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Inefficiencies in the sale of ideas: theory and empirics[1]

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Abstract

The sale of ideas (e.g. through licensing) facilitates vertical specialization and the division of labor between research and development. This specialization can improve the overall efficiency of the innovative process. However, these gains depend on the timing of the sale: the buyer of an idea should assume development at the stage at which he has an efficiency advantage. We show that in an environment with asymmetric information about the value of the idea and where this asymmetry decreases as the product is developed, the seller of the idea may delay the sale to the more efficient firm, thus incurring higher development costs. We obtain a condition for the equilibrium timing of the sale and examine how factors such as the intensity of competition between potential buyers influence it. Empirical analysis of licensing contracts signed between firms in the pharmaceutical industry supports our theoretical predictions.

Jel Codes: L13, L24, L65, O32.

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1 Introduction

Innovation is undeniably an essential engine of growth. Whereas it has often been viewed, particularly in the theoretical literature, as a "black box" inside a vertically integrated firm, specialization in different phases of the innovation process is increasingly common in many industries, such as the pharmaceutical, chemical and semiconductor sectors (Arora et al. (2001)). This division of labor, facilitated by the growth of licensing markets that allow for sale of ideas, potentially improves the efficiency of the innovative process.

We argue in this paper that these efficiency gains crucially depend on the timing of exchange, by which we mean the phase of development at which the R&D project is transferred from one firm to another. Consider two firms, one more efficient in conducting early stage research and the other more efficient in the final stage. It is socially optimal to have the relatively efficient firm own the idea at each stage, i.e. to transfer the invention from the first to the second firm at the end of the initial stage. A delay in this transfer increases the cost of innovating and might lead to the innovation being abandoned. The innovation rate thus crucially depends on the timing of the transfer. We identify, both theoretically and empirically, factors that may distort the timing of the transfer and thus reduce the productivity of R&D. In particular, we explore the relationship between market structure and the efficiency of markets for ideas.

To address this question, we build a general model of the sale of ideas in an environment with asymmetric information that decreases over time. Specifically, we consider a two period model involving one innovator and n potential buyers who compete on a downstream market. Prior to the first period, the innovator has had an idea that requires additional development to be brought to market. While she faces some positive cost of development, development is costless for the buyers. It is thus socially optimal to transfer the idea from the innovator to one of the buyers in the first period. However, the first period is also characterized by asymmetric information: the innovator knows the value of her invention, but the buyers are uncertain whether the idea is good. Development efforts from the first to the second period reveal verifiable information about the value of the idea and the buyer's uncertainty is resolved prior to the start of the second period.

Since the sale of ideas usually involves bilateral negotiations, we use a sequential bargaining setup (as in Stole & Zwiebel (1996), Smith & Thanassoulis (2007) and others). The innovator bargains sequentially with the buyers over exclusive contracts. In general,

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incorporating asymmetric information in sequential bargaining models creates challenges. In particular, the problem is typically characterized by a large multiplicity of equilibria, making it difficult to draw general conclusions. One of the contributions of the paper is to obtain testable implications in the context of such a model with asymmetric information. Furthermore, these implications prove very robust to other model for the sale of ideas, such as an auction.

We identify a condition for the contract to be signed in the first period. The key tradeoff is the following: because the price of the idea in the first period reflects buyers' uncertainty about its quality, an innovator who knows that her idea is good is tempted to wait for information about the idea's value to be revealed. However, she must incur development costs to provide such information. An agreement can therefore be reached in the first period only if the efficiency advantage of buyers in the development stage is large enough to offset the innovator's increase in the price she receives by waiting.

We find that when profits on the downstream market do not depend on the number of buyers n, an increase in the number of buyers unambiguously delays the transfer. That is, increased competition leads to increased inefficiency in the market for ideas. This is because an increase in n increases the bargaining power of the innovator and the price she can obtain in the second period. The innovator thus wants to wait, while the buyers want to purchase the idea in the first period. The former effect is shown to dominate. When profits on the downstream market also depend on n, counter to the usual intuition on the positive role of competition, we find that greater competition among the buyers may inefficiently delay the sale. An increase in the number of buyers has two countervailing effects on the second period price: it increases the bargaining power of the innovator, but it also decreases the downstream profits obtained from the innovation. That is, the innovator obtains a larger slice of a smaller pie. For unconcentrated markets, the second effect dominates and the second period price decreases with the number of buyers, thus leading to earlier sale. The opposite is true for concentrated markets in several standard examples we examine. Thus, our theory suggests that the typical shape for the effect of the number of competitors on the delay in licensing will be an inverted U.

