The timing of licensing: theory and empirics*

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April 27, 2009

Abstract

Markets for technology licenses are thought to create e ciency gains by allowing for division of labor in research and development of innovations. However, these gains depend on the timing of technology transfer: the licensee should take over development at the stage at which he has an e ciency advantage. We show that in an environment with asymmetric information about the value of the innovation and where information becomes available over time, deviations from the optimal timing of technology transfer will occur. Competition between potential licensees has an ambiguous e ect on this timing. For concentrated markets, in which there are few potential licensees, an increase in the number of potential licensees may delay licensing. The opposite is true for very competitive markets. We test these predictions with data on contracts signed between biotechnology rms and large pharmaceutical rms, and nd evidence consistent with our theory.

PRELIMINARY AND INCOMPLETE

Jel Codes: L13, L24, L65.

Keywords: Innovation, Licensing, Market structure, Pharmaceuticals, Biotechnology.

1 Introduction

Licensing has become an increasingly popular means of transferring innovative technologies over the last decades.[1] As markets for technology grow in importance, the timing of licensing becomes an essential consideration. For instance, in an industry with two rms and two main stages of research, one rm may be more e cient in conducting early stage research and the second more e cient in the nal stage. It is socially optimal to transfer the invention at the end of the rst stage. Any other

We thank Josh Gans, Denis Gromb and J.P. Benoit for comments on an earlier draft, and seminar participants at Duke, EARIE 2008, London Business School, Lucca, Wharton, the University of Missouri, Harvard Business School, Emory, INSEAD, Université Libre De Bruxelles and HEC Lausanne for useful suggestions.

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[1]Estimates of the size of the global market for technology licensing range from $5.6 billion in the 1980s and $36 billion to $100 billion in the late 1990s, and Japanese firms reported earning ¥340 billion ($3.2 billion) from licenses to foreign firms in 2002 (Organisation for Economic Co-operation and Development, 2005) .

timing increases the cost of innovating and might lead to the innovation being abandoned. Thus, the timing of licensing may impact the overall innovation rate, and may ultimately a ect economic growth.

Specialization in di erent phases of the innovation process is common in many industries. For instance, small biotechnology companies might have a comparative advantage in achieving early stage discoveries in certain elds while large pharmaceutical rms are considered more e cient in conducting later stage clinical testing. Guedj and Scharfstein (2004) show clear di erences in the success rates of drug candidates in cancer between experienced, larger rms and small biotech rms. In an article in *Nature Reviews: Drug Discovery*, Kalamos and Pinkus (2003) claim that \[f]or the pharmaceutical industry, innovative biotech compounds have served to buttress lagging R&D productivity...pharma brings clinical development, portfolio management and commercialization skills that are lacking in many biotech companies". Both the academic literature and the popular press note that a signi cant proportion of the drugs marketed by major pharmaceutical companies originate from licensing deals with smaller biotechnology rms. Angell (2004) claims that one third of the drugs marketed by major pharmaceutical companies originate from licenses with biotechs or universities, and in a 2006 survey of innovation, *The Economist* notes that \Big Pharma's R&D activity is now concentrated as much on identifying and doing deals with small, innovative rms as it is on trying to discover its own blockbuster drugs" (Economist, 2006). Understanding the factors that in uence the timing of licensing between biotech and large pharmaceutical rms is essential. Ine cient delay could contribute to the decrease in productivity in this industry.

There is some evidence that pharmaceutical licensing contracts have been signed with increased delays in recent years, a period also characterized by a low numbers of new drugs launched. This delay does not merely re ect an increase in the total time required for drug development; rather, the technology transfer is occurring at later stages of development, after the completion of more advanced clinical trials. This is illustrated in Figure 1, where we show the fraction of deals signed in each development phase over the last three decades. This delay in technology transfer also coincides with a period of increased market concentration, as the industry has known substantial merger activity. The link between the number of competitors and the timing of licensing is one of the central considerations in this paper. It is an important issue that could become an essential factor in merger reviews.

If markets for technology work e ciently, then the timing of licensing depends only on the productive e ciency of the contracting rms. However, we focus on two factors that are typical in many innovative industries and that may create deviations from the socially optimal timing of technology transfer. First, innovative environments are often characterized by asymmetric information. The innovator is often better informed about the value of her idea than a potential licensee. Second, as research progresses, information is revealed about the underlying value of the invention and the information asymmetry shrinks. For instance, drug candidates undergo a series of clinical trials required for regulatory approval. Once a clinical trial phase is successfully completed, outside observers become more con dent of the drug candidate's value.

We capture the elements previously discussed in a two period model involving one sole innovator and n producers. The rst period is characterized by asymmetric information: the innovator knows the value of her invention whereas the producers are uninformed. In the second period, the uncertainty is resolved. The product is costly to develop from the rst to the second period for the innovator, but is costless for the producers. It is thus socially optimal to transfer the innovation to one of the producers in the rst period. However, the existence of asymmetric information can create deviations from this socially optimal timing.

Innovations are transferred by signing licensing contracts. An exclusive license can be signed

between the innovator and one of the producers at either period. The innovator bargains sequentially with the n producers. This model captures in an intuitive way the influence of the number of potential buyers of the license on the respective bargaining powers. Indeed we show that an increase in n increases the bargaining power of the innovator.

In the context of this model, we identify a necessary and sufficient condition for a license to be signed in the first period. We examine how the number of competitors influences this decision. If the number of producers n affects the respective bargaining powers, but does not impact the profits on the downstream market, we find that an increase in the number of producers delays licensing. The intuition is the following. An increase in the number of potential buyers n increases the bargaining power of the innovator and the price she obtains in the second period. The innovator thus wants to delay signature, while producers want to sign early. The incentives of the innovator to delay nevertheless dominate as a consequence of her private information. She knows the quality of the invention, whereas the producers consider the possibility that the invention is bad (and generates no profits).

When profits also depend on n, an increase in the number of producers has two countervailing effects on the second period price for the license. Greater competition increases the bargaining power of the innovator, but decreases the profits derived from the innovation. The innovator obtains a larger slice of a smaller pie. For initially non concentrated markets, the second effect dominates and the second period price decreases with the number of producers, thus leading to earlier signing. The opposite is generally true for initially concentrated markets. We therefore find an inverted U-shape for the effect of the number of competitors on the delay in licensing.

These theoretical predictions are confirmed by our empirical analysis on licenses in the pharmaceutical industry. We combine data on licensing deals and their stage of development at signing with data on the number of firms in different therapeutic classes (firms with drugs treating similar diseases). Controlling for various measures of financial constraints and other factors, we confirm empirically the inverted U-shape relationship between delay in signing and the number of competitors.

Though the question addressed in this paper was motivated by the particular application to the pharmaceutical industry, the theoretical model is quite general. The results should be relevant in industries with the following characteristics. First, there should exist some asymmetry of information between the innovator and potential buyers, a reasonable feature in most innovative sectors. Second, information should be revealed during the development of the invention. Third, there should be some specialization in the innovation process.[2] Finally, exclusive licensing should be prevalent; this tends to be the case when development costs are significant, so that no firm has the incentive to sink those costs without exclusive rights.[3] Accordingly, we believe that the results could be applied more directly to sectors such as chemicals than to the computer industry.

The paper proceeds as follows. In section 2, we present the model and determine the main theoretical results in section 3. In section 4, we examine a number of robustness checks. We test these results on data on licensing contracts in the pharmaceutical industry in section 5 and 6. In section 7 we compare our paper to the existing literature and conclude in section 8. All proofs are presented in the appendix.

[2] See Arora et al. (2001) for a discussion of specialization and the division of innovative labor.

[3] According to Anand and Khanna (2000), exclusive contracts are most common in chemicals and least common in computers.

2 Model

We consider a model with n symmetric producers competing on the market and one monopolist innovator. The innovator has already developed an innovation before the start of the game. The n producers are the only potential buyers of a license from the inventor.[4] The game has two periods. The first period is characterized by asymmetric information about the quality of the innovation. The innovator knows the quality of her innovation, but none of the producers do. They share a common prior that the innovation is of a good type with probability q or a bad type with probability $1-q$.[5] At the beginning of the second period, the type of the innovation is revealed.

The innovator and one of the producers can sign an exclusive license in the first or in the second period. The price is determined by a bargaining process that we describe in detail below. A license transfers the full ownership of the invention in exchange for a fixed fee. We consider more complicated contracts in section 4.

At the end of the first period, after bargaining has concluded, if the innovator has not licensed the innovation she needs to decide whether to develop the product further. Development of the innovation from period 1 to period 2 costs for the innovator. The producers are assumed to be more efficient in development and in particular we suppose that the cost of development for a producer is zero. thus represents the difference in efficiencies between the innovator and the producer. Early licensing minimizes total cost because the more efficient firm handles development, but waiting allows for revelation of information. This trade-off is the central focus of our paper.

Before describing more precisely the details of the model, it is useful to relate it to the particular application to the pharmaceutical industry. We consider the interaction between one biotechnology firm and n large pharmaceutical companies. The biotechnology firm (or innovator) has identified a promising compound. The larger pharmaceutical firms (producers) tend to be more efficient at running clinical trials and obtaining regulatory approval, but are uncertain about the quality of the biotech's drug candidate. If a license is signed early, the trials are conducted at a minimal cost but the pharmaceutical firms might choose to sign late to obtain more information about the quality of the drug.

2.1 Payoffs

We introduce the following measures for a good type innovation (the payoffs are specified in reduced form except in the two examples of section 3).

- $V_o(n)$ is the utility of a producer if neither he nor any of his competitors sign a license
- $V_l(n)$ is the utility of a producer if one of his competitors signs a license
- $\pi(n)$ is the profit of a producer if he signs a license

We assume $\pi(n) \geq V_o(n) \geq V_l(n)$: each producer wants to license a good type innovation, and prefers that no rival producer license the innovation if he fails to do so himself.

[4] We suppose that the producers do not attempt to innovate themselves.

[5] In section 3.3, we examine the case where the innovator is overconfident about the value of her invention.

