The timing of licensing: theory and empirics

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PRELIMINARY AND INCOMPLETE

Abstract

The timing of licensing may have a significant impact on overall innovation rates if the licensee is more efficient than the licensor in certain phases of research. 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. We demonstrate that market structure has an ambiguous effect on this timing. For concentrated markets, an increase in the number of potential licensees tends to delay licensing, while the opposite is true for less concentrated markets. We test these predictions with data on contracts signed between biotechnology firms and large pharmaceutical firms, and find evidence consistent with our theory.

Jel Codes: L13, L24, L65.

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1 Introduction

"Markets for technology," or the licensing of innovations, have increased significantly over recent decades. 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). As markets for technology grow in importance, the timing of licensing becomes an essential consideration. Consider two firms and two periods of research. Firm 1 might be more efficient in conducting early stage research, but less efficient for the final stage than firm 2. It is socially optimal to transfer the invention from firm 1 to firm 2 at the end of the first phase. Any other 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 has important consequences for economic growth.

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A distribution of competencies, or specialization in particular activities, is common in many industries. For instance, large pharmaceutical firms are considered more efficient in conducting later stage clinical testing, while small biotechnology companies might have a comparative advantage in achieving early stage discoveries in certain fields. Guedj and Scharfstein (2005) show clear differences in the success rates of drug candidates in cancer between experienced, larger firms and small biotech firms. Two McKinsey analysts claim in an article in *Nature Reviews: Drug Discovery* 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" (Kalamos and Pinkus, 2003). Both the academic literature and the popular press note that a significant proportion of the drugs marketed by major pharmaceutical companies originate from licensing deals with smaller biotechnology firms. 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 firms as it is on trying to discover its own blockbuster drugs."(Economist, 2006)

In this industry, there is some evidence that licensing contracts have been signed with increased delays in recent years. This delay does not merely reflect 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.[1] This delay in technology transfer coincides with a period of low numbers of new drugs launched and consolidation in the industry.

If markets for technology work efficiently, then the timing of licensing depends only on the productive efficiency of the contracting firms. However, we focus on two factors that are typical in many innovative industries and that may impact the 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. As a clinical trial phase is successfully completed, outside observers become more confident of the drug candidate's value.

We present a theoretical model that generates testable predictions for the timing of licensing. We show that these two common characteristics of innovative activities may often lead to deviations from the socially optimal timing of licensing. A contribution of this paper is to offer a systematic understanding of the link between technology transfer and market structure. This can have wide-ranging implications. In particular, it suggests another factor that should be taken into account in merger reviews.[2] We then test these predictions using data on licensing contracts in the pharmaceutical industry.

The paper proceeds as follows. We review related literature in the next section. In section 3, we present the model, and we solve the bargaining game and determine the factors that influence the timing of licensing in section 4. To provide more intuition for the results, we examine two special cases (the case where the payoffs do not depend on the number of players on the market and the case of Cournot competition). In section 5, we examine a number of robustness checks. We test these results on data on licensing contracts in the pharmaceutical industry in section 6, and conclude in section 8.

[1]We describe the construction of our data and development stage index and in section 6.

[2]Note that mergers are not explicitly considered in this paper, but the impact of mergers on the timing of technology transfer has been generally overlooked.

2 Literature Review

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.) and on conditions that may facilitate markets for technology. 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. We discuss related theoretical and empirical literature on licensing here; in section 3.3, we discuss the literature on bargaining as it applies to our model.

There exists a literature on technology licensing 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, 2002) examine solutions to this problem.[3] 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.

Many papers have examined issues in licensing of pharmaceuticals. 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. For example, Lerner and Merges (1998) find that biotechnology firms cede more control rights to licensees when financially constrained; additional work by Higgins (2007) confirms 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 firm 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 find that for licenses that apply to very early stage research, where contractability is most difficult, 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 firms for licenses from biotech firms 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 firm and a licensee. Pisano (1997) finds higher failure rates of drug candidates licensed in from biotechnology firms than those developed in-house by pharmaceutical firms, though Arora et al. (2004) find 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 reflect this. Nicholson et al. (2005) exploit additional information on deal terms and product and market characteristics to estimate how much of a "discount" biotech firms are forced to offer for a license. They show that this discount is not related to failure rates, and argue that licensing serves another function for biotech firms: the need to signal their quality to venture capitalists and other external sources of finance. That is, the information asymmetry is not between the biotech firm and a licensee, but rather between the biotech firm and venture capitalists.

[3] 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.

Very little work has examined the timing of licensing. Gans et al. (2008) look at how a reduction in uncertainty affects when technology transfer occurs using both a theoretical model and data on a range of innovations in a cross-section of industries. They find that the resolution of uncertainty over the scope of intellectual property (specifically, the claims granted to a patent) speeds licensing, though this effect 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 find evidence that biotech firms 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.

3 Model

We consider a model with n symmetric producers who compete with existing products on the market. These producers are the only potential buyers of a license from a single innovator. The innovator is less efficient than the producers in commercializing her idea. We take commercialization to mean the development of an innovation for the product market, not necessarily just manufacturing or production.

The model has two periods. The first period is characterized by asymmetric information about the quality of the innovator. The innovator knows her type, but none of the producers do. They share a common prior that the innovator is a good type with probability q or a bad type with probability $1 - q$. Initially, we restrict the licensing contract to a single up-front payment from the producer to the innovator, and we assume the innovator faces no liquidity constraint (we relax both assumptions in section 5). Bargaining takes place in the first period, and if no license is signed, bargaining resumes in the second period when the type of the innovator is revealed. We describe the bargaining game in detail below. Because the innovator is less efficient than the producers, the value of the final product resulting from her idea is higher the earlier a license is signed.

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. The biotech can establish the quality of its compound by conducting clinical trials, which reveal verifiable information about the compound's efficacy, or the biotech can license its compound to a pharmaceutical firm. Early licensing increases value because the more efficient firm handles development, but waiting allows for revelation of information. This trade-off will be the central focus of our paper.

3.1 Payoffs

To be as general as possible, we describe the payoffs of the players in reduced-form. These payoffs may depend on various factors, such as the market game being played (e.g., Cournot or Bertrand competition), the characteristics of demand for the final product and the characteristics of the innovation.[4] We focus on one such factor in particular: the number of producers n. These producers compete both to acquire the innovation as well as on the product market.

We introduce the following measures in the case where the innovator is of the good type:

- $\kappa(n)$ is the utility of the innovator if no licensing contract has been signed by the end of the second period

- $V_o(n)$ is the utility of a producer if neither he nor any of his competitors reach an agreement with a good innovator

- $V_l(n)$ is the utility of a firm if one of the competitors reaches an agreement with a good innovator

- $\pi(n)$ is the profit of the producer if he reaches an agreement with a good innovator[5]

- Δ is the cost of late signing ($\Delta \leq \pi(n)$)

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

If the innovator is of the bad type, we suppose that the innovation does not generate any profits.

3.2 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.[6] We call each bilateral negotiation between the innovator and an individual producer a bargaining session. If bargaining breaks down with the current producer, the innovator starts a bargaining session with the next producer in the sequence.

As previously described, our model has two periods. The first period is characterized by asymmetric information, and the type of the innovator is revealed before the start of the second period. If bargaining is unsuccessful with all producers in the first period, the innovator must wait for the second period to start another sequence of negotiations. The order of bargaining is redrawn in the second period.[7] If all bargaining sessions fail in the second period, the players obtain their outside options. In each periods, the innovator cannot restart negotiations with a producer with whom bargaining previously broke down. Thus to summarize, each period involves at most n bargaining sessions, and the game overall $2n$ sessions.