We also study a variant of the model in which we distinguish two types of potential buyers: incumbents with existing products on the market and entrants without any stake. While additional entrants affect competition for the innovation, the downstream

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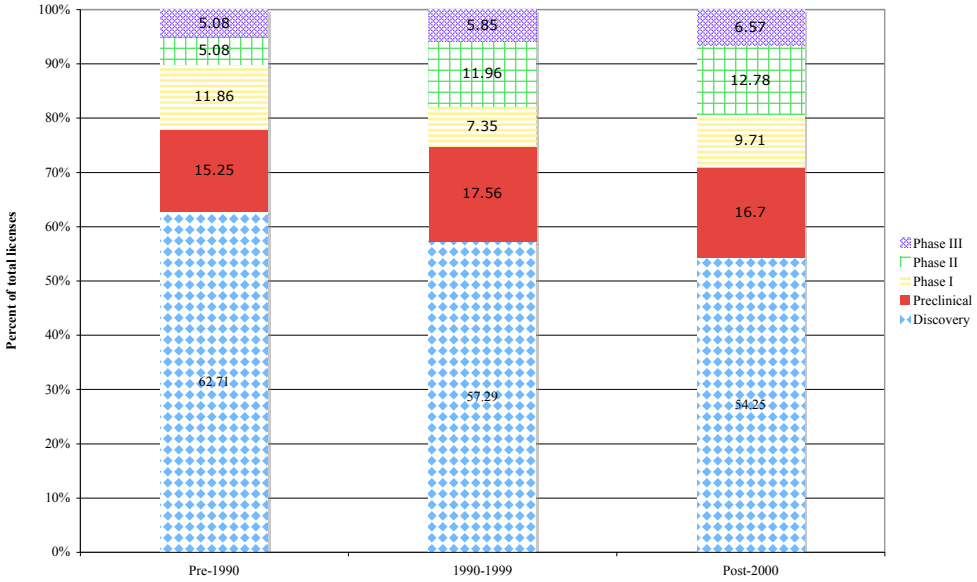
profits an entrant realizes from signing depend only on the number of incumbents. We show theoretically that delay in the transfer is increasing in the number of entrants and typically decreasing in the number of incumbents.

Our empirical analysis of licensing contracts in the pharmaceutical industry provides strong support for our theoretical predictions. This industry is a very good illustration of the process we described. There appears to be an increasing division of innovative labor between small biotechnology firms and large pharmaceutical companies. For instance, Angell (2004) claims that one third of the drugs marketed by major pharmaceutical companies originate from licenses with biotechs or universities. Biotechnology companies seem to have a comparative advantage in achieving early stage discoveries, while large pharmaceutical firms are considered more efficient in conducting later stage clinical testing. We argue that biotechnology firms are initially better informed about the quality of their drug candidates. However, verifiable information is revealed during the clinical trials that are required for regulatory approval. Once a clinical trial phase is successfully completed, the information asymmetry shrinks and potential buyers of a license become more confident of the drug candidate's value.

Figure 1 illustrates that in this industry, the fraction of licensing contracts signed after the discovery and preclinical stages has increased by more than 30% since 1990, a period also characterized by low numbers of new drugs launched. This delay in technology transfer also coincides with a period of increased market concentration, as the pharmaceutical industry has experienced substantial merger activity. This justifies our particular focus on the link between the number of potential buyers and the timing of technology transfer.

To test the model's predictions, we combine data on licensing deals and the stage of drug development at signing with data on the number of firms in different therapeutic classes (firms with drugs treating similar diseases) who compete on the downstream product market as well as for the license. Controlling for various measures of financial constraints and other factors, we provide empirical evidence that is consistent with our theoretical prediction for the relationship between competition and licensing delay. We also test the variant of the theoretical model that distinguishes entrants from incumbents and again confirm the predictions of the theoretical model across a range of specifications to evaluate robustness. We find that the percentage change in the probability of

Figure 1: Stage at licensing signing over time



late signing for a one-percent increase in the number of incumbents is -0.31, and the corresponding figure for entrants is 0.17.