We denote $\kappa(n)$ the outside option of an innovator who has developed a good type innovation until the second period. It represents pro ts that can be obtained from alternative uses. Note that if the innovation is not developed until the second period it does not generate any pro ts. We impose the following assumption:

ASSUMPTION 1: $\pi(n) - V_o(n) > \kappa(n)$

Assumption 1 guarantees that there are gains from trade in the second period when the innovation is known to be good. Indeed, if an agreement is reached the aggregate pro t of the negotiators is π while the aggregate pro t without trade is given by $\kappa + V_o$. This assumption is only made to minimize the number of cases considered and thus to simplify the exposition of our results.

If the innovation is of the bad type, we suppose that it does not generate any pro ts. If the innovator has not signed a license, she obtains zero pro ts. An innovator with a bad type innovation will therefore not develop the product from the rst period to the second period. The producers, regardless of whether they signed a license, obtain their status quo payo $V_o(n)$.

2.2 Bargaining

Bargaining between the innovator and the producers takes place as follows. All producers are randomly ordered in a sequence. The innovator negotiates one by one with each producer. Since producers are symmetric, the innovator sees all orderings as equivalent. We call each bilateral negotiation between

The information structure is as follows. All players know the value of n, and producers know their positions in the sequence. The producers cannot observe the negotiations between the other producers and the innovator. In particular, following breakdown of a negotiation between the innovator and a particular producer, producers positioned later in the sequence do not know the o ers that were made and do not even know if the session ever started with that producer.

2.3 Discussion of the bargaining model

Bargaining being central to our study, we further motivate our assumptions in light of our empirical application and discuss the links with the literature on bargaining.

One of the main purposes of this paper is to examine the in uence of the number of competitors on the timing of licensing. First note that license contract are exclusive: only one of the downstream rms will buy the license. In this framework, the sequential nature of negotiations captures the in uence of n on the bargaining power of the innovator. We show that the larger the number of potential buyers in the sequence, the higher the price extracted by the innovator. Many simple models of negotiations do not have this feature. For instance, if the innovator made take-it-or-leave-it o ers, n would not in uence the bargaining power of the innovator.[9] A model of auction can yield a similar result if the bidders have heterogenous values. In that case, a larger n mechanically increases the expected value of the highest valuation and thus the amount extracted by the seller (see section 3.3).

This type of sequential negotiations model is related to Stole and Zwiebel (1996), who examine bargaining over labor inputs.[10] Recent applications of this approach include Smith and Thanassoulis (2007), who study buyer-supplier relationships, and Raskovich (2007), where suppliers are non symmetric and the buyer chooses the order with which he will bargain with the suppliers. We also assume that licenses are exclusive. This is an important di erence with the previously mentioned literature. For instance, in Stole and Zwiebel (1996), the rm may contract with multiple workers. Considering non-exclusive licences could modify our result. De Fontenay and Gans (2005) provide a complete study of the outcome of negotiations with interlocking relationships between buyers and sellers and externalities among the buyers.[11]

Both the sequentiality and the exclusivity are common features in the pharmaceutical industry. Negotiations typically involve an exclusive period during which the licensor may not hold discussions with any other potential licensee.[12] Furthermore, most contracts in this industry are exclusive. They involve the transfer of a single compound to a particular rm (in our data, more than 85% of the

probability $\eta^3(1-\eta)$, the innovator cannot make an offer to the first three producers in the sequence and so makes his first offer to the fourth producer. This assumption will prove essential to limit the multiplicity of equilibria, as discussed in section 3.1.2.

[9] For a take it or leave it offer, the innovator would extract the full surplus regardless of n. Note also that if the buyers made simultaneous offers to the innovator, competition between them for an exclusive license would leave them with no rents, independently of their number (as long as $n \geq 2$).

[10] In Stole and Zwiebel (1996), workers are also ordered in a sequence. In a bilateral negotiation, if a worker agrees to a wage, the firm moves on to the next worker in the sequence. However, these agreements are not binding. If there is a breakdown in a later negotiation, this triggers a replaying of the sequence between the firm and each remaining worker. This additional complexity does not arise in our framework because of the exclusivity of licenses.

[11] We assume that all buyers are symmetric, which excludes the strategic issues highlighted by Marx and Shaffer (2007).

[12] Press releases such as this are common: "Micrologix Biotech Inc. has entered into an exclusive negotiation period to license MBI-226, an antimicrobial cationic peptide in Phase III clinical development for the prevention of catheter-related infections, to a US-based specialty pharmaceutical company "Specialty Pharma"). The negotiation period is for up to 60 days (the "Exclusivity Period") during which Micrologix will negotiate exclusively with Specialty Pharma the terms of a definitive license agreement for MBI-226." (http://www.secinfo.com/d12MGs.1n4.htm)

licenses are exclusive).[13]

Finally, an important characteristic of our model is that the innovator holds private information on the value of the innovation. There is a large literature on bargaining under asymmetric information, summarized in Ausubel et al. (2001). The typical situation studied in these papers involves a seller of a unique good making o ers at discrete points in time to a buyer with private information on his valuation. Both the seller and the buyer discount the future at a certain rate. Under certain assumptions that limit the large multiplicity of equilibria, the seller faces the following trade-o : delay the sale to screen the di erent buyer types or sell earlier at a lower price.[14]

We di er from this literature in terms of the individual building block of bargaining. We assume that the agents do not discount the future but face an exogenous risk of breakdown of the negotiation (following the alternating o er model of Binmore et al. (1986)). Without such discounting, the trade-o previously mentioned is not relevant. This allows us to characterize the way private information interacts with market concentration and thus to describe precisely the factors that in uence the timing of licensing.[15]

3 The timing of licensing

The socially optimal timing is to transfer the innovation from the innovator to the producer in the rst period as development is costless for producers. We show in this paper that asymmetric information can delay the transfer. We solve the game by backward induction. All the results are limit results when ϵ and η converge to zero. All proofs are presented in the appendix.

3.1 The bargaining game

3.1.1 Bargaining in the second period

At the beginning of the second period, the innovation's type is known to all. If it is bad, no license is signed. In the description that follows, we therefore concentrate on the case where the innovation is of the good type. We denote $p_2(k)$ the price of a license in second period when there are k producers left in the sequence with whom the innovator has not yet negotiated.

Consider the negotiations with the $(n-k)$th producer (k producers left in the sequence). We rst concentrate on the case $k \geq 1$ and discuss the case of the last producer separately. If the negotiations are successful, the innovator obtains the price of the license $p_2(k)$ and the producer is guaranteed $\pi - p_2(k)$. As shown in Binmore et al. (1986), the outcome of the bargaining game when the probability of breakdown ϵ converges to zero is given by the Nash bargaining solution with the disagreement points equal to payo s following breakdown. In our setting, the payo s in case of breakdown are determined by the outcome of the remaining negotiations. If an agreement is expected to be signed with the next

[13] Licenses for technology platforms, such as techniques for screening compounds, are also prevalent and may be non-exclusive. These are not our focus here.

[14] The multiplicity is reduced by the assumption of stationarity introduced inFudenberg et al. (1985). Drugov (2006) considers a single take it or leave it offer in each period and faces the same tradeoff. This setting also limits the number of equilibria and allows to focus on the effect of an exogenous signal on the timing of contracting.

[15] In particular, we can limit the multiplicity of equilibria. Note that Inderst (2008) and Fuchs and Skrzypacz (2008) examine the impact of the random arrival of new buyers whereas the set of potential buyers is fixed and known in our application, and we examine how its size influences the timing of bargaining.

producer in the sequence, the innovator can expect the price $p_2(k-1)$ while the producer expects pro ts V_l (the pro ts of a producer if a license is signed by one of his competitors). This determines the following recursive relationship for $k > 1$:

$$p_2(k) - p_2(k-1) = \pi - p_2(k) - V_l \tag{1}$$

This reasoning depends on the expectation that bargaining will succeed with the next producer. Under Assumption 1, this is always the case. Assumption 1 ($\pi(n) - V_o(n) > \kappa(n)$) guarantees that there are gains from trade with the last producer. Furthermore, producers positioned earlier in the sequence have more incentives to sign since they expect V_l rather than V_0 if no agreement is reached. Thus, as shown in the following Proposition, an agreement will be reached with the rst producer.

PROPOSITION 1: *If the innovation is good, an agreement is reached in the second period with the rst producer in the sequence at a price*

$$p_2(n) = (\frac{1}{2})^n(\kappa + V_l - V_o) + (1 - (\frac{1}{2})^n)(\pi - V_l) \tag{2}$$

We note that the price $p_2(n)$ is increasing in n. More producers in the sequence allows the innovator to extract a larger share of the surplus.

3.1.2 Bargaining in the first period

In the rst period, bargaining is more complex due to the information asymmetry between the innovator and the producers. We show that there is a multiplicity of Perfect Bayesian Nash Equilibria (PBNE), but that they all share a common property that will allow us to determine the equilibrium timing of licensing.

To understand the mechanics of the negotiation, it is useful to consider the last bargaining session. Under Assumption 1, all players know that bargaining will ultimately succeed in the second period if the innovation is of a good type. However, an innovator only develops the product if the expected rents can cover the cost . If $p_2(n) <$ the innovator never develops the invention herself. Her outside option at the end of bargaining is then zero, and a mutually bene cial agreement can always be found in the rst period.

We now consider the last bargaining session and the o er made by the innovator in the case where $p_2(n) \geq$. A good type innovator will never o er a price less than $p_2(n) -$, as she can guarantee herself a price of $p_2(n)$ in the second period but will need to develop the product at a cost of . A bad type innovator wants to mimic the good type, and thus requests the same price. If the producer accepts the o er, his expected utility is $q\pi + (1-q)V_o$. However, he can always guarantee himself his outside option if bargaining fails. His expected bene ts following a failure are $q[\frac{1}{n}(\pi - p_2(n)) + \frac{n-1}{n}V_l] + (1-q)V_o$. If he waits until the second period, he knows that a contract will be signed with the rst producer in the random sequence, at a price of $p_2(n)$. He has a probability $\frac{1}{n}$ of being the rst and obtaining pro ts $\pi - p_2(n)$. However, with probability $\frac{n-1}{n}$ one of his competitors is the rst in the sequence and he therefore obtains bene ts V_l. The following proposition re ects this reasoning.