We now describe the bargaining procedure inside a bargaining session. We suppose it occurs as in the alternating offer game with exogenous probability of breakdown introduced by Binmore et al. (1986). As in their paper, there is no discounting and the two players alternate making offers. If an offer is accepted, the game terminates. If it is rejected, the bargaining session breaks down exogenously with probability ϵ. If not, a new offer is made. Binmore et al. (1986) show that as the probability of

[4] For example, the innovation may be either a product or a process innovation, either incremental or drastic, etc.

[5] This is the reduced-form profit, i.e. net of any potential costs of development. In the application to pharmaceutical firms, it is the profit that can be made from the drug net of the cost of trials for the large pharmaceutical firms. If the biotechs conduct the testing there is an additional cost Δ of testing.

[6] Since producers are symmetric, the innovator sees all orderings as equivalent.

[7] We show in section 5 that imposing an identical order is identical across periods does not qualitatively affect our results.

breakdown converges to zero, the two parties split the surplus evenly.[8]

We introduce an additional assumption. We suppose that with the same probability ϵ, a bargaining session does not even start. The consequences of this assumption can be illustrated in the following example: with probability $\epsilon^{n-1}(1-\epsilon)$ the innovator will start a bargaining session with the last producer in the sequence without having started sessions with any of the previous producers. This assumption will prove essential to limit the multiplicity of equilibria, as discussed in section 4.[9]

Finally, we make the following assumptions relative to information. 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 offers that were made and do not even know if the session ever started with that producer. However, we suppose all players know the exact sequence of bargaining: they know their position k in that sequence and the overall number of producers n.

3.3 Discussion of the bargaining model

The bargaining model is the central component of our study, so here we further motivate our assumptions and examine more thoroughly the links with the literature. A number of features of bargaining appear essential for our particular application. First, we need a mechanism where the market structure, the number of potential buyers, influences the outcome of bargaining. Second, we concentrate on exclusive licenses. In other sectors, such as information technology, licenses are often non-exclusive and apply to intermediate inputs; they are often a response to so-called patent thickets and involve cross-licensing. In contrast, licensing the pharmaceutical sector typically involve the transfer of a single compound to a particular firm (in our data, more than 85% of the licenses are exclusive).[10] Third, we need to assume that the innovator holds private information regarding the quality of her invention.[11] The model we propose incorporates all these features in a very tractable way.

First, the sequential nature of negotiations captures the influence of n on the bargaining power of the innovator.[12] 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 could make take-it-or-leave-it offers or run an auction, n would not influence the bargaining power of the innovator.[13] Note also that if the buyers made simultaneous offers to the innovator, competition between them would leave them with no rents, independently of their number (as long as $n \geq 2$).

Moreover, this model of sequential bargaining seems to correspond to the way negotiations are

[8]We insist on the following technical point. It is important that all bargaining sessions take a finite amount of time so that potentially all n sessions can take place before the end of period 1. As pointed out by Stole and Zwiebel (1996), "one can think of alternating offers being made at times $t, t+\frac{1}{2}, t+\frac{2}{3}, ..., t+\frac{k-1}{k}$ to ensure that each bargaining session ends with probability 1 in one unit of time".

[9]In particular, it becomes essential combined with the information structure presented below. In particular, even in an equilibrium where the third producer in the sequence signs with the innovator if negotiations start, the fourth producer can still be reached on the equilibrium path.

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

[11]We show in section 5 that with symmetric information there is no deviation from the optimal timing.

[12]Note that n also has a direct influence on the profits of the innovator.

[13]For a take it or leave it offer, the innovator would extract the full surplus regardless of n. In an auction, as long as $n > 2$ and for bidders with the same valuation, the innovator would also extract the full surplus. The effect of n could be obtained for an auction where each producer would draw a random value for the innovation.

conducted in the pharmaceutical industry, which typically involve an exclusive period during which the licensor may not hold discussions with any other potential licensee. 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)

This type of sequential negotiations model is related to Stole and Zwiebel (1996), who examine bargaining over labor inputs.[14] Recent applications of this approach include Smith and Thanassoulis (2007), who studies 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.

The second key feature of our model is that licenses are exclusive. This is an important difference with the previously mentioned literature. For instance, in Stole and Zwiebel (1996), the firm 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.[15] As we previously emphasized, most contracts in our dataset are exclusive licenses.

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 offers 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-off: delay the sale to screen the different buyer types or sell earlier at a lower price.[16]

We differ 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 offer model of Binmore et al. (1986). Without such discounting, the trade-off previously mentioned is not relevant. This allows us to characterize the way private information interacts with market structure and thus to describe precisely the factors that influence the timing of licensing.[17] Building on the previous literature, Inderst (2008) and Fuchs and Skrzypacz (2008) examine the impact of the random arrival of new buyers. The set of potential buyers is well known in our application, and we examine how its size influences the timing of bargaining.

[14]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.

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

[16]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.

[17]In particular, we can limit the multiplicity of equilibria.

4 The timing of licensing

4.1 The bargaining game

4.1.1 Bargaining in the second period

To examine the determinants of the timing of licensing, it is necessary to start by studying bargaining in the second period. If the type of the innovator is revealed to be bad, no license will be signed. We therefore concentrate on the case where the innovator is revealed to be of a good type. We denote $p_2(k)$ the price of a license in second period when there are k producers left in the sequence for possible negotiations. $p_1(k)$ is defined in a similar fashion for the first period.

Consider the bargaining game when there are k producers left with which the innovator has not yet negotiated. 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 payoffs following breakdown. Note that these payoffs in case of breakdown are determined by the outcome of the remaining negotiations. This determines the following recursive relationship for $k > 1$, under the assumption that both players expect a deal to be signed between the innovator and the next producer in the sequence if their own negotiation fails:

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

If the negotiation is successful, the innovator obtains the price of the license $p_2(k)$ and the producer is guaranteed $\pi - \Delta - p_2(k)$. If the negotiations break down, the innovator can expect the price $p_2(k-1)$ from negotiating with the next producer in the sequence while the producer obtains profits V_l (the profits of a producer if a license is signed by one of his competitors). This reasoning depends on the expectation that bargaining will succeed with the next producer, so we therefore need to establish the conditions that guarantee that bargaining is successful at each round.

PROPOSITION 1:

- *If* $\pi - \Delta - V_o \geq \kappa$, *an agreement is reached with the first producer in the sequence at price* $p_2(n) = (\frac{1}{2})^n(\kappa + V_l - V_o) + (1 - (\frac{1}{2})^n)(\pi - \Delta - V_l)$
- *If* $\pi - \Delta - V_o < \kappa$, *no agreement will be reached.*

PROOF. *See Appendix*

Let us first examine the second part of Proposition 1. It is easy to see that when $\pi - \Delta - V_o < \kappa$, no agreement can be reached between the last producer and the innovator. The producer expects profits $\pi - \Delta$ from signing a license and V_0 if no agreement is reached, while the innovator can guarantee herself benefits of κ. The aggregate surplus from signing a license, $\pi - \Delta$, is lower than the aggregate surplus with no license, $\kappa + V_o$, so no agreement can be reached at the last round. If bargaining fails with the last producer, the one before last effectively plays the same role as the last. Thus, no agreement can be reached with any of the producers if this condition holds.