A key assumption in the theoretical model is that the innovator is better informed about the quality of the idea than the buyers. Indeed, in the absence of asymmetric information, competition has no effect on the timing of transfers in our model. In the empirical analysis we examine subsets of the data based on criteria related to the extent of asymmetric information about the quality of innovators and their ideas. We find that the effect of the number of entrants and incumbents on delay is insignificant for the "low asymmetry" subsets and significant for the "high asymmetry" subsets, which is consistent with the model's prediction on the relationship between competition and information asymmetry.

There is a large literature that examines different aspects of licensing contracts, such as the choice between fixed fees and royalty rates, allocation of control rights, both theoretically and empirically (Lerner & Merges (1998), Lerner & Malmendier (2005), Kamien & Tauman (1986), Beggs (1992) and Choi (2001)).[1] However, with the exception

[1]See also Anand & Khanna (2000), Vishwasrao (2006), Mendi (2005), Higgins (2007).

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of Gans et al. (2008), the question of the timing of licensing has been left aside. Gans et al. (2008) describe several reasons for deviations from the socially optimal timing of technology transfer, including search costs, asymmetry of information and uncertain property rights. Focusing on the last, they show that the resolution of uncertainty over the scope of intellectual property (specifically a clarification of the claims granted to a patent) speeds licensing. We concentrate instead on asymmetry of information, and we examine more specifically the impact of market structure on timing.

In terms of methodology, as previously pointed out, our approach builds on other models of sequential negotiations, in particular Stole & Zwiebel (1996), which examine bargaining over labor inputs. In Stole & Zwiebel (1996), workers are also ordered in a sequence. In a bilateral negotiation, if a worker agrees to a wage, the firm moves on to the next worker in the sequence. However, these agreements are not binding. If there is a breakdown in a later negotiation, this triggers a replaying of the sequence between the firm and each remaining worker. This additional complexity does not arise in our framework because of the exclusivity of licenses. This assumption is not only realistic in many sectors, including the pharmaceutical industry, but also necessary for tractability, since we introduce an essential feature to the model: asymmetric information. Despite this additional complexity, we are able to unambiguously predict the timing of technology transfer.

Much of the existing literature on technology transfers under asymmetric information focuses on the case of weak or nonexsitent intellectual property rights. In particular, Anton & Yao (2002) examines the problem of an innovator revealing some information to convince a potential buyer of the quality of her product under the risk that the buyer can then fully appropriate the invention without any form of payments. We concentrate here on a different aspect: property rights do exist, but in order to convince a buyer of the idea's value, the innovator is forced to incur development costs even when she has no comparative advantage in development.

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

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2 Model

We consider a model with $n \geq 2$ symmetric firms competing on a downstream market and one innovator with a pre-existing idea. The n firms are the only potential buyers of the idea from the innovator, and do not themselves attempt to innovate (for instance, because their cost of early stage innovation is very high). The idea can be transferred by signing a fixed price contract (more complex contracts are discussed in section 4.2). The exact price is determined by a bargaining process that we describe below. Once a contract is signed, the game ends: we consider only exclusive transfers that grant the full ownership of the innovation to the buyer. Note that, to clarify the exposition, we will from now on use the term 'license' for the contract, although the transfer could also be done through other means, such as a direct acquisition of the innovator's firm.

The game has two periods that differ from each other in two important ways. First, at the end of the first period, if the innovator has not yet licensed the innovation, she needs to decide whether to develop the product further. The potential buyers are assumed to be more efficient in development. Development of the innovation from period 1 to period 2 costs Δ for the innovator and zero for the buyers. Second, the information structure differs between period one and two. Period 1 is characterized by asymmetric information about the quality of the innovation. The innovator knows the quality of her idea, but none of the buyers do. They share a common prior that the innovation is of a good type with probability q or a bad type with probability $1 - q$. At the beginning of the second period, the type of the innovation is revealed. This is a result of the verifiable evidence generated during the development process.