PROPOSITION 2: *In all PBNE, bargaining succeeds in the rst period if and only if the following condition is satis ed:*

$$q\pi - q[\tfrac{1}{n}(\pi - p_2(n)) + \tfrac{n-1}{n}V_l] \geq p_2(n) -$$

If this condition is satis ed, the optimal timing of licensing is achieved: technology transfer takes place in the rst period and the more e cient producer develops the innovation. However, if either the probability of facing a good type q or if the di erence in e ciency between the innovator and the producers decreases, late (and ine cient) signature is more likely. The condition of Proposition 2 can be re-expressed as follows: a license is signed in the rst period if and only if the cost of development for the innovator is su ciently large $\geq \_(n)$. In the next sections, we examine how $\_(n)$, that we name the e ciency threshold, varies with n. If $\_(n)$ increases with n, delays in licensing become more likely.[16]

It is important to point out that though there are many PBNE, they all share the property speci ed in Proposition 2. We emphasize one particular assumption that limits the multiplicity of equilibria. We assume that before the start of each individual bargaining session, there is an exogenous risk of breakdown with probability η. Therefore, regardless of the equilibrium that we consider, starting negotiations with any producer in the sequence is always on the equilibrium path.[17] Thus, in all equilibria, all producers start negotiating with the same belief q that the innovator is of a good type. The fact that the innovator approaches a producer positioned late in the sequence does not change that producer's belief about the innovator's type. In other words, the producer does not interpret this fact as an endogenous breakdown of prior negotiations that might indicate he is facing a bad type.

3.2 The effect of market structure

In this section, we examine how the number of producers in the market n a ects the condition of Proposition 2 and thus the timing of licensing. n in uences both the bargaining power of each player and the downstream pro ts. We consider separately the case where payo s of the players (π,V_o...) do not depend on the number n of producers on the market.

3.2.1 Payoffs do not depend on n

We begin with the case where the payo s (κ, V_l, V_0, π) do not depend on n. This case highlights the e ect of n, the number of rms competing for the license, on the bargaining power of the producers and the innovator. Indeed, according to our results in Section 3.1, in this particular case, the price of the license in the second period $p_2(n)$ increases with n. When the innovator negotiates with the rst producer in the sequence, she can extract a larger share of the surplus since her outside option is now larger. The following proposition states that the e ect of n on the timing of licensing is also unambiguous in this case.

PROPOSITION 3: *If the payo s on the market do not depend on n, the e ciency threshold increases with n*: licensing delays become more likely.

[16]Note that we could have considered a variation of the model where Δ would be drawn in a certain interval. An increase in $\underline{\Delta}(n)$ would then increase the probability of late signing.

[17]For instance, suppose that an equilibrium is such that a license is signed with the third player in the sequence if the innovator approaches him. In equilibrium, the fourth player might still negotiate (with an increasingly small probability η) if negotiations do not even start with the third player.

To understand the intuition of this result, we consider the incentives of the innovator and those of the producers separately.

- As n increases, the bargaining power of the innovator increases in the second period and therefore $p_2(n)$ increases.[18] The good type innovator has an incentive to wait to sign a license.
- As n increases, a producer's expected profit in the second period decrease for two reasons: (1) if he is the first to negotiate in the second period, he will have to pay a higher price for the license and (2) the probability that he is the first to negotiate decreases with n. Each producer therefore has an incentive to sign early.

Proposition 3 demonstrates that the marginal effect on the innovator's incentive to delay always dominates the effect on the producers' incentives.

To understand more precisely the effect of n on producers' incentives, we focus on the expected profits of the last producer to negotiate in the first period. If negotiations fail, he expects to obtain in the second period: $\pi_2(n) = \frac{q}{n}(\pi - p_2(n) + (n-1)V_l) + (1-q)V_o$. The marginal effect of n on this expression is summarized in the following expression.

$$\pi_2'(n) = \underbrace{-\frac{q}{n}p_2'(n)}_{\substack{\textit{Increase} \\ \textit{in price} \\ (<0)}} + \underbrace{(-\frac{q}{n^2})(\pi - p_2(n) - V_l)}_{\substack{\textit{Decrease in} \\ \textit{recognition probability} \\ (<0)}} < 0 \quad (3), (4)$$

The first term reflects the increase in the expected price paid in the second period caused by an increase in n. The second term corresponds to the decrease in the recognition probability in second period when n increases. It is of order $\frac{1}{n^2}$ and we can therefore ignore it in the rest of our discussion.

The increase in the second period price only affects the producer with probability $\frac{q}{n}$ (the probability of simultaneously being first in the sequence and of facing a good type). In contrast, the marginal effect on the innovator's incentive is $p_2'(n)$, as the innovator knows she can fully capture the expected increase in price. Therefore the innovator's incentives to delay dominate those of the producers to sign early.[19] The innovator knows that if she waits for her type to be revealed in the second period, she can fully capture the increase in the license price. The producers, though, are uncertain in the first period about the type of the innovator. This uncertainty decreases their incentives to sign early. This intuition appears to be quite general (see section 3.3).

Proposition 3 therefore demonstrates that if the payoffs on the product market do not depend on the number of producers, an increase in the concentration of the market will lead to earlier signature of the license. We show in the next section that, if the number of competitors also impacts the profits of the producers, the results may be different.

[18] Note that $p_2(n)$ converges to $\pi - V_l$ when n tends to infinity: with perfect downstream competition, the innovator has all the bargaining power and is able to capture the whole benefit of the innovation in the second period.

[19] We can show that $\pi_2^0(n) = -\frac{q}{n}p_2^0(n)[1 + \frac{1}{n\ln(2)}]$ to convince the reader that the result also holds for small values of n.

3.2.2 Payoffs depend on n

When the payo s depend on n, the e ect of a change in competition is more subtle. The e ect of n on the second period price becomes ambiguous. It raises the bargaining power of the innovator, who gets a larger share of the pie. At the same time, it decreases the actual pro ts derived from the innovation, so the size of the pie shrinks. The same tension exists for the e ect on the timing of licensing.

To obtain precise predictions, more structure needs to be imposed. We assume that payo s decrease with n, a natural assumption in most models of competition. We obtain a limit result for large values of n that is valid under a minimal condition on payo s.

PROPOSITION 4: *If $\pi'(n) - (1-q)V_l'(n) \leq 0$, then for su ciently large values of n, the e ciency threshold decreases with n: licensing delays become less likely.*

The intuition of this result is the following. As the number of producers becomes large, the innovator enjoys all the bargaining power and can extract all the surplus in the second period. The price in the second period converges to $\pi(n) - V_l(n)$. As pointed out previously, to examine the e ect of n on the date of signing, we need to examine the impact on the incentives of each player. The innovator has incentives to sign earlier if $p_2(n)$ decreases with n. When considering a license in the rst period, a producer knows that he has an in nitesimal probability of being the rst to negotiate in the next period, but he knows that a competitor will sign for sure if the innovation is of a good type. His decision to delay thus only depends on how n in uences $qV_l(n)$. If $p_2(n) + qV_l(n)$ decreases with n, the probability of delay in signing will decrease. This leads to the condition in Proposition 4.

Note that a su cient condition for Proposition 4 is that an increase in the number of rms in the market n has a larger negative impact on the pro ts of a rm that signs a license ($\pi(n)$) than on a rm that does not sign ($V_l'(n)$). This is an intuitive property, satis ed in the applications that we describe below, given that the rm that buys the innovation naturally obtains a higher share of the surplus. To provide some intuition of the e ect of n for initially concentrated markets, we examine two cases.

Cournot competition with homogenous products

Suppose each producer owns a symmetric plant in a Cournot market, producing a homogeneous good at zero marginal cost. The initial pro ts on the product market are $V_o = \pi_n = \frac{1}{n^2}$. Signing a licence results in the creation of a new plant that will compete with the existing ones.[20] The licensee becomes the owner of a trust that comprises two among the $n + 1$ active plants, and he receives the sum of the pro ts from the two competing plants: $\pi = 2\pi_{n+1}$. The other downstream rms face a new entrant and receive $V_l = \pi_{n+1}$. We also assume that the innovator's outside option is $\kappa = 0$.

Given these payo s, Assumption 1 requires that

$$2\pi_{n+1} - \pi_n \geq 0$$

Proposition 1 states that in the second period the innovator would sign with the rst producer in the sequence for a price:

$$p_2(n) = \pi_{n+1} - (\frac{1}{2})^n \pi_n$$

[20] As in the "decentralized game" studied by Kamien and Zang (1990).

There are two e ects of an increase in n on the second period price: (1) an increase in the bargaining power, and (2) a decrease in pro ts. For this example, the marginal e ect of n on pro ts is relatively large since the products are homogenous and we nd that the rst e ect dominates for $n \geq 2$. The condition of Proposition 2 that guarantees that a license is signed in the rst period can then be reexpressed as follows:

$$\geq (1-q)\pi_{n+1} - \frac{1}{2^n}(1-\frac{q}{n})\pi_n$$

The condition is satis ed for $n \geq 3$. This is a consequence of the fact that the second period price decreases in n and that the incentives of the innovator to sign early dominate the incentives of producers to postpone.

Bertrand competition with differentiated products

Consider another example based on a di erentiated goods model. Assume that there are initially n producers selling n symmetrically di erentiated goods with a constant marginal cost c, and that innovation allows the introduction of a new product. Firms compete in prices. Following Motta (2004), we use a simple model of consumer preferences from Shubik and Levithan (1980): the consumer's utility is given by

$$U(q_1,...,q_n) = v\sum_{i=1}^{n} q_i - \frac{n}{2(1+\mu)}[\sum_{i=1}^{n} q_i^2 + \frac{\mu}{n}(\sum_{i=1}^{n} q_i)^2]$$

where q_i is the quantity of good i consumed, μ is the degree of product substitution between the goods ($\mu \in [0, +\infty]$) and v is positive and larger than c.

The demand for each good is thus

$$D_i = \frac{1}{n}(v - p_i(1+\mu) + \frac{\mu}{n}\sum_{j=1}^{n} p_j)$$

If no license is signed, the market is composed of n symmetric rms with di erentiated products. Consider now that one rm, say n, signs a license with the innovator, thus introducing a new product. The competition game is now asymmetric, with rm n selling two of the existing $(n+1)$ products. We derive the prices set by rms and equilibrium pro ts in the appendix.

