies lay the prerequistes for transactions costs. But whether there is evidence for such transaction costs to be present, this study aimed at investigating. In order to operationalize this question, I first asked whether the owner of complementary assets is necessarily priviledged in the distribution of profits from innovations. When the potential 'commercializer of technologies' is not dependent on access to specific technology, this is likely to be the case. However, when complementary assets are specific and sunk, it may equally well be the case that the technology supplier can hold-up the downstream innovator. This hold-up threat increases with the degree of sunk investments by the downstream innovator and decreases with the degree of sunk investments by the technology supplier. I therefore investigated whether capital stock characteristics of technology suppliers affect the propensities to invest in innovation-specific assets. Contrary to this hold-up reasoning, I found that heterogeneous capital stocks of potential technology suppliers increase the propensity to invest in innovation-related complementary assets. Thus it appears that the benefits from a division of innovative labour dominate transaction costs from hold-up threats. Nevertheless, there is evidence for other sources of transaction costs: Fragmentation of technologies and the prevalence of small patenting entities seem to reduce innovators' propensities to invest in innovation-related machinery and equipment. However, the net-effect of the presence of small-patenting entities is still positive. This is the case, although the associated hold-up potential would be large, since the *differential* of sunk investments between the small technology supplier and the large downstream innovator is large. This indicates that discussed hold-up threats may be exaggerated, although, of course, there are cases of opportunistic and expropriative behaviour.

Thus, lack of coordination among different owners of exclusion rights to technologies seems to be the major source of transaction costs within a vertical division of innovative labour. Further research will investigate whether institutional arrangements can attenuate the preconditions for transaction costs to emerge and whether these arrangements foster the diffusion of technological knowledge into innovative products and processes. Therefore, I will investigate whether the opposition system of European patents is such an institutional arrangement that helps to resolve uncertainty regarding validity and scope of granted patents. Furthermore, I will study whether standard-setting organizations provide a forum to coordinate fragmented claims to technologies.

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A Estimation Technique

Propensities to invest are estimated by the usual Probit discrete-choice framework (see e. g. Greene 2005). The latent net-benefit from investing y^* is estimated as linear function of the explanatory variables $\mathbf{x}$ and an error term ν that is independent of $\mathbf{x}$:

$$y^* = \boldsymbol{\beta' x} + \nu.$$

.

Since we cannot observe the latent net-benefit y^*, the estimation equation has to be reformulated in terms of the observable investment decision y.

$$y = \begin{cases} 1 & \text{if } y^* > 0 \\ 0 & \text{if } y^* \leq 0 \end{cases}$$

When $F(\quad)$ denotes the cumulative distriubtion of the error term ν, the probability that observation i (conditional on its explanatory variables) has decided to invest is given by $P(y^*_{it} > 0) = P(\nu > -\boldsymbol{\beta' x_{it}} = F(\boldsymbol{\beta' x_{it}}))$. The estimatated likelihood function for a sample of N individuals is then given by:

$$L = \prod_{it=1}^{N} F(\boldsymbol{\beta' x_{it}}))^{y_{it}}[1 - F(\boldsymbol{\beta' x_{it}})]^{1-y_{it}}$$

Since estimated coefficients from this likelihood are not easily interpretable, my estimation results provide the sample average of marginal effects. According to

$$\frac{\partial E(y|\boldsymbol{x})}{\partial x_j} = \frac{P(y^* > 0)}{\partial x_j} = F(\boldsymbol{\beta' x})\beta_j$$

,

they can be interpreted as marginal changes in the expected probability of observing a positive investment decision in my sample, when the respective explanatory variable x_j changes by a marginal unit.

The usual problem in econometric panel studies is the assumption of treating all unobserved effects that could further explain investment behaviour as random noise. One source of such unobserved effects could be systematic differences between the units of observations. Therefore, the overall error term ν should be more appropriatedly illustrated as composed of a cross-sectional component u_i, that is time-invariant and a remainder η_{it}: $\nu_{it} = u_i + \eta_{it}$. With respect to the estimation equation considered in this study, such individual heterogeneity effects could, for instance, originate by increased propensities to invest in complementary assets by firms that are embedded within a vertical division of innovative labour network. When efficiency benefits outweigh transaction costs, their unobserved comparative advantage u_i could induce them to invest more frequently in complementary assets. Thus, conditional on this unobserved heterogeneity, the probability to invest is then given by:

$$P(y_i^* > 0) = P(\eta_{it} > -\boldsymbol{\beta' x_i} - u_i = F(\boldsymbol{\beta' x_i} - u_i)).$$

Under the assumption that u_i is strictly exogeneous to the explanatory variables $\mathbf{x}$ and is distributed according to $G(\quad)$, the log-likelihood can be expressed in its marginal (on u) form by:

$$logL = \sum_{i=1}^{N} \int \prod_{T}^{t=1} F(\boldsymbol{\beta' x_{it}} - u_i)^{y_{it}} [1 - F(\boldsymbol{\beta' x_{it}} - u_i)]^{1-y_{it}} dG(u|\delta)$$

When $G(\quad)$ and $F(\quad)$ are normally distributed, the above equation shows the estimation of the random-effects probit model. This random-effects likelihood is unconditional on unobserved heterogeneity and depends on the (normalized) parameters $\boldsymbol{\beta}$ and the variation parameter δ of $G(\quad)$. However, this estimator relies on the strong strict exogeneity assumption. Fixed effects expressions of the likelihood (conditional on u_i) may be more appropriate, when there are doubts on this assumption.