2.1 Payoffs

If the innovation is of a bad type, we assume that it does not generate any profits. The profits obtained from a good type innovation are given by:

- $\pi_0(n)$ is the profit of a buyer if neither he nor any of his competitors sign a license.
- $\pi_l(n)$ is the profit of a buyer if one of his competitors signs a license.
- $\pi(n)$ is the profit of a buyer if he signs a license.

We assume $\pi(n) \geq \pi_0(n) \geq \pi_l(n) > 0$: each buyer wants to license a good type innovation, but should he fail to do so, he prefers that no rival licenses the innovation. We assume that all profit functions are weakly decreasing in n and are continuously differentiable.

We denote by κ the outside option of an innovator who has developed a good type innovation until the second period and has not sold a license. It represents profits that can be obtained from alternative uses. Note that if the innovation is not developed until the second period, it does not generate any profits. We impose the following assumption:

ASSUMPTION 1: $\pi(n) - \pi_0(n) > \kappa$

Assumption 1 states that if the quality of the innovation is known to be high, there are gains from trade between the innovator and any buyer. Indeed, if a license is sold, the aggregate profits of the negotiators are $\pi(n)$ while the aggregate profit without sale is given by $\kappa + \pi_0(n)$.

2.2 Bargaining

Bargaining between the innovator and the buyers takes place as follows. All buyers are randomly ordered in a sequence. The innovator negotiates one by one with each buyer. We call each bilateral negotiation between the innovator and an individual buyer a bargaining session. If bargaining breaks down with the current buyer, the innovator starts a bargaining session with the next buyer in the sequence. If bargaining succeeds, the game ends since licenses are exclusive.

As previously described, our model has two periods. If bargaining is unsuccessful with all buyers in the first period, the innovator must wait for the second period to start another sequence of negotiations. The order of bargaining is the same in the second period.[2] If all bargaining sessions fail in the second period, the players obtain their outside options. Within a period, the innovator cannot restart negotiations with a buyer with whom bargaining previously broke down. To summarize, each period involves at most n bargaining sessions, and the game overall contains at most $2n$ sessions.

The bargaining procedure inside a session occurs as in the alternating offer game with exogenous probability of breakdown introduced by Binmore et al. (1986). As in their

[2]Redrawing the order across periods does not qualitatively affect our results but complicates the exposition: see Allain et al (2011).

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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 and the innovator moves to the next buyer in the sequence. If not, a new offer is made. We also assume that with probability ϵ, a bargaining session does not even start. That is, a breakdown can occur even before the start of a session.[3]

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

Our goal is to construct a general model of the sale of ideas, involving asymmetric information between the buyers and the seller, that nevertheless allows us to obtain clean predictions. In particular we are interested in examining how competition between potential buyers influences the timing of sale. This requires us to abstract from heterogeneities between firms. Most models of oligopsony with homogenous firms do not capture any effect of the number of buyers on price. For instance, if the innovator made take-it-or-leave-it offers, n would not influence the bargaining power of the innovator, the innovator would extract the full surplus regardless of n. Note also that if the buyers made simultaneous offers to the innovator, competition between them for an exclusive license would leave them with no rents, independent of their number (as long as $n \geq 2$). However, competition between homogeneous buyers does affect price in our model. The assumption of homogenous firms is not absolutely required; we show that an auction model where the bidders have heterogenous values yields similar results (see section 4.1). Since sequential bargaining is a more realistic description of how ideas are sold in practice, we emphasize that approach here.

3 The timing of the sale of an ideas

In the context of this model, the socially optimal timing is to transfer the innovation from the innovator to the buyer in the first period, as development is costless for buyers.

[3]The assumption that a breakdown may occur before the first round will prove essential to limit the multiplicity of equilibria, as discussed in section 3.1.2.

We show however that asymmetric information on the value of the innovation can delay the transfer. We solve the game by backward induction. All the results are limit results as the probability of exogenous bargaining breakdown ϵ converges to zero.