Proposition 2 states that a license is signed in the second period when is small ($\geq$ __). In this case when n is small, __ increases in n for $n \geq 2$ but, as shown in Proposition 4, the minimum threshold __ decreases for n large enough. The following table presents the integer approximation of $\widehat{n}$, the value of n for which __ is maximum in the case where $c = 0$, $v = 1$, $\mu = 10^8$.

q	0.9	0.99	0.999	1-10^{-5}	1-10^{-7}	1-10^{-9}	1-10^{-12}	1-10^{-15}	1-10^{-20}
$\widehat{n}$	6	10	13	21	28	35	45	55	72

3.3 The role of asymmetric information and of overconfidence

Gans et al. (2008), in a di erent context, point out three reasons that could lead to deviations from the socially optimal timing: (1) asymmetric information, (2) search costs, and (3) the absence of intellectual

property rights. They concentrate on the third case. We assume the existence of intellectual property rights and zero search costs, and focus on the interaction between market structure and asymmetric information. We show in Proposition 5 that without asymmetric information, deviations from the socially optimal timing do not occur.

Suppose that both the innovator and the producers are uncertain about the quality of the invention and both share the same belief that the type is good with probability q. Bargaining in the second period remains unchanged. In particular, given Assumption 1 ($\pi - V_o \geq \kappa$), an agreement is always reached if the innovation is of the good type. However, in the first period, the innovator is now uncertain about the quality of her invention. In this case we obtain the following result.

PROPOSITION 5: *If the innovator and the producers share the same belief q that the innovation is good, an agreement is always reached in the first period for all values of q* and n.

If an agreement can be reached in the second period (i.e Assumption 1 is satisfied) then an agreement will be reached in the first period independently of the degree of uncertainty q and of the number of competitors n. The intuition is the following. If an agreement can be reached in the second period when the type is good, then there is an even larger surplus that can be shared in the first period in that case as the producers can develop the product at a lower cost than the innovator. With uncertainty and symmetric information, we find that the license is signed at the socially optimal time.

Several authors have documented that entrepreneurs firms may be overconfident about the prospects of their products (see Puri and Robinson (2007) for an overview). It is interesting to point out how our results change in the presence of overconfidence, rather than private information.

PROPOSITION 6: *If the innovator is overconfident and believes that the innovation is good with probability $\hat{q} > q$, an agreement is reached in the first period if and only if*

$$q\pi - q[\tfrac{1}{n}(\pi - p_2(n)) + \tfrac{n-1}{n}V_l] \geq \hat{q}p_2(n) -$$

Furthermore, if payoffs do not depend on n, the efficiency threshold increases in n when n increases: early signing becomes less likely.

Proposition 6 shows that when the innovator is overconfident, inefficient delays in licensing may reappear.[21] Furthermore, we find that the effect of market structure n is the same as the one identified in Proposition 3. The intuition is similar to the case of asymmetric information. When n increases, the price in the second period increases. This affects the producers' incentives with probability $\frac{q}{n}$ whereas, because of her overconfidence, the innovator is affected with probability $\hat{q}$. Note that in addition to any inefficiency stemming from late signature, overconfidence leads some innovators to spend and pursue development of some bad ideas.

4 Robustness and Extensions

We now consider a number of extensions of our model to examine the robustness of our results under different assumptions about contracts and bargaining.

[21] Note that in the case where $\hat{q} = q$, i.e the case of Proposition 5, the threshold also increases in n but remains always negative.

4.1 Liquidity constraints

It is often argued that biotech rms want to sign early because of liquidity constraints. We capture this e ect in our model in a reduced form. An increase in liquidity constraints increases the cost of development for the innovator. High development costs may result from the di culty or cost of obtaining external capital or the opportunity cost of pursuing another project. In the context of our model, an increase in liquidity constraints renders late signing more costly and thus leads to earlier signing.

4.2 Milestone payments

We previously limited the analysis to contracts that involved a single up-front payment for the innovation. In practice, most licensing contracts are more sophisticated and employ milestone payments and/or royalties to mitigate the problem of asymmetric information. The problem of asymmetric information can be entirely overcome if the contract involves only a milestone payment. In that case, the license is signed in the rst period, the producer develops the product and makes the nal payment in the second period if the product is revealed to be good.

However, we never observe contracts with pure milestone payments in our data of licensing contracts. Milestone-only contracts may not be feasible in the presence of a liquidity-constrained innovator. As well, such contracts may lead to moral hazard for producers, who may not have su cient incentives to develop the product. It is not the object of this paper to examine in details these factors. If we introduce an explicit constraint on how large the up-front payment needs to be, the e ect of market structure on the date of licensing is still relevant (see Allain et al. (2009)).

4.3 Model of auctions

In the case of a second price auction, detailed in the appendix, we obtain the same result as Proposition 3. We consider a model where the value of the license π_i is di erent for each buyer and is drawn from a certain distribution. As n increases, the price the innovator hopes to extract in the second period mechanically increases as more draws from the distribution are taken. The same logic as in Proposition 3 then applies. The good type innovator, who knows her type, knows that she can fully extract this increase in the price in the second period. The producers, though, only consider the added cost, corresponding to a higher price in period 2, if the innovator is good with probability q. The incentives of the innovator to delay are stronger than the incentives of the producers to sign earlier. We note that this basic intuition seems very general as long as the price in the second period is increasing with n.

4.4 Low type with valuable idea

In section 2, we assumed that a bad type innovation generated no value. Here, we relax this assumption and instead suppose the low type innovation generates strictly positive pro ts. Speci cally, the value of the invention is π_L for the low type π_H for the high type. Furthermore, we assume that $\pi_L - V_o \geq \kappa$, so that in period 2 a license will be signed with both types. We also assume that V_l is independent of the value of the innovation, which simpli es the calculations without a ecting the results.

In the second period, the types are revealed as before. We denote the outcome of the bargaining game with the low type as p_2^L and with a high type as p_2^H.

PROPOSITION 7: *All PBNE have the following properties:*

1. *The low type signs in the rst period.*
2. *If* $q\pi_H - \frac{q}{n}[\pi_H + (n-1)V_l] > p_2^H(1-\frac{q}{n}) - (1-q)p_2^L -$ *, then the high type also signs in the rst period*
3. *If* $q\pi_H + (1-q)\pi_L - [\frac{1}{n}[(1-q)(\pi_L - p_2^L) + q(\pi_H - p_2^H)] + \frac{n-1}{n}V_l] < p_2^H -$ *, then the high type signs in the second period and the low type in the rst.*

It is intuitive that there never exists a separating equilibrium in which the low type signs in the second period. If the high type signs the contract in the rst period, the low type will mimic her to obtain the higher payment and the extra bene t from early signing. However, a separating equilibrium may exist in which the high type signs in the second period.

5 Empirical analysis

5.1 Background on the pharmaceutical industry

Drug development is an expensive and lengthy process. It involves many distinct phases de ned by regulatory agencies such as the Food and Drug Administration (FDA) in the United States or the European Medicines Agency (EMEA). During the discovery phase, rms identify molecules for further development in targeting a disease or indication. These are tested in animal subjects during the preclinical phase. At this point, regulatory approval is required to begin clinical trials in humans; for example, in the United States, rms must le an Investigational New Drug application with the FDA. Phase I trials involve a small number of healthy volunteers to establish a molecule's safety. Phase II trials focus on the e cacy of the molecule in treating patients with the disease and begin to identify side e ects. Phase III trials are much larger studies that continue to gather data on safety and e cacy. At the completion of each phase, rms decide whether the results look promising enough to merit continued development. Regulators also may intervene and prevent the continuation of trials if they conclude a study is unsafe. Thus, veri able evidence of a drug candidate's quality is produced at each phase.

Costs increase signi cantly with each phase, and failure is common. According to the Tufts Center for the Study of Drug Development, \[b]etween the time research begins to develop a new prescription medicine until it receives approval from the Food and Drug Administration (FDA) to market the drug in the United States, a drug company typically spends $802 million over the course of 10 to 15 years." This center also claims that out of 5000 drug candidates, only 1 is ultimately approved for marketing. These features justify the focus of the theoretical model on the cost of developing an innovation from the early stage to commercialization.

Most biotech rms license their product at some stage to large pharma rms. In general, the licensee acquires a drug candidate in a disease area in which the licensee has existing strength or experience; licensing lls its pipeline and exploits its relationships with medical practitioners who participate in running clinical trials or prescribe drugs (Levine, 2007). Licensing between large pharma rms also

occurs; one firm may have superior marketing skills in a particular disease area, for example. Superior skills correspond to θ in our theoretical model, and would apply to any pair of firms with a difference in productive efficiency in different stages.

Asymmetric information is an important element of the model and one of the reasons for deviations from the socially optimal timing. In section 7, we describe some papers attempting to assess the extent of asymmetric information in biotechnology licensing. Demonstrating adverse selection is an empirical challenge, but there is at least casual evidence that industry practitioners worry about it (Mason et al., 2008). We find it plausible that the licensing firm has some additional information about the value of its drug candidate, even if considerable uncertainty exists. In particular, it may know more about possible shortcomings: it may have internal data that suggests problems or limitations, and it will not want to share this information with a potential buyer. Note that some contractual terms and licensing procedures, such as milestone payments and due diligence, are aimed at partly overcoming this problem. However, these solutions are costly and imperfect, and some asymmetries will remain.

However, as we pointed out in section 3.3, if our assumption of asymmetric information is incorrect but the other elements of our model are appropriate, we should not expect to find any effect of market structure on the timing of licensing. In our empirical analysis, we examine the effect of market structure in cases where the severity of asymmetric information may differ. We also showed that market structure would have a similar effect on delay in a model with overconfidence, rather than information asymmetry. While we do not attempt to distinguish these explanations empirically, they can be considered as two separate contributions of this paper.

5.2 Data

We draw our sample of licensing contracts from Recombinant Capital's rDNA database.[22] It contains detailed information on all licensing deals in the pharmaceutical industry signed since 1973, including financial details of the agreements (total value, up-front and milestone payments, royalty rates). Some of this information comes directly from the contracts, and some is recovered by Recombinant Capital from regulatory filings or press releases. It also provides information about the geographical region covered by the license and about the type of contract (marketing, production, research). Finally, it records the phase of development of the drug at the time the license was signed.