The first part of Proposition 1 states that if a license is ultimately signed, it will be signed with the first producer in the sequence. All but the last producer in the sequence expect profits $\pi - \Delta$ from signing a license and V_l if no agreement is reached, since they know that a competitor will subsequently sign a license if they do not. As $V_o \geq V_l$, the aggregate surplus from signing a license is greater with producers who precede the last one in the sequence. As long as an agreement creates surplus, negotiations will succeed. Hence, the first producer in the sequence in the second period signs a license. Furthermore, the price is increasing with the number k of producers left in the sequence with which the innovator has not yet negotiated. This result is quite intuitive: k influences the innovator's outside option.

For the rest of the paper, to make our arguments interesting, we make the following assumption to guarantee that a license will be signed either in the first or the second period:

ASSUMPTION 1: $\pi - \Delta - V_o > \kappa$.

4.1.2 Bargaining in the first period

In the first period, the information asymmetry between the innovator and the producers complicates bargaining. We will 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.[18]

To understand the mechanics of the negotiation, it is useful to consider the last round of bargaining and the first offer made by the innovator. Under Assumption 1, all players know that bargaining will ultimately succeed in the second period if the innovator is a good type. Therefore, a good type innovator will never offer a price less than $p_2(n)$, as she can guarantee herself this price in the second period. A bad type innovator wants to mimic the good type, and thus requests the same price. If the producer accepts the offer, his expected utility is $q\pi + (1-q)V_o$. However, he can always guarantee himself his outside option if bargaining fails. His expected benefits following a failure are $q[\frac{1}{n}(\pi - \Delta - p_2(n)) + \frac{n-1}{n}V_l] + (1-q)V_o$. If he waits until the second period, he knows that a contract will be signed with the first producer in the random sequence, at a price of $p_2(n)$. He has a probability $\frac{1}{n}$ of being the first and obtaining profits $\pi - \Delta - p_2(n)$. However, with probability $\frac{n-1}{n}$ one of his competitors is the first in the sequence and he therefore obtains benefits V_l. The following proposition is based on this reasoning.

PROPOSITION 2: *In all PBNE, bargaining succeeds in the first period if and only if the following condition is satisfied:*

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

PROOF. *See Appendix*

If this condition is satisfied, the optimal timing of licensing is achieved: technology transfer takes place in the first period and the more efficient producer develops the innovation. However, if either the probability of facing a good type q or the cost from signing late Δ decreases, late (and inefficient) signature is more likely. We revisit this condition in the next section, when we examine the relationship between market structure and the timing. It is important to point out that though there is a large multiplicity of PBNE, all share this property.

We emphasize one particular assumption that we make in the model to limit the multiplicity of equilibria. We assume that before the start of each individual bargaining session, there is an exogenous

[18]We examine in section 5.1 the case of uncertainty when the innovator and the producers have the same information. In that case, the socially optimal timing is always achieved.

risk of breakdown with probability ε. Therefore, regardless of the equilibrium that we consider, starting negotiations with any producer in the sequence is always on the equilibrium path.[19] Thus, in all equilibria, all producers start negotiating with the same belief q that the innovator is of a good type. They do not update their beliefs based on the fact that the innovator comes to negotiate with them. In other words, they do not interpret this fact as an endogenous breakdown of prior negotiations that might reveal information about the type of the innovator. Therefore as previously suggested, the condition of Proposition 2 guarantees that the last producer in the sequence signs in period 1, given that he holds beliefs q that the innovator is of a good type.

4.2 The effect of market structure

As we have previously observed, the number of producers in the market influences both the bargaining power of each player and the profits of the producers. If the profits of the players (π,V_o...) do not depend on the number n of producers on the market, an increase in n unambiguously increases the price of the license in the second period. Indeed, an increase in n increases the bargaining power of the innovator. When the innovator negotiates with the first producer, she can extract a larger share of the surplus as her outside option is now larger. However, the profits of the players on the market will typically decrease with the number of players, in other words with competition. This creates a countervailing effect on the price of the license in the second period. The innovator captures a larger slice of the pie, but this pie is now smaller. The overall effect of n on the price of a license signed in second period is ambiguous. We consider two examples in order to understand the subtlety of the effects.[20]

4.2.1 Payoffs do not depend on n

We begin with the case where the payoffs (κ, V_l, V_0, π) do not depend on n. This case highlights the effect of n, the number of firms in the downstream market, on the bargaining power of the producers and the innovator. Note that according to our results in Section 4.1, in this particular case, the price of the license in the second period $p_2(n)$ increases with n. The following proposition states that the effect of n on the timing of licensing is also unambiguous in this case.

PROPOSITION 3: If the payoffs on the market do not depend on n, the probability of signing in the first period decreases with n.

PROOF. *See Appendix*

We show in the Appendix that if q is low or κ large, it may not be possible to sign in the first period irrespective of Δ. Otherwise, early signature occurs in equilibrium when Δ is relatively large.

[19] 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. The fourth player might still negotiate in equilibrium with probability ϵ if negotiations do not even start with the third player.

[20] We can consider first a benchmark where the innovator has all bargaining power. Assume for instance that all negotiation sessions happen simultaneously: in that case, perfect competition among the producers drives their surplus to their outside option as soon as $n \geq 2$. In an equilibrium with signature in the second period, the price would then be $p_2 = \pi(n) - \Delta - V_l(n)$. If an equilibrium with signature in the first period exists, perfect competition between the buyers necessarily drives the price to $p_1 = q\pi(n) - V_l(n)$ which leaves each producer indifferent between signing and not signing in the first period. No producer deviates from that price as another buyer would then sign the licence, and the innovator signs a licence in the first period as soon as $\Delta \geq (1-q)\pi(n)$. This condition depends on n and shows that, even without any effect of n on the bargaining power of the firms, as the industry profit decreases in n and we model a fixed cost Δ, the condition for early signature becomes less stringent when n increases.

To understand the influence of n on the timing of signature, 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.[21] The good type innovator has an incentive to wait to sign a license.
- As n increases, a producer's expected profits 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 illustrate, we focus again 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: $\pi_2(n) = \frac{q}{n}(\pi - \Delta - p_2(n) + (n-1)V_l) + (1-q)V_o$. The marginal effect of n on this expression is summarized in the following expression.

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

The first term reflects the increase in the expected price paid in the second period caused by an increase in n. This affects the producer with probability $\frac{q}{n}$ (the probability of being first in the sequence for negotiation times probability of facing a good type). 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.

The second term corresponds to the decrease in the recognition probability, or the probability that the producer will be the first in the sequence for negotiation with the innovator, associated with an increase in n. The marginal effect of an increase in n on the recognition probability is of order $\frac{1}{n^2}$, whereas the marginal effect of n on $p_2(n)$ is of first order.[22]

Overall, if the payoffs on the product market do not depend on the number of producers, an increase in competition will delay the signature of the license. This contrasts with the relationship illustrated in Figure 1, showing increasingly late contracting in the pharmaceutical industry despite consolidation during this period. We therefore must account for the fact that the market structure will also impact the profits the producers can expect on the product market.

4.2.2 Payoffs depend on n

We now consider a model where the number of players influences the profits on the product market. Each producer owns a symmetric plant in a Cournot market, producing a homogeneous good at

[21] Note that $p_2(n)$ converges to $\pi - \Delta - V_l$ 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.