3.1 The bargaining game

3.1.1 Bargaining in the second period

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

Consider the negotiations with the $(n-k)$th buyer (k buyers left in the sequence). We first focus on the case $k \geq 1$ and discuss the case of the last buyer separately. If the negotiations are successful, the innovator obtains the price of the license $p_2(k)$ and the buyer $\pi - p_2(k)$. As shown in Binmore et al. (1986), the outcome of the bargaining game when the probability of breakdown ϵ converges to zero is given by the Nash bargaining solution with the disagreement points equal to payoffs following breakdown.

In our setting, the payoffs in case of breakdown are determined by the outcome of the remaining negotiations. If an agreement is expected to be signed with the next buyer in the sequence, the innovator can expect the price $p_2(k-1)$ while the buyer expects profits π_l (the profits of a buyer if a license is signed by one of his competitors). This determines the following recursive relationship for $k > 1$:

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

Under Assumption 1, the expectation that bargaining will succeed with the next buyer in the sequence is correct. Indeed, Assumption 1 ($\pi(n) - \pi_0(n) > \kappa$) guarantees that there are gains from trade with the last buyer. A buyer positioned earlier in the sequence has even more incentive to sign, since he expects π_l rather than π_0 if he does not sign himself. The outside option of the seller in the sequence of negotiations decreases by construction: $p_2(k) > p_2(k-1)$, as each buyer has to leave the seller a higher rent than the next potential buyer. Thus, as shown in the following Proposition, an agreement is reached

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with the first buyer in the sequence.

PROPOSITION 1: *If the innovation is good and bargaining failed in the first period, a license is sold in the second period to the first buyer in the sequence at a price:*

$$p_2(n) = \left(\frac{1}{2}\right)^n (\kappa + \pi_l - \pi_0) + \left(1 - \left(\frac{1}{2}\right)^n\right)(\pi - \pi_l) \tag{2}$$

Note that the price $p_2(n)$ is increasing in n. A larger number of buyers in the sequence allows the innovator to extract a larger share of the surplus.

3.1.2 Bargaining in the first period

In the first period, bargaining is more complex due to the information asymmetry between the innovator and the buyers. We show that all Perfect Bayesian Nash Equilibria (PBNE) share a common property that allows us to determine the equilibrium timing of licensing.

PROPOSITION 2: *In all PBNE, a license is sold in the first period if and only if the following condition is satisfied:*

$$q(\pi - \pi_l) \;\geq\; p_2(n) - \Delta \tag{3}$$

To understand the mechanics of the negotiation, it is useful to consider the last bargaining session in period one. Given Proposition 1, all players know that bargaining will ultimately succeed in the second period if the idea is good. However, an innovator only develops the product if the expected profits can cover the cost Δ: if $p_2(n) < \Delta$, the innovator never develops the invention herself. Her outside option at the end of bargaining is then zero, and a mutually beneficial agreement can always be found in the first period.[4]

[4]Note that, for a similar reason, an innovator with a bad idea would never wait for the second period if her innovation generated strictly positive profits (and thus a positive price in the second period). In such a case, there exist pooling equilibria where a license is signed in the first period when Δ is high, and separating equilibria where the good innovator signs in the second period and the bad innovator signs in the first period for low Δ (proof available upon request).

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We now consider the last bargaining session and the offer made by the innovator in the case where $p_2(n) \geq \Delta$. A good innovator will never offer a price less than $p_2(n) - \Delta$, as she can guarantee herself a price of $p_2(n)$ in the second period at a cost of Δ. A bad innovator wants to mimic the good type, and thus requests the same price. If the buyer accepts the offer and believes the probability of facing a good type innovator is still q (and in equilibrium this belief is correct), his expected utility is $q\pi + (1-q)\pi_0$. However, he can always guarantee himself his outside option, given by $q\pi_l + (1-q)\pi_0$. Indeed, if he waits until the second period, he knows that a contract will be signed with the first buyer in the random sequence if the innovation is good and he will therefore obtain π_l.

We focused in the previous discussion on the last buyer in the sequence. If the last potential buyer is expected not to sign, the one positioned just before the last in the sequence finds himself in an identical situation as the last and will therefore not sign either. The only potential buyer with a different perspective is the first in the sequence: his outside option is higher than that of his competitors, as he anticipates that he will be the one who signs a license in the second period. He therefore has even less incentive to buy a license in the first period than his competitors. The condition for early signature is thus determined by the incentives of the last buyer in the sequence.