Testing our theory requires us to identify a downstream market and the number of potential licensees of an innovation. We define a market using a drug's pharmacological/therapeutic subgroup according to its Anatomical Therapeutic Chemical classification (hereafter therapeutic class).[23] Drugs within a therapeutic class may be considered as substitutes, but substitution is unlikely across therapeutic classes. For example, \arthritis" is a separate market from \diabetes." We define the set of potential licensees of an innovation as those with existing products in the same disease area as the innovation. As stated in the previous section, licensees usually acquire drug candidates in a disease area in which they already compete.

[22] This database is typically licensed by major pharmaceutical companies or other firms for a large fee but is also made available for a lower rate for academic research.

[23] The World Health Organization describes this classification scheme as follows: "In the Anatomical Therapeutic Chemical (ATC) classification system, the drugs are divided into different groups according to the organ or system on which they act and their chemical, pharmacological and therapeutic properties. Drugs are classified in groups at five different levels. The drugs are divided into fourteen main groups (1st level), with one pharmacological/therapeutic subgroup (2nd level). The 3rd and 4th levels are chemical/pharmacological/therapeutic subgroups and the 5th level is the chemical substance. The 2nd, 3rd and 4th levels are often used to identify pharmacological subgroups when that is considered more appropriate than therapeutic or chemical subgroups."

Since the rDNA database contains no information on potential licensees or any other market level data, we exploit an additional data source called R&D Focus, produced by IMS Health. This database tracks all drug candidates, or projects, in development since the early 1980s. From this source, we not only add additional information about the development status of each licensed product, but we can determine the set of potential licensees and the experience (in developing drugs as well as marketing approved products) of both the licensor and licensee.

Finally, we used a number of standard sources for firm-level information, such as VentureXpert, Compustat, Osiris, and CorpTech. We identify whether each firm is public or private and collect some financial data, where possible, such as the amount of venture capital financing. Because many of the firms in our study are privately held and/or foreign (roughly half are headquartered outside of the United States), and financial information is somewhat limited.

We restrict our analysis to contracts involving R&D on drug candidates that have not yet been approved for launch, excluding co-marketing alliances. We focus on exclusive deals with no geographic restriction, and on deals that are signed in the discovery, preclinical or clinical phases of development. These exclusions reduce our sample of interest to 6,426 (including observations for which the stage at signing is missing) from a total of 14,976 deals in ReCap. In addition, we concentrate on deals that involve a specific drug candidate (or candidates, in some cases) rather than those for the use of a technology platform.[24] In practice, this requires us to match each licensing agreement from the rDNA database with a project in the R&D Focus database by hand using information on the partnering firms and the subject of the license. This process results in 2,389 matches. We have the least success in matching deals with a missing stage at signing and very early stage deals.

Table 1 provides summary statistics for the key variables in our analysis. [25] Note that we examine only drug candidates that were licensed as of 2007, not the set of all drug candidates that were ever (or are currently) available for licensing. Our estimates therefore apply only to a selected sample.

5.3 Empirical specification

We are interested in testing factors that affect whether a license is signed early or late in the development process. Our starting point is the condition for signing in the first period given in Proposition 2. We have shown that this condition is more likely to be met when the number of competitors increases in an already very competitive market, but in a very concentrated market this condition is less likely to hold. The theoretical model therefore predicts an inverted-U shape relationship between market structure and delay in licensing. We test this prediction.

One approach is to define an "early" stage of licensing, such as the discovery and preclinical phases, and a "late" stage as Phase I, II and III clinical trials. Because regulators are directly involved beginning in Phase I, we consider this stage to be the point at which information about quality is verifiable. As well, this is the point at which testing involves human subjects and more complicated study design. An alternative is to treat each of these distinct phases as a "period" and assume that a similar trade-off exists between signing in stage i and delaying until stage $i + 1$ for each stage i; the difference is that rather than disappearing completely, the informational asymmetry shrinks as each

[24] The latter are rarely exclusive agreements, and it is more difficult to identify a downstream market, which is critical for our analysis.

[25] Most of the empirical studies of pharmaceutical licensing have also used the rDNA database, but they focus on the subset of licensing agreements for which very detailed contract information is available (about 1/3 of the total deals covered in the rDNA data). We examine a larger number of contracts.

development stage is completed. We can think of the trade-o as an unobserved variable y^*. Two natural empirical models are the logit (for early vs. late) and ordered logit (for each phase). In the case of the ordered logit, for example, the observed dependent variable takes a discrete value corresponding to the development stage at signing as follows:

$$\begin{aligned} y &= 0 \quad \text{(discovery phase) if } y^* \leq 0 \\ &= 1 \quad \text{(preclinical phase) if } 0 < y^* \leq \mu_1 \\ &= 2 \quad \text{(Phase I) if } \mu_1 < y^* \leq \mu_2 \\ &= 3 \quad \text{(Phase II) if } \mu_2 < y^* \leq \mu_3 \\ &= 4 \quad \text{(Phase III) if } \mu_3 \leq y^* \end{aligned}$$

Our latent regression is

$$y^* = \beta N + \gamma X + \epsilon$$

where N is a vector of competition measures and X is a vector of controls, described below.

Another approach, and that taken by Gans et al. (2008), is the use of a hazard model. This approach treats a biotechnology rm's innovation as \at risk" for licensing from the time the drug candidate reaches the preclinical stage of development, and examine what factors a ect the hazard rate of the drug candidate's transfer to a licensee. Since censoring is not an issue in our data, we take the simplest approach and regress the natural log of the months since a drug candidate entered the discovery phase on the same variables as used in the ordered logit.

The logit and ordered logit approaches have a number of appealing features. They correspond very closely to our theoretical model, where the two periods di er in the information available to the potential buyers. As a drug candidate progresses through each stage, veri able information is indeed revealed. Also, there is considerable heterogeneity in the time required to complete clinical trials; drugs for chronic conditions may require longer trials than those for acute conditions, for example, and a hazard model may confound the complexity of trials with the strategic delay that is our interest. However, neither the logit nor the ordered logit allows for time-varying regressors, such as rm-level characteristics (like liquidity constraints or experience) that may change over time and a ect license timing. We therefore present results from both the logit and hazard approaches.

We exploit variation in the number of competitors across therapeutic classes, and within therapeutic classes at di erent points in time, to identify the e ect of market structure. While this is our primary interest, we include a number of controls that might also a ect licensing behavior. These include the extent to which a licensor faces capital constraints, and various other factors such as experience in licensing (measured as the number of previous licenses the biotech rm has granted), experience in drug development (measured as the number of drug candidates the licensing rm has previously initiated), market experience (measured as the number of drugs the licensing rm has successfully launched). Because the availability of nancing may vary over time, we also include annual commitments by venture capitalists within the biotechnology and medical industries. All speci cations also include therapeutic class xed e ects, to control for di erences in demand as well as development costs that are likely to vary by disease.

Many of our explanatory variables reflect several of the underlying structural parameters of interest. For example, venture funding, a successful initial public offering, and experience are all likely to increase with a firm's age; with greater experience, the difference in the efficiency of an innovator and a licensee shrinks. A firm that successfully raises additional venture capital financing may be less liquidity constrained than another that did not. However, the venture capitalist provides these funds only after scrutiny of the firm's drug candidates and these funds may signal that the licensor is of high quality to potential buyers. A publicly traded firm may be less liquidity constrained than one dependent on venture capital, but having survived long enough to go public is also informative about its quality. Market experience also reflects both quality and a source of income (from sales of existing products). In our model, a higher q makes the condition for signing early easier to meet, but liquidity constraints, as captured by a high , work in the opposite direction. Our reduced-form empirical approach limits the interpretation of the coefficients on these measures.

6 Results

The theoretical model predicts that, in the presence of information asymmetries, market structure influences the timing of licensing. We test for this effect by estimating our three empirical specifications on our full sample of licensing agreements, and on subsets for which we expect asymmetric information to be high or low.

Asymmetric information is difficult to quantify, but we argue that it is likely to be greatest in the case of licensors that have yet to establish themselves as capable of producing good drug candidates or as trustworthy partners. Nicholson et al. (2005) show that these firms receive the largest discount from new partners, for example, and cite deal experience as a means of signalling quality. We therefore define "high asymmetry" licensors as those with fewer than 10 deals prior to its current one; we obtain similar results using a definition based on development experience. An alternative definition is based on a firm's status as a public or private firm. Public firms are subject to greater scrutiny and required by law to disclose specific information to shareholders. Therefore, we might expect public licensors to have less private information as well as less subject to liquidity constraints. We estimate our models using this split as well.[26]

Tables 2 and 3 present results from our logit and ordered logit estimation, and estimates from the hazard model are contained in Table 4. Because of missing values for the start date of the discovery phase, the hazard model has fewer observations than the other models. Our key variable of interest is the number of firms that are potential licensees. We include a squared term to capture the inverted U-shape predicted by our model. We expect a positive coefficient on the number of firms and a negative coefficient on its square.

Overall, our results show the expected pattern, though coefficients in the hazard model are not significant. Late stage licensing appears to increase with the number of potential licensees, but at very high levels, the quadratic effect dominates and licensing is more likely to take place earlier in the development process. Figure 2 illustrates the effect of competition on the predicted probability of late signing, using results from the full sample logit (column 1 of Table 2), where the other regressors are set to their mean values. The marginal effect of competition is shown in Figure 3. Our estimates indicate that increases in competition speed licensing when the number of firms is greater than approximately 90; the average number of firms per class is 37.

[26] We acknowledge that this split can also possibly separate firms according to their degree of over-confidence. A firm with a longer experience should also be more realistic about its chances of success

This result highlights an important lesson: in many of the therapeutic class markets we analyze, an increase in competition increases inefficient delays in signing. This in turn could have effects on overall innovation rates. This suggests that regulators consider the impact of a change in competition on the timing and efficiency of upstream licensing in addition to the downstream market when evaluating mergers.

Interestingly, our results – at least for the logit and ordered logit – are strongest for the subset of deals where asymmetric information is likely to be high. Licensing agreements involving licensors with an established history of partnerships do not yield statistically significant coefficients on competition. Similarly, competition does not have a statistically significant effect on licensing agreements involving public licensors. We interpret these findings as additional support for our model: if the effect of competition were the same in both high asymmetry and low asymmetry cases, this would suggest that informational asymmetry is not an underlying mechanism driving the timing of licensing.