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

constant identical marginal cost. The initial profits on the product market are $V_o = \pi_n$. Signing an innovation licence results in the creation of a new plant that will compete with the existing ones, as in the "decentralized game" studied by Kamien and Zang (1990). The licensing producer becomes the owner of a trust that comprises two among the $n+1$ active plants, and he receives the sum of the profits from the two competing plants: $\pi = 2\pi_{n+1}$. The other downstream firms face a new entrant and receive $V_l = \pi_{n+1}$. We also assume that the innovator's outside option is $\kappa = 0$. [23]

Assumption 1 requires that

$$\Delta \leq 2\pi_{n+1} - \pi_n$$

As $\pi_{n+1} \leq \pi_n$, this implies also that $\Delta \leq \pi_{n+1}$ which means that a successful innovation does not imply negative profits or exit of some competitors in period 2. As long as $n \geq 2$, keeping the two plants (among at least three) in competition brings about a larger profit to their owner than coordinating their quantity choices ($2\pi_{n+1} > \pi_n$). Another interpretation of this model is the launching of a new product in a market for n horizontally differentiated products, where the producers of the goods compete in prices. In that case, however, the assumption that the licensing producer does not coordinate the decisions of his two plants is limiting, as allowing coordination of these decisions would increase his total profit. It would also relax overall competition and increase the profits of all producers. For simplicity here, we restrict our analysis to the Cournot game.

Proposition 1 states that in the second period the innovator would sign with the first producer to negotiate for a price:

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

LEMMA 1: *The price $p_2(n)$ paid to the innovator in the second period decreases in n for sufficiently competitive industries. However, for initially concentrated industries, $p_2(n)$ may increase in n.*

PROOF: *Both π_{n+1} and π_n decrease in n, with $\pi_n \geq \pi_{n+1}$, so that for small values of n the balance of the positive effect of the increase in $-(\frac{1}{2})^n(\pi_n - \Delta)$ (effect on the innovator bargaining power) and the negative effect of the decrease in π_{n+1} is ambiguous; however the second effect is of order $\frac{1}{2^n}$ and is dominated by the first for n large enough.*

For Cournot competition with zero marginal costs, $\pi_n = \frac{1}{(n+1)^2}$, and the second effect dominates: $p_2(n)$ decreases in n for $n \geq 2$.$\square$

We now consider the negotiations in the first period and interpret the condition obtained in Proposition 2.

PROPOSITION 4: *When downstream competition influences the payoffs, an increase in competition has an ambiguous effect on the timing of licensing.*

The incentives to sign early may first decrease with n for very concentrated industries, but there exists a number of firms above which an increase in competition strengthens these incentives.

PROOF: The condition given in Proposition 2 for a successful negotiation in the first period can be rewritten:

[23] Alternatively, the innovator's outside option may to be commercialize the product herself, in which case $\kappa > 0$.

$$\frac{q}{n}\Delta \geq \underbrace{p_2(n)(1-\frac{q}{n})}_{(i)} - \underbrace{q(1-\frac{1}{n})\pi_{n+1}}_{(ii)}$$

The left term $\frac{p}{n}\Delta$ is the cost of signing in the second period multiplied by the probability of being first in the sequence of negotiations with a good type innovator.

The first term (i) on the right side is the overall impact of the price in the second period (including its effect on the outside option of the innovator). It decreases with n for $n \geq 3$, but may increase with n for $n \leq 3$.

The second term (ii) illustrates the difference of the expected profit of the downstream firm (before the payment to the innovator, and net of Δ) between the first and the second periods: it translates the decrease of the probability of being the first to bargain in the second period with n. Term (ii) is positive and decreases with n for $n \geq 2$.

The probability of recognition effect (ii) is dominated by the price effect (i). This expression can be rewritten:

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

On the left side, coefficient $(1-\frac{1}{2^n}(1-\frac{q}{n}))$ increases in n. On the right side, both $(1-q)\pi_{n+1}$ and $\frac{1}{2^n}(1-\frac{q}{n})\pi_n$ decrease in n (the former strictly if $q<1$), but the second term in $(\frac{1}{2^n})$ goes to zero at a much steeper rate than the first. As a consequence, the right term is likely to decrease in n for large values of n, although it may increase for small values of n.$\square$

The results of this section show that while introducing some competition in a very concentrated market may postpone the signature, further increasing competition will increase the incentives for early signature in a very competitive market. The critical factor underlying this finding is that effect of n on the second period price $p_2(n)$ is negative when n is large enough.

4.3 The role of asymmetric information

Gans et al. (2008), in a different 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 this section 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, an agreement is reached if and only if $\pi - \Delta - V_o \geq \kappa$. However, in the first period, the innovator is now uncertain about the quality of her invention. The condition of Proposition 2 is modified and an agreement is reached in the first period if and only if:

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

We can show that, if an agreement can be reached in the second period (i.e if $\pi - \Delta - V_o \geq \kappa$) then an agreement will be reached in the first period. Moreover, this is satisfied independently of the degree of uncertainty q and of the market structure 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 are more efficient than the innovator). However, in the first period, the price accounts for the uncertainty about quality. An agreement will therefore be reached only if the expected surplus is positive. This is the case here, since the surplus generated by a bad type is zero.[24]

With uncertainty and symmetric information, the license will be signed at the socially optimal time. Importantly, the number of producers n does not influence the timing in this case. Thus, if the assumption of asymmetric information is incorrect, we would expect to find no relationship between license timing and market structure in our empirical analysis below.

5 Robustness and Extensions

In this section, we consider a number of extensions of our model to examine the robustness of our results under different assumptions about contracts and bargaining.

5.1 Milestone payments

We previously limited the analysis to contracts that involved a single up-front payment for the innovation. In practice, of course, most licensing contracts are more sophisticated and employ milestone payments and/or royalties to mitigate the problem of asymmetric information. We therefore extend our model as follows. In the first period, the producer can offer the a contract with total price $p_1 = p_{11} + p_{12}$, where p_{11} is paid in the first period and a milestone payment p_{12} is paid in the second period only if the innovator is revealed to be of a good type.

Milestone payments remove part of the uncertainty of contracting. For a given transfer p_1 such that $sp_1 = p_{11}$ and $(1-s)p_1 = p_{12}$, the expected profit of the producer if he signs in the first period is now $q(\pi + \Delta - (1-s)p_1) - sp_1 \geq q(\pi + \Delta) - p_1$. The producer chooses the minimum possible s to reduce the cost of uncertainty. However, we assume the innovator is liquidity constrained and requires a positive part of the final price to be paid in the first period. Her participation constraint is $\frac{p_{11}}{p_1} \geq \delta$ where $0 \leq \delta \leq 1$. The innovator and producer will therefore agree on a timing of the payment such that $s = \delta$ and the innovator's participation constraint binds.

Any second period negotiation is unaffected: an agreement can be reached with the first producer in the sequence iff $\pi - V_0 \geq \kappa$ and the price they agree on is $p_2(n) = (\frac{1}{2})^n(\kappa + V_l - V_0) + (1 - (\frac{1}{2})^n)(\pi - V_l)$.

Consider now bargaining in the first period. In 9, we show that signature occurs in the first period in equilibrium iff $\Delta > \underline{\Delta}^{TP}$ with:

$$\underline{\Delta}^{TP} = \frac{(1-q)(\pi - V_l)\delta}{q} + \frac{1}{2^n}\frac{(\pi - \kappa - 2V_l + V_0)(q - nq(1-\delta) - n\delta)}{nq}$$

[24]Note that the result might be different if the surplus was negative for a bad type.

5.1.1 No liquidity constraint: $\delta = 0$

If the innovator has no liquidity constraint (i.e. $\delta = 0$), conditioning milestone payments on the type of innovator removes the adverse selection problem completely and the contract has no up-front payment in the first period. Furthermore, we can show that all contracts are signed immediately. The producer prefers to sign early and obtain the extra benefits Δ, while the good type innovator gains nothing by waiting.