If the condition is satisfied, the socially optimal timing of licensing is achieved: technology transfer takes place in the first period and the more efficient buyer develops the innovation. However, for low values of the probability of facing a good type q or of the efficiency difference Δ between the innovator and the buyers, the threshold for early signature is more difficult to meet and late (and inefficient) signature is more likely. The condition of Proposition 2 can be re-expressed as follows: a license is signed in the first period if and only if the cost of development for the innovator is sufficiently large $\Delta \geq \underline{\Delta}(n)$, where

$$\underline{\Delta}(n) \equiv p_2(n) - q(\pi - \pi_l). \tag{4}$$

In the following sections, we examine how $\underline{\Delta}(n)$, which we call the efficiency threshold, varies with n. If $\underline{\Delta}(n)$ increases with n, delays in licensing become more likely as the number of competitors increases.[5]

It is important to point out that one particular assumption limits the multiplicity

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

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of equilibria. We assume that before the start of each individual bargaining session, there is an exogenous risk of breakdown with probability ϵ. Therefore, regardless of the equilibrium that we consider, starting negotiations with any buyer in the sequence is always on the equilibrium path. For example, suppose that an equilibrium is such that a license is signed with the third player. In equilibrium, the fourth player might still negotiate if negotiations do not even start with the third player (an event that occurs with probability ϵ). Thus, in all equilibria, all buyers start negotiating with the same belief q that the innovator is of a good type: the fact that the innovator approaches a buyer positioned late in the sequence does not change that buyer's belief about the innovator's type. In other words, the buyer does not interpret this fact as an endogenous breakdown of prior negotiations that might indicate he is facing a bad type.

Note that delays are always inefficient in our framework because we assume a zero cost of development for the buyer. Allowing for the buyer to face a positive cost of development $\delta < \Delta$ could mitigate the welfare effects of a delay in licensing, as the buyer would waste resources in developing an idea if he bought a bad type idea (which would happen with probability q). However, as long as the buyer has a significantly lower cost of development, $\delta < q\Delta$, welfare remains higher in any equilibrium with signature in the first period than in any equilibrium with signature in the second period. Even if the total development cost of the buyers does not satisfy this condition, it is sufficient to assume that any buyer can incur a minor cost $\delta' < q\Delta$ to observe the quality of the innovation before sinking the large development costs.

3.2 The effect of market structure

In this section, we examine how the number of buyers in the market n affects the condition of Proposition 2 and thus the timing of licensing. n may influence both the bargaining power of each player and the downstream profits.

3.2.1 Profits do not depend on n

As a benchmark, we begin with the case where the profits $(\kappa, \pi_l, \pi_0, \pi)$ do not depend on n. For example, an additional competitor may not affect profits if innovations are purely market expanding and have no business stealing effect. This case isolates the effect of n, the number of firms competing for the license, on the bargaining power of the buyers

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and of the innovator. According to our results in section 3.1, in this particular case, the price of the license in the second period $p_2(n)$ increases with n. 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 efficiency threshold increases with n: the condition for early licensing is harder to meet as the number of buyers increases.*

This result is intuitive. As n increases, the bargaining power of the innovator increases in the second period and therefore $p_2(n)$ increases. The innovator with a good idea has a greater incentive to wait to sign a license. Furthermore, as n increases, the expected profit in the second period is unchanged for all buyers except the first in the sequence. As we saw in the previous section, only the incentives of buyers *later* in the sequence determine the condition to sign early. Thus, overall, an increase in n will delay signature. We show in the next section that the results may be different if the number of competitors impacts downstream profits in addition to bargaining power.

3.2.2 Profits depend on n

When the profits depend on n, the effect of a change in the number of competitors is more subtle. There are two countervailing effects of n on the second period price. On the one hand, it raises the bargaining power of the innovator, who gets a larger share of the pie. On the other, it decreases the actual profits derived from the innovation, so the size of the pie shrinks. The tension between these two effects on the second period price yields an ambiguous effect of n on the timing of licensing.