As discussed in the previous section, the interpretation of the coefficients on other variables is not meaningful in this reduced-form setting. Many are not statistically significant, which may reflect two opposing effects (of access to funds and quality) that are difficult to identify separately. Overall, we find that public firms are more likely to license their candidates in later stages of development, and the availability of venture financing in the industry also enables innovators to delay licensing.

7 Literature Review

In this section we review the relevant literature. We start with the general theoretical and empirical contributions on licensing and later focus on the papers studying specifically the pharmaceutical industry. Note that the literature on bargaining was reviewed in section 2.3.

There is a large theoretical literature that examines different aspects of licensing contracts (such as the choice between fixed fees and royalty rates, the allocation of control rights, etc.). Kamien and Tauman (1986) show in a Cournot oligopoly that fixed fees dominate royalty rates as they do not affect the production decision of the licensee. A large body of literature examines the choice between fixed fees and royalties under a variety of assumptions (e.g., Beggs (1992) and Choi (2001)). However, with the exception of Gans et al. (2008), who examine how a reduction in uncertainty affects the timing of contracting, the question of the timing of licensing has been left aside. We propose a tractable model to examine this question and to describe the influence of market structure.

There also exists a literature on technology transfer under asymmetric information when intellectual property rights do not exist. Two problems arise when the parties attempt to sign a contract. First, the asymmetry of information makes the uninformed party wary of signing a contract. Second, if the innovator does reveal her information, the producer can then fully appropriate the invention without any form of payments. Anton and Yao (1994) and Anton and Yao (2002) examine solutions to this problem.[27] We concentrate here on a different aspect: property rights do exist, but the innovator has no means to credibly disclose information about the value of the invention.

One of the key features of our model and of the industry we focus on is that firms are specialized in different innovative tasks. The specialization of innovative activity between early and later stage is the basis for several papers that focus on different questions. For instance, Bhattacharya and Guriev

[27] For instance, Anton and Yao (2002) propose a mechanism based on partial disclosure of the idea and the issuance of a bond that allows the innovator to appropriate some of the returns from her invention. The amount of self exposure to expropriation through disclosure and through the bond, signals the value of the invention.

(2006) examine the choice between patents and trade secrets for an innovator performing early stage research who wants to license her discovery. Patents prevent theft of knowledge but are costly because of spillovers of the disclosed information in the application. Trade secrets do not prevent the potential buyer from stealing the knowledge or the seller to sell the knowledge to competitors after signing an exclusive license.

The empirical literature on licensing is more limited. Much of the work in this area has focused on the allocation of control rights and other contracting terms in examining bargaining power and moral hazard. Anand and Khanna (2000) describes the distribution of contractual terms in a sample of contracts. Vishwasrao (2006) tests some theoretical results on the choice between xed fees and royalty payments, while Mendi (2005) examines how this choice is a ected by the duration of the contract using a sample of Spanish rms. Many papers have examined issues in licensing of pharmaceuticals. For example, Lerner and Merges (1998) nd that biotechnology rms cede more control rights to licensees when nancially constrained; additional work by Higgins (2007) con rms the importance of bargaining power both for the licensor and the licensee. However, the results in Lerner and Merges (1998) do not support the prediction that the R&D rm will have greater control rights when its marginal contribution is most important. Lerner and Malmendier (2005) study contract design when research activities are hard to verify. They nd that for licenses that apply to very early stage research, where contractibility is most di cult, the licensee is more likely to demand the right to terminate a project and rights to the intellectual property associated with it. Like us, Levine (2007) considers competition by pharmaceutical rms for licenses from biotech rms and its role in bargaining power. She estimates the potential licensees' values for a license using information on market size and concentration. She does not consider the timing of licenses.

A second stream of the empirical literature on pharmaceutical licensing has addressed the question of asymmetric information between the biotechnology rm and a licensee. Pisano (1997) nds higher failure rates of drug candidates licensed in from biotechnology rms than those developed in-house by pharmaceutical rms, though Arora et al. (2004) nd the opposite. However, the existence of a positive correlation between licensing and failure is only evidence of adverse selection if it holds after conditioning for all observable information used to determine the price of a license. That is, licensed-in projects may be higher risk and therefore have higher failure rates, but if the risk is easy for the licensee to assess (no information asymmetry), the price of the license will re ect this. Nicholson et al. (2005) exploit additional information on deal terms and product and market characteristics to estimate how much of a \discount" biotech rms are forced to o er for a license. They show that this discount is not related to failure rates, and argue that licensing serves another function for biotech rms: the need to signal their quality to venture capitalists and other external sources of nance. That is, the information asymmetry is not between the biotech rm and a licensee, but rather between the biotech rm and venture capitalists.

Very little work has examined the timing of licensing. Gans et al. (2008) look at how a reduction in uncertainty a ects when technology transfer occurs using both a theoretical model and data on a range of innovations in a cross-section of industries. They nd that the resolution of uncertainty over the scope of intellectual property (speci cally, the claims granted to a patent) speeds licensing, though this e ect is moderated by other factors such as the length of the product life cycle and the availability of other means of appropriation. Katila and Mang (2003) study the timing of collaboration for 86 biotechnology alliances, and nd evidence that biotech rms with partnering experience and many patent applications tend to sign licenses earlier in the development process. As well, institutions that reduce uncertainty and informational asymmetry, such as public organizations to support the commercialization of biotech within a local area, are associated with earlier licensing. We are not

aware of any empirical study relating market structure to the timing of licensing, which is our focus here.

8 Conclusion

This paper considers factors that may a ect the timing of licensing in markets for technology. Though these markets have received considerable attention from academics and are quite important in some industries, the timing of licensing is relatively unexplored. We present a theoretical model that captures many features we believe are important in practice. This model generates testable predictions for the e ect of competition and other variables on the timing of licensing. A particularly interesting prediction is that if downstream pro ts decline with the number of competitors, the e ect of competition on the timing of licensing is non-monotonic.

The prevalence of licensing in the pharmaceutical industry and certain characteristics of the drug development process make it an ideal setting in which to test these predictions. Using data on licensing contracts over the last several decades, we nd evidence of the inverted U-shaped relationship between competition and licensing delays that our model predicts. This relationship is strongest when asymmetric information is most severe, as expected.

The results presented in this paper have important implications. We highlight the role of market structure: in certain situations, increasing competition can postpone licensing. Ine cient late signing can increase signi cantly the cost of R&D and in turn a ect innovation rates and growth. The shift in timing documented in Figure 1 could potentially explain some of the fall of productivity in the pharmaceutical sector in the last decades. Thus, understanding factors that in uence this timing is essential both for merger authorities and for industry participants.

9 Appendix

9.1 Proof of Proposition 1:

The game is solved recursively. Consider the bargaining with the last producer, de ning the price $p_2(1)$. As ϵ converges to zero, Binmore et. al. (1986) show that the bargaining outcome is de ned by the Nash bargaining solution where the surplus is split equally:

$$p_2(1) - \kappa = \pi - p_2(1) - V_0$$

A license will be granted in the last round if and only if $p_2(1) \geq 0 \Leftrightarrow \pi - V_0 - \kappa \geq 0$, i.e under Assumption 1.

Consider a round of negotiations prior to the last, where there are k producers left in the sequence. As ϵ converges to zero, the price is determined by an equal split of the surplus. The disagreements points converge to $p_2(k-1)$ for the innovator and V_l for the producer[28] We obtain the following recursive relation

$$p_2(k) - p_2(k-1) = \pi - p_2(k) - V_l$$

A license will be signed in that round if and only if $\pi - V_l \geq p_2(k-1)$

Solving the recursive equation, we nd:

$$p_2(k) = (\tfrac{1}{2})^k(\kappa + V_l - V_0) + (1 - (\tfrac{1}{2})^k)(\pi - V_l)$$

The condition that guarantees that a license is signed in a period $k > 1$ is $\pi - V_l \geq p_2(k-1)$. Using the previous expression for $p_2(k-1)$ we nd that this is equivalent to $\pi - V_l \geq \kappa + V_l - V_0$ or in other words

$$\pi + V_0 - 2V_l \geq \kappa \tag{5}$$

Because $V_0 > V_l$, we have $\pi - V_0 < \pi + V_0 - 2V_l$. Therefore, Assumption 1 implies condition (5) ($\pi + V_0 - 2V_l \geq \kappa$), and an agreement can be reached with any producer in the sequence. In particular, bargaining succeeds with the rst producer and a license is sold at a price $p_2(n)$.

9.2 Proof of Proposition 2

We rst note that if $> p_2(n)$, if no license is signed in the rst period, the innovator does not develop the product. Thus, when the innovator negotiates with the last producer in the sequence in period 1, her outside option is zero. Bargaining will therefore necessarily succeed in period 1. For the rest of the proof we thus concentrate on the case $\leq p_2(n)$. Note that the condition stated in Proposition 2, is $\geq \_(n) = p_2(n) - q[\frac{n-1}{n}[\pi - V_l] + \frac{1}{n}p_2(n)]$. We note that $\_(n) < p_2(n)$. Thus if we show that the result of Proposition 2 holds for $\leq p_2(n)$ we have completed the proof.

[28] Formally, the disagreement points are: $(1-\epsilon)p_2(k-1) + \epsilon(1-\epsilon)p_2(k-2) + ... + \epsilon(k-1)\kappa =$ for the innovator and $(1-\epsilon(k-1))V_l + \epsilon(k-1)V_0$. As ϵ converges to zero we obtain the reported disagreement points.

Step 1: If the condition of Proposition 2 is satis ed then the bargaining must succeed in period 1.

Suppose there exists a PBNE such that the contract is signed in period 2. We know that in all equilibria that succeed in period 2, bargaining will immediately succeed at the start of the second period and the price paid will be $p_2(n)$.

Consider the last bargaining session in period 1. Consider a round where the producer makes an o er. If he o ers a price $p' > p_2(n) -$ this o er will be accepted by both types of innovators. Indeed the best the innovator can hope for in equilibrium is to obtain $p_2(n)$ in the following period and he will have to pay to develop the product from period 1 to period 2. With this o er, the utility of the producer is $q\pi$ + $(1-q)V_0 - p'$. In the current equilibrium, his expected utility is $q[\frac{1}{n}(\pi - p_2(n))$ + $\frac{n-1}{n}V_l]$ + $(1-q)V_0$. The condition given in Proposition 2 guarantees that such an o er is indeed attractive and will be accepted in period 1 by the innovator.