PROPOSITION 5: *When $\delta = 0$ all contracts are signed in the first period, regardless of competition.*

PROOF: *The condition for signing in the first period becomes $\Delta > \frac{1}{2^n}\frac{(2V_l - V_0 - \pi + \kappa)(n-1)}{n}$. This is always satisfied since the right hand side is negative.*

5.1.2 Liquidity constraint: $\delta > 0$

When a liquidity constraint exists, removing the adverse selection problem with a pure milestone payment is no longer possible. It is therefore intuitive that the incentives to sign in the first period decrease in δ. We consider in the next proposition the effect of competition.

PROPOSITION 6: *When contracts include both up-front and milestone payments and when payoffs do not depend on n, and increase in n delays licensing. This effect increases with δ.*

PROOF: *See Appendix.*

As in Proposition 3, competition delays licensing when payoffs in the product market are independent of n. The second part of the proposition indicates that allowing for milestone payments favors efficient early signature of the license. Furthermore, the smaller the liquidity constraint, the easier it is to include such payments. Note that this result also extends to the case where profits depend on n.

5.2 Fixed order of bargaining

We previously assumed that the sequence of producers for negotiating with the innovator was redrawn in the second period. We now consider the case where the order of bargaining is identical in both periods. This change introduces an asymmetry among the producers, as the first producer to bargain in the first period now has an outside option that differs from his competitors. If all negotiations fail in the first period, the first producer is the only one to have another chance of success in the second period. This change in the assumed sequence does not affect the results of the second period, but we need to reconsider the results of negotiations in the first.

PROPOSITION 7: *If the order of bargaining is the same in both periods, the following condition guarantees signature in the first period. This condition is easier to satisfy than in the case with random* *ordering.*

$$q\pi > qV_l + p_2(n) \ (FO)$$

Proof: *see Appendix.*

Paradoxically, if the order of bargaining is the same in the two periods, the bargaining power of the first producer decreases. At first glance, the first producer to negotiate in the first period may seem to benefit from higher bargaining power. However, if he fails in his negotiation in the first period, all other producers know that they have no chance of appearing first in the sequence of bargaining in the second period, and thus buying the license is impossible. This reduces their outside option from $q[\frac{1}{n}(\pi - \Delta - p_2(n)) + \frac{n-1}{n}V_l] + (1-q)V_o$ to $qV_l + (1-q)V_o$. Following a breakdown in negotiations between the innovator and the first producer, the producer to negotiate is willing to pay a higher price to the innovator. As a consequence, the innovator's outside option actually *increases* in his negotiation with the first producer. This explains why it is easier to achieve early efficient contracting when the order is fixed.

5.3 Low type with valuable idea

In section 3, the we assumed the bad type innovator yielded an invention of no value. Here, we relax this assumption and instead suppose the low type innovator yields an invention that generates strictly positive profits. Specifically, if the technology transfer occurs in the first period, the value of the invention is π_L for the low type π_H for the high type. If the transfer occurs in the second period, it is π_L for the low type and π_H for the high type. Furthermore we assume that $\pi - \Delta - V_o \geq \kappa$ such 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 simplifies the calculations without affecting 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 8: *All PBNE have the following properties:*

(1) The low type signs in the first period.

(2) If $q\pi_H - \frac{q}{n}[\pi_H - \Delta + (n-1)V_l] > p_2^H(1-\frac{q}{n}) - (1-q)p_2^L$*, then the high type also signs in the first period*

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

Proof: *see Appendix.*

It is intuitive that there will never exist a separating equilibrium where the low type signs in the second period. If the high type signs the contract in the first period, the low type will mimic her to obtain the higher payment and the extra benefit from early signing. However, result (3) indicates that a separating equilibrium may exist where the high type signs in the second period.

6 Empirical analysis

6.1 Background on the pharmaceutical industry

Drug development is an expensive and lengthy process. The process of drug development involves many distinct phases, illustrated in Figure X. Costs increase significantly 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.

Licensing products from biotech firms to large pharma firms has increased as the number of biotech firms has grown. In general, the licensee acquires a drug candidate in a disease area in which the licensee has existing strength or experience; licensing fills its pipeline and exploits its relationships with medical practitioners who participate in running clinical trials or prescribe drugs (Levine, 2007). Licensing between large pharma firms also occurs; one firm may have superior marketing skills in a particular disease area, for example. Superior skills correspond to Δ in our theoretical model, and would apply to any pair of firms with a difference in productive efficiency in different stages.

In section 2, we described some efforts 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. Most licensing contracts include terms that mitigate problems of asymmetric information, such as milestone payments. The problems of asymmetric information are discussed at length in an article in *Nature Biotechnology* targeted at entrepreneurs in the life sciences, in which the authors explain: "A potential buyer will ask: Why does the bioentrepreneur want to sell the drug? There may be very good reasons, such as difficulty with financing the next stage of development, but one possible reason is that the drug is a 'lemon'. The potential buyer won't know. The bioentrepreneur, however, has privileged information about the product, just like the used-car seller, and may well have good reasons to suspect it to be a lemon. Knowing this, the buyer will offer a lower price to compensate for the risk of buying a carefully disguised lemon. If the drug is really good, the owner will not accept this lower price and will try to find other ways of financing it. Therefore, what is left in the market is mainly mediocre drugs, as is the situation with used cars." (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, the licensing firm 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. As well, it will be difficult for a licensor to convince a potential buyer that it has no such information, because even if it can demonstrate some positive findings, the licensee will always wonder what might not have been disclosed. However, 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.

6.2 Data

We draw our sample of licensing contracts from Recombinant Capital's rDNA database.[25] 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).[26] 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.

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.

Ideally, we would like additional measures of competition, such as the Herfindahl index, and market size for each therapeutic class over time. We have only limited information about market-level sales or profits, however. Also from IMS, we have worldwide sales in US dollars and the number of prescriptions written in each therapeutic class for 2005, a single cross-section. We hope to supplement this in the future.

Finally, we used a number of standard sources for firm-level information, such as Compustat, Osiris, and CorpTech. We identify whether each firm is public or private and some financial data, where possible.

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

[25]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.

[26]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."

technology platform.[27] 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 resulted in 2,389 matches. We had the least success in matching deals with a missing stage at signing and very early stage deals, and are continuing these efforts.

Table 1 provides summary statistics for the key variables in our analysis. [28] 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.

6.3 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. One obvious 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 II clinical trials. 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 development stage is completed. We can think of the trade-off 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 firm's innovation as "at risk" for licensing from the time the drug

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

[28] 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.

candidate reaches the preclinical stage of development, and examine what factors affect 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. Future analysis will include other hazard models, such as the Cox model with time-varying covariates.

The logit and ordered logit approaches have a number of appealing features. They correspond very closely to our theoretical model, where the two periods differ in the information available to the potential buyers. As a drug candidate progresses through each stage, verifiable 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 firm-level characteristics (like liquidity constraints or experience) that may change over time and affect 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 different points in time, to identify the effect of market structure. While this is our primary interest, we include a number of controls that might also affect licensing behavior. These include the extent to which a biotech firm faces capital constraints, and various other factors such as experience in licensing (measured as the number of previous licenses the biotech firm has granted), experience in drug development (measured as the number of drug candidates the licensing firm has previously initiated), and market experience (measured as the number of drugs the licensing firm has successfully launched). In particular, if liquidity constraints are binding, our model predicts a smaller effect of market structure. Similarly, if the severity of asymmetric information is limited, we do not expect competition to influence the timing of licensing. Thus, we examine different subsets of the data in which asymmetric information and liquidity constraints are likely to vary in importance, and test whether the effect of competition differs across these subsets.