In linear econometric models, fixed-effects transformations can eliminate this unobserved heterogeneity and circumvent thereby the resulting incidental parameter problem when the likelihood is conditional on u_i and the time-dimension is asymptiotically fixed. However, for non-linear models, usually no such transformations exit. Fortunately, a consistent fixed-effects estimator exits for the panel-logit model, when $G(\quad)$ is normally distributed and $F(\quad)$ logistically distributed (see Hsiao, 2002 for more details). Wheter the assumptions of the random effects specification are be met will be tested using the Hausman test (see e.g. Wooldridge, 2002), which essentially tests whether estimated coefficients between the fixed-effects- and random-effects-approach are significantly different.

Since the Hausman tests cannot reject the hypothesis that estimated coefficients from the fixed-effects and random-effects framework are asymptotically equal in the discrete choice models, I do not further discuss the difficulties encountered in truncated regressions due to spurious correlations between individual heterogeneity and explanatory variables ((see Hsiao, 2002 for a discussion of alternative approaches).

B Further Results

Table 4: Random Effects Model: Marginal Threat point effects on propensities to invest

Dependent Variable	Innovation-Specific Investments		Non-Specific Investments	
	Coef.	Std.Err.	Coef.	Std.Err.
Occasional R&D activities	2.325***	0.239	-0.299**	0.177
Continuous R&D activities	2.425***	0.197	-0.064	0.146
Sales	0.0001	0.0001	0.000	0.000
Planned Product Inno. Act.	0.806***	0.256	-0.504**	0.254
Planned Process Inno. Act.	0.843***	0.218	0.094	0.179
Fragmentation Index	-6.940*	4.090	4.906	3.487
Mean Industry Equity Invested	-0.002*	0.001	0.001	0.001
Standard Dev. Equity Invested	0.003**	0.001	0.001	0.001
Share Small Entities	-0.084	0.490	-0.969**	0.396
Part of Conglomerate	0.098	0.126	0.205*	0.105
Invested Equity Intensity	-0.008	0.031	0.053	0.048
Capital Asset Intensity	-0.033	0.141	0.187	0.170
Material Cost Intensity	-0.505	0.394	0.916**	0.457
Labour Cost Intensity	0.235	0.537	-1.131***	0.417
Location in Eastern Germany	0.058	0.208	-0.013	0.163
	Time Dummies included			
	Sector Dummies included			
σ_u	0.932	0.137	0.825	0.115
ρ	0.465	0.073	0.405	0.067
LR $\chi^2(\quad)$	211.52***		81.44***	

***, ***, * indicate significance of 1%, 5% or 10%

Table 5: Random Effects Model: Threat point effects on investment intensities

Dependent Variable	Innovation-Specific Investment Intensity		Non-Specific Investment Intensity	
	Coef.	Std.Err.	Coef.	Std.Err.
Occasional R&D activities	0.022***	0.002	-0.010**	0.005
Continuous R&D activities	0.022***	0.002	-0.007*	0.004
Sales	0.000	0.000	0.000	0.000
Planned Product Inno. Act.	0.013***	0.004	-0.001	0.007
Planned Process Inno. Act.	0.007***	0.002	0.005	0.006
Fragmentation Index	-0.082*	0.048	0.103	0.092
Mean Industry Equity Invested	-0.00002	0.00001	0.0001***	0.00003
Standard Dev. Equity Invested	0.000	0.000	-0.0007***	0.00002
Share Small Entities	0.012**	0.005	-0.038***	0.011
Part of Conglomerate	-0.001**	0.001	0.003	0.003
Invested Equity Intensity	-0.000	0.000	0.000	0.001
Capital Asset Intensity	0.003**	0.002	0.067***	0.003
Material Cost Intensity	0.018***	0.005	0.083***	0.010
Labour Cost Intensity	0.050***	0.005	0.044***	0.010
Location in Eastern Germany	0.010***	0.002	-0.002	0.004
	Time Dummies included			
	Sector Dummies included			
σ_u	0.016***	0.001	0.016***	0.002
σ_η	0.022***	0.001	0.055***	0.001
ρ	0.332	0.036	0.075	0.019
LR $\chi^2()$	441.43***		884.33***	