The reasoning is valid for any PBNE that does not succeed in period 1 (in particular it does not depend on the shape of beliefs). We have therefore shown that if the condition is satis ed, the bargaining will succeed in period 1.

Step 2: If the condition of Proposition 2 is not satis ed then the bargaining must succeed in the rst period.

Consider an equilibrium where the license is signed in period 1 with the kth producer ($k > n$)

Consider the last negotiation session in period 1 when the innovator has negotiated with all but one producer. Suppose the beliefs of the producer are that the innovator is of a good type with probability q'.

Consider a round where the innovator makes the o er. A good type will always o er a price $p_t \geq p_2(n) -$ as she knows she can guarantee herself at least $p_2(n) -$ by developing the product herself. The bad type will always mimic the behavior of a good type. If she reveals her type, no o er will be accepted or made to her.

We examine the optimal response of the producer. If the producer accepts the o er, he obtains an expected payo of $q'\pi$ + $(1-q')V_0 - p_t$. However, he will never accept an o er that yields a smaller payo than what he can guarantee himself if he rejects all o ers and obtains his outside option $q'[\frac{1}{n}(\pi - p_2(n))$ + $\frac{n-1}{n}V_l]$ + $(1-q')V_0$. So, if $q'\pi - q'[\frac{1}{n}(\pi - p_2(n))$ + $\frac{n-1}{n}V_l] < p_2(n) -$ no equilibrium o er by the innovator will be accepted by the producer.

Consider a round where the producer makes an o er. In equilibrium he will o er a price p_t that is such that $q'\pi - p_t \geq q'[\frac{1}{n}(\pi - p_2(n))$ + $\frac{n-1}{n}V_l]$.

Furthermore, he knows that all o ers lower than $p_2(n) -$ will be rejected by the good type innovator and might be accepted by the low type. Such an o er will never be made in equilibrium. So if $q'\pi - q'[\frac{1}{n}(\pi - p_2(n))$ + $\frac{n-1}{n}V_l] < p_2(n) -$ no equilibrium o er by the producer will be accepted by the innovator.

Finally, in all pure strategy equilibria, q' = q. Indeed, given that there is an exogenous probability of breakdown η before each session, a bargaining session between the innovator and the last producer in the sequence is on the equilibrium path regardless of the equilibrium. Therefore, the last producer does not update his beliefs based on the fact that the innovator comes to him.

Therefore if the condition of Proposition 2 is not satis ed, no agreement can be reached in the

negotiations with the last producer in the sequence. When the innovator negotiates with the producer who is the one before last in the random sequence, both know that the negotiations will fail in the last round of negotiations in phase 1. The continuation values are then identical to those of the last and we find that the same condition. Reasoning recursively we can conclude that if the condition is not satisfied, no agreement can be reached in period 1.

9.3 Proof of proposition 3

According to the result of Proposition 1, the price of a license in the second period is given by:

$$p_2(n) = (\pi - V_l) - \frac{1}{2^n}(\pi - 2V_l + V_o - \kappa)$$

Furthermore, Assumption 1 and $V_l \leq V_o$ imply that $\pi - 2V_l + V_o - \kappa > 0$. Thus, $p_2(n)$ increases with n.

We can reexpress the condition of Proposition 2 that guarantees that the license is signed in the first period:

$$\begin{aligned} q\pi - q[\frac{1}{n}(\pi - p_2(n)) + \frac{n-1}{n}V_l] &\geq p_2(n) - \\ &\Leftrightarrow \quad \geq \_(n) \\ \text{where } \_(n) &= p_2(n)(1 - \frac{q}{n}) + q[\frac{1}{n}\pi + \frac{n-1}{n}V_l] \end{aligned}$$

We can examine the impact of n on the benchmark value $\_(n)$

We find:

$$\_'(n) = [\pi - 2V_l + V_o - \kappa]\ \frac{1}{2^n}\left[\ln(2)(1 - \frac{q}{n}) - q\frac{1}{n^2}\right]$$

Therefore for $n \geq 2$ we obtain that $\_(n)$ is increasing in n

9.4 Proof of proposition 4

The calculation of payoffs is similar to the case of Proposition 3 but we now take into account the fact that all payoffs depend on n

$$p_2'(n) = (\pi'(n) - V_l'(n)) + \frac{\ln(2)}{2^n}(\pi - 2V_l + V_o - \kappa) - \frac{1}{2^n}(\pi'(n) - 2V_l'(n) + V_o'(n) - \kappa'(n))$$

Furthermore, we examine how the benchmark $\_(n)$ varies with n

$$\_'(n) = p_2'(n)(1 - \frac{q}{n}) + p_2(n)(\frac{q}{n^2}) + \frac{1}{n^2}[V_l - \pi] + q[\frac{1}{n}\pi'(n) + \frac{n-1}{n}V_l'(n)]$$

We see that if we take the limit as $n \to +\infty$

$$\lim_{n\to+\infty} \_\_'(n) = \lim_{n\to+\infty} p_2'(n) + V_l'(n) = \lim_{n\to+\infty} (\pi'(n) - (1-q)V_l'(n))$$

Under the condition of Proposition 4 $\lim_{n\to+\infty} \_\_'(n) < 0$ and thus the probability of signing in period 1 increases in n

9.5 Bertrand competition with differentiated products

The consumer's utility is given by

$$U(q_1, ..., q_n) = v\sum_{i=1}^{n} q_i - \frac{n}{2(1+\mu)}[\sum_{i=1}^{n} q_i^2 + \frac{\mu}{n}(\sum_{i=1}^{n} q_i)^2]$$

where q_i is the quantity of good i consumed, μ is the degree of product substitution between the goods ($\mu \in [0, +\infty[$) and v is positive and larger than c.

The demand for each good is thus

$$D_i = \frac{1}{n}(v - p_i(1+\mu) + \frac{\mu}{n}\sum_{j=1}^{n} p_j)$$

If no license is signed, all n firms are symmetric, each selling one good. Profit maximization of the symmetric game yields the following prices and profits:

$$\begin{aligned} p_i &= c + \frac{n(v-c)}{2n+\mu(n-1)} \\ V_o(n) &= \frac{(v-c)^2(n+\mu(n-1))}{(2n+\mu(n-1))^2} \end{aligned}$$

Consider now the case where one firm, say n, signs a license with the innovator in possession of a good type innovation, thus introducing a new product. The competition game is now asymmetric, firm n selling two of the existing $(n+1)$ products, whereas its competitors sell one each.

Firm n's profit is now

$$\_n(p_n, p_{n+1}) = (p_n - c)D_n(p_1, ...p_n, p_{n+1}) + (p_{n+1} - c)D_{n+1}(p_1, ...p_n, p_{n+1})$$

Whereas firm i's profit, for $i \in \{1, .., n-1\}$, is

$$\_i(pi) = (p_i - c)D_i(p_1, ...p_n, p_{n+1})$$

The equilibrium of the pricing game yields the following prices (all prices are above c and generate positive demands):

$$\begin{aligned} p_i &= \frac{v + (1+\mu)(nv + c(1+n+(n-1)\mu))}{2 - \mu^2 + n(1+\mu)(2+\mu)} \text{for } i \in \{1, ..., n-1\} \\ p_n &= p_{n+1} = \frac{v(2+\mu+2n(1+\mu)) + c(2+2n(1+\mu)^2 - \mu(1+2\mu))}{4 - 2\mu^2 + 2n(1+\mu)(2+\mu)} \end{aligned}$$

and the pro ts are

$$\pi = {}_n = \frac{(c-v)^2(1+n+\mu(n-1))(2+\mu+2n(1+\mu))^2}{2(1+n)^2(2-\mu^2+n(1+\mu)(2+\mu))^2}$$

$$V_l = {}_i = \frac{(c-v)^2(1+n+\mu n)^3}{(1+n)^2(2-\mu^2+n(1+\mu)(2+\mu))^2} \text{for } i \in \{1,...,n-1\}$$

We check that $V_l \leq V_o$. The table presented in the main text uses these results for particular values of the parameters.

9.6 Proof of proposition 5

The proof is similar to the proof of Proposition 2 except that the beliefs of the producer are not updated during the bargaining process as there is no private information. The condition for signing in period 1 thus becomes

$$q\pi - q[\frac{1}{n}(\pi - p_2(n)) + \frac{n-1}{n}V_l] \geq qp_2(n) -$$

This is equivalent to

$$\geq \_(n) = q\frac{n-1}{n}[V_l - \pi + p_2(n)]$$

In Proposition 1 we established that $p_2(n) < \pi - V_l$ and thus $\_(n) < 0$ for all values of q and n

9.7 Proof of proposition 6

The proof is identical to the proof of Proposition 2 with two main distinctions:

- the beliefs of the producer are not updated during the bargaining process as there is no private information

- if the innovator develops the innovation herself, her expected pro ts are $\hat{q}p_2(n) -$. The condition thus becomes

$$q\pi - q[\frac{1}{n}(\pi - p_2(n)) + \frac{n-1}{n}V_l] \geq \hat{q}p_2(n) -$$

A license is signed in period 1 if and only if

$$\geq \_(n)$$

$$\text{where } \_(n) = p_2(n)(\hat{q} - \frac{q}{n}) + q[\frac{1}{n}\pi + \frac{n-1}{n}V_l]$$

We nd:

$$\_'(n) = [\pi - 2V_l + V_o - \kappa]\ \frac{1}{2^n}\left[\ln(2)(\hat{q} - \frac{q}{n}) - q\frac{1}{n^2}\right]$$

Therefore for $n \geq 2$ we obtain that $\_(n)$ is increasing in n

9.8 Proof of proposition 7

Step 1: there is no pooling equilibrium where both types sign in period 2.