7 Results

As noted above, our model predicts that the effect of competition is strongest in the presence of high information asymmetries and low liquidity constraints. In these cases, the licensor has the greatest incentive to wait. At present, we have limited information on liquidity constraints (though we hope to use data on venture capital funding and other financial information in the future). We therefore estimate our two empirical specifications on three samples: the full sample, a subset for which we expect asymmetric information to be high, and a subset for which asymmetric information may be less severe.

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.

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. Delay 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 zero (for market and development experience) and the mean (for market size). 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 57.

Interestingly, our results 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. We interpret this finding 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.

Other coefficients also have signs consistent with our theory. For example, the positive coefficient on licensor experience may be related to a reduction in the relative productive efficiency of the licensee, i.e. a smaller Δ, which would tend to delay licensing. For a given number of competitors, a larger market may correspond to higher profits, another factor that delays signature; we find a positive coefficient on market size in some specifications.

Of course, there are many qualifications to our results. At this stage, we have only a limited number of explanatory variables, particularly firm-level financial information. However, it is important to note that these omissions do not necessarily bias our results. Our hope is that this additional information will allow us to refine our analysis, and eventually to test additional predictions of the model.

8 Conclusion

This paper considers factors that may affect 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 effect of competition and other variables on the timing of licensing. A particularly interesting prediction is that if downstream profits decline with the number of competitors, the effect 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 find 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.

We continue to refine and extend both the theory and empirical sections of this work. However, our preliminary results suggest that the effect of competition on the timing of licensing is subtle but potentially quite important. Further consolidation in the industry could either accelerate or decelerate licensing, depending on the current level of competition. This effect should be considered in the analysis of proposed mergers. In addition, increased delay in licensing could raise the total costs of drug development. This has important consequences for the productivity of research and development and incentives to invest in innovation.

9 Appendix

9.1 Proof of Proposition 1:

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

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

A license will be granted in the last round if and only if $p_2(1) \geq 0 \Leftrightarrow \pi - \Delta - V_0 - \kappa \geq 0$

The condition guaranteeing that a license is signed with the last producer is therefore:

$$\pi - \Delta - V_0 \geq \kappa \quad (3)$$

Suppose a license is granted at a price $p_2(k-1)$ when there are $k-1$ left in the sequence of negotiations. As ϵ converges to zero, the price in the previous round of bargaining, when there are k producers left is also determined by an equal split of the surplus. Furthermore the disagreements points converge to p_2^{k-1} for the innovator and V_l for the producer[29]:

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

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

Solving the recursive equation, we find:

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

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

$$\pi - \Delta + V_0 - 2V_l \geq \kappa \quad (4)$$

It is important to note that this is also the condition that guarantees that p_2^k is increasing in k.

Because $V_o > V_l$, we have $\pi - \Delta - V_0 < \pi - \Delta + V_0 - 2V_l$. Therefore, if an agreement can be reached with the last bargainer, it will be reached with the first one at a price $p_2(n)$.

We now prove the second part of Proposition 1. If $\pi - \Delta - V_0 < \kappa$, we have seen at the beginning of the proof that the negotiation will fail with the last bargainer. Consider the negotiation between the

[29] 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.

innovator and the $n-1$th producer. If the bargaining fails, the innovator knows that she will obtain her outside option κ and the producer knows he will obtain V_0. The problem is identical to the one faced by the last producer and we can therefore conclude that licensing will also fail. We can thus show recursively that if $\pi - \Delta - V_0 < \kappa$ no agreement can be reached.

9.2 Proof of Proposition 2

Step 1: If the condition of Proposition 2 is satisfied 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 first bargaining session in period 1. Consider a round where the producer makes an offer. If he offers a price $p' > p_2(n)$ this offer 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. With this offer, the utility of the producer is $q\pi - p'$. In the current equilibrium, his expected utility is $q[\frac{1}{n}(\pi - \Delta - p_2(n)) + \frac{n-1}{n}V_l]$. The condition given in Proposition 2 guarantees that such an offer 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 satisfied, the bargaining will succeed in period 1.

Step 2: If the condition of Proposition 2 is not satisfied then the bargaining must succeed in period 1.

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 offer. A good type will always offer a price $p_t \geq p_2(n)$ as she knows she can guarantee herself at least $p_2(n)$ by waiting for period 2. The bad type will always mimic the behavior of a good type. If she reveals her type, no offer will be accepted or made to her.

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

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

Furthermore, he knows that all offers lower than $p_2(n)$ will be rejected by the good type innovator and might be accepted by the low type. Such an offer will never be made in equilibrium. So if $q'\pi - q'[\frac{1}{n}(\pi - \Delta - p_2(n)) + \frac{n-1}{n}V_l] < p_2(n)$ no equilibrium offer 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 ϵ before each session, a session of negotiation 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 satisfied, 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:

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

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

We can reexpress the condition of Proposition 2 that guarantees that the license is signed in period 1:

$$\begin{aligned} q\pi - q[\frac{1}{n}(\pi - \Delta - p_2(n)) + \frac{n-1}{n}V_l] &\geq p_2(n) \\ &\Leftrightarrow \Delta \geq \underline{\Delta} \\ \text{where } \underline{\Delta} &= (\pi - 2V_l + V_o - \kappa) + \frac{(\pi - V_l)(1-q) - \pi + 2V_l - V_o + \kappa}{(1 - (1 - \frac{q}{n})\frac{1}{2^n})} \end{aligned}$$

As $(1 - (1 - \frac{q}{n})\frac{1}{2^n})$ is positive for all q in [0,1] and all n, this condition is incompatible with Assumption 1 as soon as $(\pi - V_l)(1-q) - \pi + 2V_l - V_o + \kappa \geq 0$, *i.e.* for small values of q or for large κ. In that case, signature in period 1 is never an equilibrium outcome. The number of producers n does not affect the outcome.

On the contrary, if $(\pi - V_l)(1-q) - \pi + 2V_l - V_o + \kappa \leq 0$, signature in period 1 is the equilibrium outcome for all Δ in the interval $[\underline{\Delta}, \pi - 2V_l + V_o - \kappa]$, whereas signature in period 2 occurs for $\Delta \leq \underline{\Delta}$.

Consider the role of n on these intervals. When $(\pi - V_l)(1-q) - \pi + 2V_l - V_o + \kappa \leq 0$, as $(1 - (1 - \frac{q}{n})\frac{1}{2^n})$ increases in n, $\underline{\Delta}$ increases in n and the interval $[\underline{\Delta}, \pi - 2V_l + V_o - \kappa]$ where signature in period 1 is the equilibrium outcome shrinks with n. An increase in competition thus makes contracting in the first period more difficult.

9.4 Two-part tariffs

Consider negotiations in stage 1. If the innovator has only one producer left to negotiate with in the first period, the price will now be determined by:

$$p_1(1) - p_2(n) = q(\pi + \Delta - (1-\delta)p_1(1)) - \delta p_1(1) - q[\tfrac{1}{n}(\pi - p_2(n)) + \tfrac{n-1}{n}V_l]$$

Thus

$$p_1(1) = \frac{1}{1+\delta+q(1-\delta)}[(1+\frac{q}{n})p_2(n) - \frac{q}{n}(\pi - V_l) + q(\pi + \Delta - V_l)]$$

The bargaining in stage 1 will succeed if and only if

$$\begin{aligned} p_2(n) \quad &< \quad \frac{q[(\pi - V_l)(n-1) + n\Delta]}{n(\delta + q(1-\delta)) - q} \\ \iff \quad \Delta > &\frac{(1-q)(\pi - V_l)\delta}{q} + \frac{1}{2^n}\frac{(\pi - \kappa - 2V_l + V_0)(q - nq(1-\delta) - n\delta)}{nq} \quad (i) \end{aligned}$$

As in section 3, we show that this condition is necessary for any negotiation to be successful in period 1 : if it is not satisfied for the last negotiation, then in the previous negotiation the firms anticipate that the lst negotiation will break, and their status-quo become similar to those of the last negotiating pair: this implies a breach in all previous negotiations. Besides, it is sufficient for the last negotiation of period 1 to be successful if it happens.