***, ***, * indicate significance of 1%, 5% or 10%

Table 6: Fixed Effects Model: Threat point effects on investment propensities

Dependent Variable	Innovation-Specific Investment Intensity		Non-Specific Investment Intensity	
	Coef.	Std.Err.	Coef.	Std.Err.
Occasional R&D activities	4.073***	0.757	-0.912*	0.517
Continuous R&D activities	3.779***	0.625	-0.106	0.472
Sales	0.000	0.001	-0.000	0.000
Planned Product Inno. Act.	-1.396**	0.609	-0.652	0.481
Planned Process Inno. Act.	1.048*	0.599	0.134	0.445
Fragmentation Index	-7.234	20.000	37.798*	22.572
Mean Industry Equity Invested	-0.001	0.007	0.010	0.006
Standard Dev. Equity Invested	0.004	0.007	-0.007	0.005
Share Small Entities	-4.033**	1.620	-3.334***	1.186
Part of Conglomerate	0.567	0.489	-1.388**	0.553
Invested Equity Intensity	10.708	7.871	0.417	0.564
Capital Asset Intensity	0.013	1.501	-0.797	0.562
Material Cost Intensity	-3.561	2.358	1.917	1.565
Labour Cost Intensity	1.937	4.395	-4.326**	2.660
Location in Eastern Germany	1.836	2.792	-0.607	1.292
	Time Dummies included			
	Sector Dummies included			
Hausman $\chi^2(9)$ p-value	0.15		0.15	
LR $\chi^2(28)$	129.84***		39.14***	
No. of observations	400		455	

***, ***, * (†) indicate significance of 1%, 5% or 10% (11%)

Table 7: Descriptive Statistics - Fixed Effects Sample for Innovation Specific Investments

	Mean	Median	Stand.dev.	Minimum	Maximum
Innovation-Specific Investments	0.58	1	0.49	0	1
Non-Specific Investments	0.90	1	0.29	0	1
Innovation-Specific Investment Intensity	0.01	0.001	0.01	0	0.15
Non-Specific Investment Intensity	0.02	0.01	0.04	0	0.47
Occasional R&D activities	0.14	0	0.35	0	1
Continuous R&D activities	0.50	0	0.50	0	1
Sales	343.68	87.91	2046.12	0	29924.2
Planned Product Inno. Act.	0.35	0	0.48	0	1
Planned Process Inno. Act.	0.30	0	0.46	0	1
Fragmentation Index	0.88	0.88	0.02	0.80	0.91
Share Small Entities	0.29	0.21	0.21	0.10	1
Mean Industry Equity Invested	69.60	20.73	144.82	0.06	816.19
Standard Dev. Equity Invested	94.78	35.15	172.30	0.09	863.63
Part of Conglomerate	0.58	1	0.49	0	1
Invested Equity Intensity	0.06	0.03	0.11	0	1.08
Capital Asset Intensity	0.19	0.11	0.32	0	3
Material Cost Intensity	0.25	0.24	0.11	0	1.09
Labour Cost Intensity	0.16	0.15	0.07	0	0.44
Location in Eastern Germany	0.10	0	0.30	0	1
Low-Tech Manufacturing	0.46	0	0.49	0	1
Medium High-Tech Manufacturing	0.39	0	0.49	0	1
High-Tech Manufacturing .	0.11	0	0.30	0	1
Distributive Services	0	0	0	0	0
Knowledge-intensive Services	0.01	0	0.09	0	1
Technological Services	0.03	0	0.17	0	1
No. of Observations			400		

Table 8: Descriptive Statistics - Fixed Effects Samples for General Investments

	Mean	Median	Stand.dev.	Minimum	Maximum
Innovation-Specific Investments	0.89	1	0.31	0	1
Non-Specific Investments	0.65	1	0.48	0	1
Innovation-Specific Investment Intensity	0.02	0.01	0.31	0	0.46
Non-Specific Investment Intensity	0.01	0.004	0.24	0	0.40
Occasional R&D activities	0.12	0	0.33	0	1
Continuous R&D activities	0.75	1	0.44	0	1
Sales	437.46	75	2285.93	0.10	43420
Planned Product Inno. Act.	0.42	0	0.49	0	1
Planned Process Inno. Act.	0.37	0	0.48	0	1
Fragmentation Index	0.88	0.88	0.02	0.81	0.91
Share Small Entities	0.29	0.20	0.23	0.10	1
Mean Industry Equity Invested	82.52	23.05	157.75	0.05	976.90
Standard Dev. Equity Invested	115.82	39.54	196.18	0.02	863.63
Part of Conglomerate	0.62	1	0.49	0	1
Invested Equity Intensity	0.16	0.04	0.77	0	12.26
Capital Asset Intensity	0.17	0.11	0.28	0	4.93
Material Cost Intensity	0.23	0.22	0.16	0	2.94
Labour Cost Intensity	0.18	0.16	0.24	0.02	4.25
Location in Eastern Germany	0.13	0	0.34	0	1
Low-Tech Manufacturing	0.22	0	0.42	0	1
Medium High-Tech Manufacturing	0.49	0	0.50	0	1
High-Tech Manufacturing .	0.24	0	0.43	0	1
Distributive Services	0	0	0	0	0
Knowledge-intensive Services	0.01	0	0.80	0	1
Technological Services	0.05	0	0.22	0	1
No. of Observations			455		