Suppose such an equilibrium exists. In period 2, the uncertainty is resolved and given our assumption on pro ts π_L both types sign a license. The low type obtains a price p_2^L and the high type p_2^H. In the rst period, when it is the producer's turn to make an o er, he can deviate by o ering a price $p' = p_2^L + \epsilon -$ with $0 < \epsilon < p_2^H - p_2^L$. This o er will be accepted by the low type and rejected by the high type. Furthermore, this deviation is pro table for the producer if $\epsilon <$: if the innovator is of high type, the payo s are unchanged and if it is of low type, the payo s are increased $\pi_L - p_2^L - \epsilon +$ $> \frac{1}{n}(\pi_L - p_2^L) + \frac{n-1}{n}V_l$. So the pooling equilibrium where both sign in period 2 cannot exist.

Step 2: in a separating equilibrium, the contract with the high type is signed in second period

Suppose there exists a separating equilibrium where the high type signs in period 1 and the low type in period 2. This cannot be an equilibrium since the low type will always want to mimic the high type and will accept the o er in period 1.

Step 3: Suppose the condition of result (2) is satis ed then there is no sorting equilibrium.

Suppose a sorting equilibrium exists. According to Step 2 the only sorting equilibrium is such that the contract with the high type is signed in second period at a price p_2^H and the contract with a low type is signed at a price p_1 such that $p_2^H -$ $> p_1 > p_2^L -$

Consider a round of negotiations where the producer is making an o er in period 1. Suppose that in equilibrium the producer o ers p_1. For the separating equilibrium to exists it has to be such that $p_2^H -$ $> p_1 > p_2^L -$

If the producer deviates and o ers a price $p' > p_2^H -$ the contract will be accepted by both types.

The expected utility is then $q\pi_H$ + $(1-q)\pi_L - p'$ +

If he does not deviate the utility is $(1-q)[\pi_L - p_1]$ + $q[\frac{1}{n}(\pi_H - p_2^H)$ + $\frac{n-1}{n}V_l]$

Taking into account the fact that $p_2^H -$ $> p_1 > p_2^L -$, if $q\pi_H$ + $(1-q)\pi_L - [(1-q)[\pi_L - p_1]$ + $q[\frac{1}{n}(\pi_H - p_2^H)$ + $\frac{n-1}{n}V_l]] > p_2^H -$ this deviation will always be pro table and this equilibrium cannot exist.

This condition is equivalent to $q\pi_H - \frac{q}{n}[\pi_H$ + $(n-1)V_l] > p_2^H(1 - \frac{q}{n}) - (1-q)p_2^L -$. We have therefore shown result (2)

Step 4: If the condition of result (3) is satis ed, there cannot be an equilibrium where both types sign in period 1.

The reasoning follows exactly the reasoning of step 1 in the proof of Proposition 2 (case where the low type produces an invention of value zero). The only changes are the expected values and the outside options.

9.9 Second price auction

We derive the result when in each period the license is awarded according to a second price auction. Suppose also that the value of the license (if the inventor is of a good type) to each producer is unknown and follows a distribution $\pi \sim F$ with support $[\pi_L, \pi_H]$.

Second period

In the second period, the type of the inventor is known. The unique equilibrium is such that all producers bid exactly their value (equilibrium bidding strategy in a second price auction). Thus in the second period

$$p_2(n) = E[\pi_{n2}] \tag{6}$$

where π_{n2} is the second highest value among n values. The price in the second period is therefore an increasing function of n (if pro ts do not depend on n) just mechanically because you get more draws.

First period

Suppose that the condition is such that a producer with value π wants to make a bid, then his optimal bidding strategy is to bid his expected value $q\pi$. Indeed, suppose it is optimal for him to bid $b < q\pi$. We consider two cases and show that in both cases it is optimal for the producer to deviate and bid $q\pi - \quad_p$.

1) bid b is the highest bid. In that case increasing the bid does not change anything

2) bid b is not the highest value. We denote b_1 the highest bid in that case. If $b_1 > q\pi$ deviating to bidding $q\pi$ has no e ect. Suppose then that $b_1 \leq q\pi$. Note that b can only be optimal if both the good and bad type accept the o er. So the good type would also accept a higher bid. Therefore the expected pro ts if a bid $q\pi$ is made is $q\pi - b_1 \geq 0$. Thus the deviation is optimal.

So if the conditions are such that if a bid is made in equilibrium, then the bidder with value π will bid exactly $q\pi$

We now examine the condition such that a bid will be made and accepted by the innovator. The winning bidder in period 1 knows he has the highest value and would therefore also be the winning bidder the next period. Therefore a bidder who values the license at π makes a bid only if:

$$q\pi - E[p_1] \geq q[\pi - E[p_2]] \tag{7}$$

So

$$0 \leq E[p_2] - E[p_1] \tag{8}$$

Furthermore, given the strategies we identi ed, $E[p_1] = qE[\pi_{n2}]$ and $E[p_2] = E[\pi_{n2}]$. Thus the previous condition is always satis ed

However,we need to verify that the good type innovator accepts the o er. Therefore we require $p_1 \geq E[p_2] - \ _i$. Furthermore given the strategies that the bidders use, given the value of p_1 the innovator knows that $p_1 = qp_2$. Overall, the license is awarded in period 1 if and only if:

$$\geq (1-q)p_2 \tag{9}$$

Therefore, the condition that guarantees success in period 1 is the following

$$\geq (1-q)E[\pi_{n2}] \tag{10}$$

We get exactly the same result as in our bargaining model. As n increases it becomes more di cult to sign in period 1. The intuition is similar: in second period, the good type knows he can appropriate the full revenues.

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Table 1: Summary statistics

Variable	N	Mean	StdDev	Min	Max
Log(months since discovery)	1073	0.275	0.962	0.	6.112
Firms in class (# rms with launched products in ATC-2 class)	2270	37.059	32.207	1.	140.000
Licensor market experience (# marketed products originated by the licensor)	2270	0.240	1.917	0.	42.000
Licensor development experience (# products the rm has in development)	2270	1.205	3.387	0.	54.000
Licensor deal experience (# licensing deals that licensor has signed)	2270	3.076	5.106	0.	34.000
Licensor is publicly traded	2270	0.143	0.350	0.	1.000
Venture funding prior to license ($100 mill.)	2244	1.444	22.537	0.	541.230
No. of venture nancing rounds prior to deal	2244	1.790	2.623	0.	20.000
Total VC commitments in deal year ($bill.)	2269	6.262	3.292	0.0004	14.793

Table 2: Logit of Y = signing in Phase I, II or III

Variable	Full sample	Venture-funded only	Low deal exp.	High deal exp.	Private rms	Public rms
	Coef. (SE)	Coef. (SE)	Coef. (SE)	Coef. (SE)	Coef. (SE)	Coef. (SE)
Intercept	-2.7344** (0.2859)	-2.9744** (0.4341)	-2.7971** (0.3127)	-2.7992** (0.8942)	-2.6421** (0.2966)	-3.2081** (1.0772)
Firms in class	0.0116* (0.0060)	0.0142 (0.0089)	0.0137** (0.0066)	0.0059 (0.0174)	0.0127* (0.0066)	0.0047 (0.0163)
Firms in class squared	-0.0001** (0.0000)	-0.0001** (0.0000)	-0.0001** (0.0000)	0.0000** (0.0000)	-0.0001** (0.0000)	0.0000** (0.0000)
Licensor market experience	-0.0034 (0.0274)	0.0955 (0.1017)	0.0065 (0.0311)	0.1805 (0.1534)	0.1966** (0.0863)	-0.0342 (0.0389)
Licensor development experience	-0.0039 (0.0168)	-0.0383 (0.0267)	-0.0305 (0.0216)	0.0662* (0.0372)	-0.0172 (0.0210)	0.0211 (0.0293)
Licensor deal experience	0.0083 (0.0098)	0.0152 (0.0134)	0.0160 (0.0235)	0.0056 (0.0320)	0.0007 (0.0105)	0.0587 (0.0364)

Table 4: OLS regressions of log(months since discovery)

Variable	Full sample	Venture-funded only	Low deal exp.	High deal exp.	Private rms	Public rms
	Coef. (SE)	Coef. (SE)	Coef. (SE)	Coef. (SE)	Coef. (SE)	Coef. (SE)
Intercept	-0.2103** (0.1040)	-0.2391 (0.1500)	-0.1677 (0.1021)	-0.7875 (0.5860)	-0.1912* (0.1098)	-0.3415 (0.3283)
Firms in class	0.0055 (0.0036)	0.0037 (0.0052)	0.0051 (0.0037)	-0.0009 (0.0133)	0.0042 (0.0038)	0.0136 (0.0110)
Firms in class squared	-0.0000 (0.0000)	-0.0000 (0.0000)	-0.0000 (0.0000)	-0.0000 (0.0001)	-0.0000 (0.0000)	-0.0001 (0.0001)
Licensor market experience	-0.0066 (0.0153)	-0.1188** (0.0597)	0.0007 (0.0153)	-0.0215 (0.1110)	-0.0817 (0.0535)	-0.0000 (0.0253)
Licensor development experience	-0.0091 (0.0109)	-0.0211 (0.0138)	-0.0183 (0.0119)	0.0372 (0.0311)	-0.0079 (0.0119)	-0.0128 (0.0298)
Licensor deal experience	0.0216** (0.0059)	0.0360** (0.0086)	0.0436** (0.0140)	-0.0000 (0.0257)	0.0227** (0.0062)	0.0346 (0.0306)
Licensor is publicly traded	-0.0116 (0.1028)	. .	-0.0437 (0.0992)	0.6318 (0.6755)	. .	. .
Venture funding prior to license	0.0016 (0.0014)	0.0015 (0.0014)	0.0016 (0.0013)	0.5227 (0.5377)	0.0016 (0.0014)	. .
Number of venture nancing rounds prior to deal	0.0186 (0.0119)	0.0011 (0.0168)	0.0070 (0.0121)	0.0391 (0.0613)	0.0188 (0.0121)	. .
Total venture capital commitments in deal year	0.0366** (0.0097)	0.0345** (0.0145)	0.0276** (0.0095)	0.1540** (0.0555)	0.0308** (0.0105)	0.0756** (0.0278)
Number Obs	1027	527	900	127	918	109
R^2	.054	.099	.046	.217	.054	.153
* = signi cant at 10%, ** = signi cant at 5%. All speci cations include therapeutic class xed e ects.						

Figure 1: Stage at licensing signing over time

Figure 2: E ect of competition on the probability of late signature

Figure 3: Marginal e ect of competition on the probability of late signature