Consider now the previous negotiations. The producers' expected profit in case of a breach in negotiation with the innovator is qV_l. Therefore for $k \geq 2$, the recursive relation is given by:

$$p_1(k) - p_1(k-1) = q(\pi + \Delta - (1-\delta)p_1(k)) - \delta p_1(k) - qV_l$$

or

$$p_1(k) = \frac{p_1(k-1) + q(\pi + \Delta - V_l)}{1+\delta+q(1-\delta)}$$

The bargaining with the $n-k+1th$ producer will succeed if $p_1(k) \geq p_1(k-1)$, *i.e.* $p_1(k-1) \leq \frac{q(\pi+\Delta-V_l)}{(\delta+q(1-\delta))}$. If this negotiation succeeds it defines the following price:

$$p_1(k) = \frac{(1+\frac{q}{n})p_2(n) - \frac{q}{n}(\pi - V_l)}{(1+\delta+q(1-\delta))^k} + \frac{q(\pi+\Delta-V_l)}{\delta+q(1-\delta)}\left[1 - \frac{1}{(1+\delta+q(1-\delta))^k}\right]$$

A necessary condition for the innovator to sign with the first producer in period 1 is that $p_1(1) < \frac{q(\pi+\Delta-V_l)}{\delta+q(1-\delta)}$: the recursive relation implies that if $p_1(1) < \frac{q(\pi+\Delta-V_l)}{\delta+q(1-\delta)}$, then, by induction, for all $k \geq 1$, $p_1(k) < \frac{q(\pi+\Delta-V_l)}{\delta+q(1-\delta)}$ which is the fixed point of the recursive relation, and thus for all $k \geq 1$, $p_1(k) > p_1(k-1)$.

This condition is equivalent to $p_2(n) < \frac{q[(\pi-V_l)(n+q+\delta(1-q)+n\Delta]}{(n+q)(\delta+q(1-\delta))}$, or

$$\Longleftrightarrow \Delta > \frac{(1-q)(\pi-V_l)\delta}{q} - \frac{1}{2^n}\frac{(n+q)(\pi-\kappa-2V_l+V_0)(q(1-\delta)+\delta)}{nq} \quad (ii)$$

This condition is implied by (i) as we have assumed that $\pi-\kappa-2V_l+V_0 \geq 0$.

Therefore condition (i) is the necessary and sufficient condition for an equilibrium with signature in stage 1 to exist. In this equilibrium, the innovator reaches an agreement with the first producer to negotiate in period I.

9.5 Proof of proposition 6

$\frac{\partial \underline{\Delta}^{TP}}{\partial n} = \frac{(\pi-\kappa-2V_l+V_0)}{2^n}(-\ln 2\frac{p-np(1-\delta)-n\delta}{np} - \frac{1}{n^2})$ is of the same sign than $-np\ln 2 + n^2 p \ln 2(1-\delta) + n^2\delta\ln 2 - p \geq 0$.

$\frac{\partial^2 \underline{\Delta}^{TP}}{\partial\delta\partial n} = \frac{(\pi-\kappa-2V_l+V_0)}{2^n}(\ln 2\frac{1-p}{p}) \geq 0$

9.6 Fixed order of bargaining

The last producer in the sequence in period 1 is also the last in period 2. He therefore knows he will not obtain the license in period 2. If we examine the bargaining between the innovator and the last producer, the condition is now given by:

$$p_1(1) - p_2(n) = q\pi - p_1(1) - pV_l$$

Thus

$$p_1(1) = \frac{1}{2}[p_2(n) + q\pi - qV_l]$$

The bargaining will succeed if

$$q\pi - qV_l > p_2(n) \tag{5}$$

The same logic applies to all the producers except the first in the sequence. Therefore for $n > k \geq 2$, the recursive relation is given by:

$$p_1(k) - p_1(k-1) = q\pi - p_1(k) - qV_l$$

The bargaining with the $n-k+1th$ producer will succeed if:

$$q\pi - qV_l \geq p_1(k-1)$$

For the first producer to negotiate we need to consider two cases:

(1) the other producers will not sign in period 1 if the first negotiation breaks down. The problem can then be expressed in the following way

$$p_1(n) - p_2(n) = q\pi - p_1(n) - q[\pi - \Delta - p_2(n)]$$

This negotiation succeeds if

$$q\pi - q[\pi - \Delta - p_2(n)] > p_2(n) \tag{6}$$

We have $\pi - \Delta > V_l$ or the first producer would not sign in period 2. Thus

$$q\pi - qV_l > p_2(n) \tag{7}$$

We thus reach a contradiction: a license would be signed by the other producers in period 1.

(2) the other producers will sign in period 1 if this first negotiation breaks down. In this case, the recursive relationship applies for the first producer as well.

Therefore a sufficient condition for signature in period 1 is $q\pi - qV_l > p_2(n)$

9.7 Proof of proposition 8

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 profits 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 first period, when it is the producer's turn to make an offer, he can deviate by offering a price $p' = p_2^L + \epsilon$ with $0 < \epsilon < p_2^H - p_2^L$. This offer will be accepted by the low type and rejected by the high type. Furthermore, this deviation is profitable for the producer if $\epsilon < \Delta$: if the innovator is of high type, the payoffs are unchanged and if it is of low type, the payoffs are increased $\pi_L - p_2^L - \epsilon > \frac{1}{n}(\pi_L - p_2^L - \Delta) + \frac{n-1}{n}V_l$. 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 seperating 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 offer in period 1.

Step 3: Suppose the condition of result (2) is satisfied 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 offer in period 1. Suppose that in equilibrium the producer offers p_1. For the separarting equilibrium to exists it has to be such that $p_2^H > p_1 > p_2^L$

If the producer deviates and offers 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 $(1-q)[\pi_L - p_1] + q[\frac{1}{n}(\pi_H - \Delta - p_2^H) + \frac{n-1}{n}V_l]$

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

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

Step 4: If the condition of result (3) is satisfied, 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.

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Figure 1: Stage at licensing signing over time

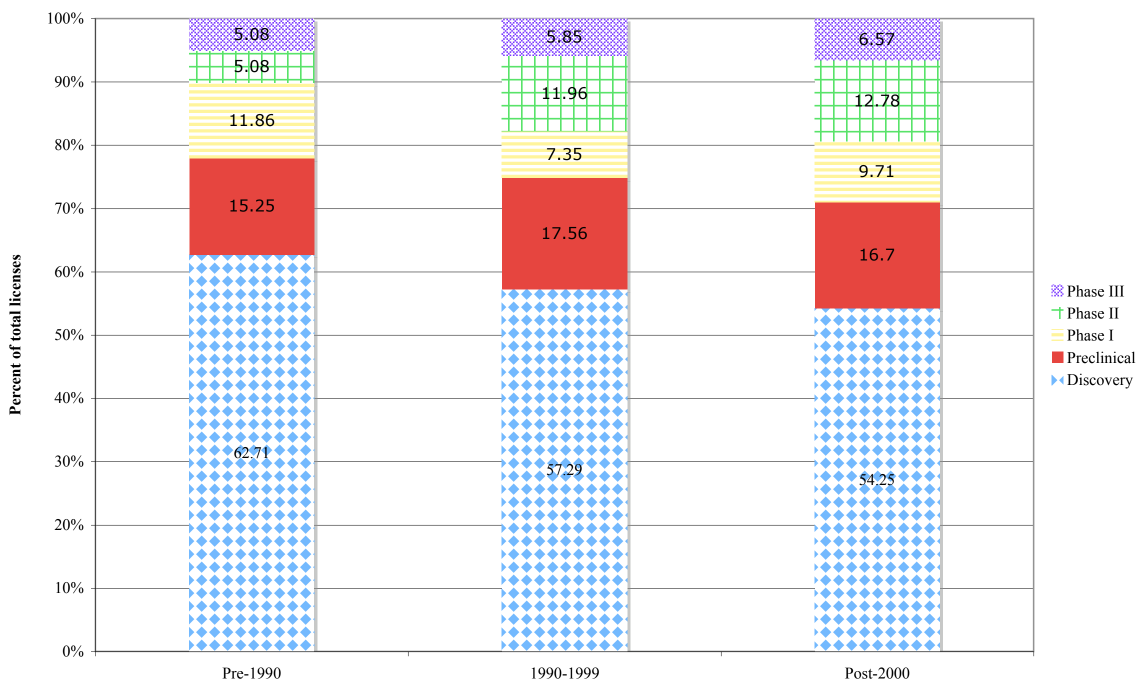

Table 1: Summary statistics

Variable	N	Mean	StdDev	Min	Max
Log(months since discovery)	1306	0.235	0.893	0	6.113
Firms in class	2263	37.066	32.241	1	140
Licensor market experience	2263	0.239	1.919	0	42
Licensor development experience	2263	1.204	3.389	0	54
Size of therapeutic class (US$)	2146	8.132	86.432	0	1946.47

Table 2: Logit of Y = 1 if signed in Phase I, II or III

Variable	Full sample	High asym.	Low asym.
Intercept	-1.1650**	-1.1412**	-1.4941**
	(0.1059)	(0.1115)	(0.3663)
Firms in class	0.0113**	0.0133**	0.0085
	(0.0048)	(0.0052)	(0.0147)
Firms in class squared	-0.0001**	-0.0001**	-0.0000
	(0.0000)	(0.0000)	(0.0001)
Licensor market experience	0.0109	0.0179	0.2022
	(0.0263)	(0.0292)	(0.1436)
Licensor development experience	-0.0136	-0.0377*	0.0539*
	(0.0161)	(0.0202)	(0.0326)
Size of therapeutic class	0.0003	0.0004	-0.0029
	(0.0005)	(0.0005)	(0.0049)
Number Obs	2146	1907	239
Log L	-1268.293	-1124.791	-135.5143

Table 3: Ordered logit of Y = stage at signing

Variable	Full sample	High asym.	Low asym.
Intercept	-0.4647**	-0.4447**	-0.6945**
	(0.0913)	(0.0961)	(0.3060)
Firms in class	0.0144**	0.0161**	0.0075
	(0.0041)	(0.0044)	(0.0126)
Firms in class squared	-0.0001**	-0.0001**	-0.0000
	(0.0000)	(0.0000)	(0.0001)
Licensor market experience	0.0021	0.0071	0.1275
	(0.0219)	(0.0229)	(0.1358)
Licensor development experience	-0.0013	-0.0153	0.0525*
	(0.0132)	(0.0153)	(0.0290)
Size of therapeutic class	0.0007*	0.0007*	0.0002
	(0.0004)	(0.0004)	(0.0013)
Limit2	0.7499**	0.7631**	0.6734**
	(0.0366)	(0.0391)	(0.1071)
Limit3	1.2597**	1.2726**	1.2108**
	(0.0489)	(0.0520)	(0.1481)
Limit4	2.4670**	2.4684**	2.5432**
	(0.0856)	(0.0904)	(0.2732)
Number Obs	2146	1907	239
Log L	-2748.123	-2447.388	-295.1347

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

Variable	Full sample	High asym.	Low asym.
Intercept	0.1245**	0.1110**	0.3186
	(0.0495)	(0.0501)	(0.1944)
Firms in class	0.0055**	0.0054**	0.0038
	(0.0024)	(0.0024)	(0.0087)
Firms in class squared	-0.0000**	-0.0000*	-0.0000
	(0.0000)	(0.0000)	(0.0001)
Licensor market experience	-0.0011	0.0038	0.0108
	(0.0131)	(0.0132)	(0.0844)
Licensor development experience	-0.0116	-0.0185**	0.0070
	(0.0081)	(0.0088)	(0.0217)
Size of therapeutic class	0.0019**	-0.0005	0.0032**
	(0.0006)	(0.0008)	(0.0009)
Number Obs	1226	1080	146
R^2	.015	.009	.092

Figure 2: Effect of competition on the probability of late signature

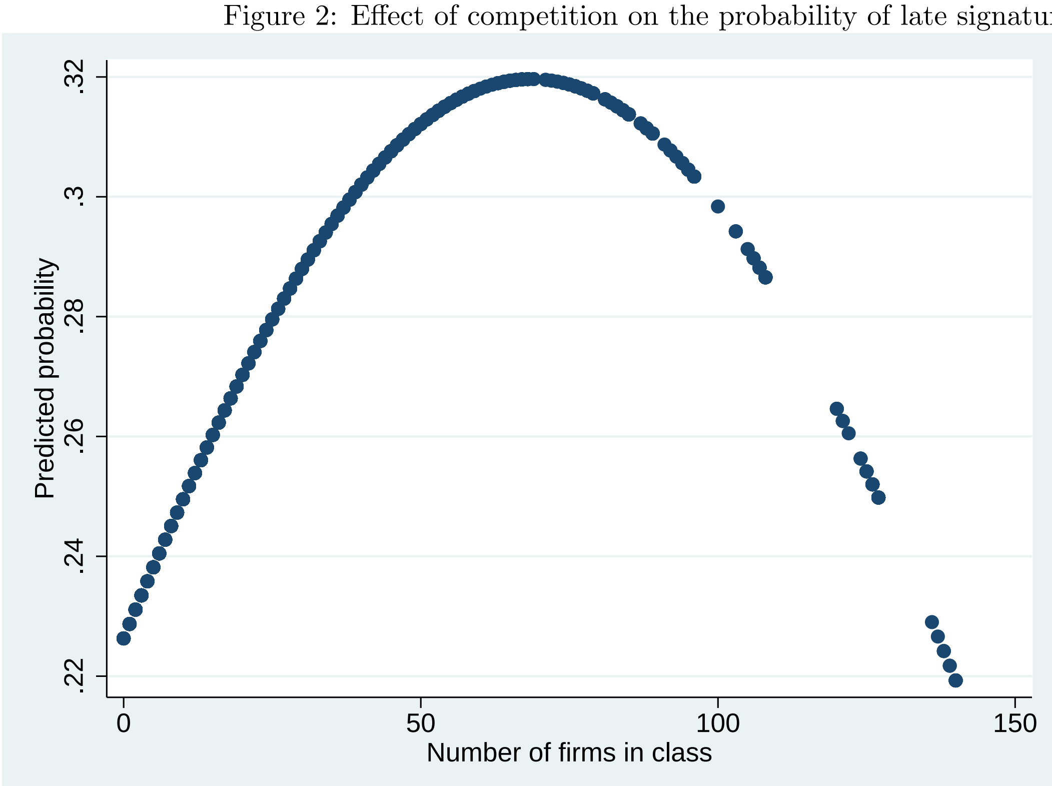

Figure 3: Marginal effect of competition on the probability of late signature