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

PROPOSITION 4: *If $\pi'(n) \leq \pi'_l(n)$, then for sufficiently large values of n, the efficiency threshold decreases in n: the condition for early licensing is easier to meet as the number of buyers increases.*

The intuition of this result is the following. As the number of buyers becomes large, the innovator enjoys all the bargaining power and can extract all the surplus in the second

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period. From Proposition 2, the price in the second period approaches $\pi(n) - \pi_l(n)$ for large values of n. So if $\pi'(n) \leq \pi_l'(n)$, the price decreases in n and licensing delays become less likely.

Proposition 4 provides an unambiguous result for very competitive markets. For small values of n, however, the opposite result may hold, leading to an inverted U-shape for the relationship between number of competitors and delays in technology transfer. We show in the Appendix that in two standard situations (namely an industry with Cournot competition and process innovations, and an industry with Bertrand competition and product innovations) the efficiency threshold follows either an inverted U shape or a decreasing shape as a function of n.[6]

3.2.3 Entrants and incumbents

Our previous analysis assumed that all potential buyers are symmetric. In reality, of course, the value of a license may differ across buyers for many reasons. In this section, we allow for some heterogeneity of buyers, focusing on what we view as a key difference between them: some potential buyers have existing products that would compete with the licensed innovation, while others don't. Formally, we assume that there are n incumbents denoted by $i \in \{1, ..., n\}$ and e potential entrants denoted by $j \in \{1, ..., e\}$. Entrants are not active on the market prior to the innovation, but they may purchase the license and thus enter the market.

The potential entrants are all symmetric. Their outside option, regardless of whether someone else buys a license, is zero (since they have no existing products on the market and we don't take into account their profits on other markets). We denote by π_e the profit of an entrant who buys the license. For simplicity, we assume that $\kappa = 0$. The profits of the incumbents are, as in the previous sections, π if they get the license and π_0 if no one buys a license. However, the profit of an incumbent if someone else buys the license now depends on the identity of the buyer, since a new entrant increases the number of competitors. We denote these profits π_l if the buyer is another incumbent and π_{le} if the buyer is an entrant.

To keep the theoretical analysis tractable, we assume that the incumbents and entrants are "grouped" in the bargaining sequence. In other words, we consider two cases:

[6]Note also that the condition for Proposition 4, $\pi'(n) \leq \pi_l'(n)$, is satisfied in these examples.

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either the innovator first bargains sequentially with all the entrants and then with all the incumbents, or the order is the reverse. We also assume that players are ordered in the bargaining sequence in such a way that the players with higher valuation bargain first: if $\pi_e < \pi$ (resp. $\pi_e > \pi$), the entrants are positioned later (resp. earlier) than the incumbents.[7] We present here the results in the case where the entrants bargain first. The results are qualitatively similar in the other case (see Allain et al. (2011)).

PROPOSITION 5: *All PBNE have the following properties:*

1. *The efficiency threshold increases with the number of entrants e (the condition for early licensing is more difficult to meet).*

2. *The effect of the number of incumbents n on the efficiency threshold can be ambiguous. However, when the number of entrants e is large enough, $e > \widehat{e}$, the efficiency threshold unambiguously decreases with n (the condition for early signing is easier to meet).*

Part 1 of Proposition 5 echoes Proposition 3. The number of entrants affects bargaining power, but not profits on the downstream market (as at most one of them will in the end be present on the market). Part 2 of Proposition 5, on the other hand, is a reflection of the case considered in section 3.2.2. The effect of the number of incumbents on the timing of licensing is potentially ambiguous as it affects both bargaining power and downstream profits. However, if the number of potential entrants is large enough, an increase in the number of incumbents unambiguously reduces licensing delays.

3.3 The role of asymmetric information

A key assumption we make in the model is that there is asymmetric information between the licensor and potential licensees in the first period. In this section we argue that in the case of symmetric information, there are no deviations from the optimal timing of licensing. Thus, our results suggest that identifying an effect of the number of buyers on timing can be seen as indirect evidence of the existence of asymmetric information between licensors and licensees.

[7] We assume as before that the order of bargaining is the same in the first and second period.

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Suppose that both the innovator and the buyers are uncertain about the quality of the invention and both share the same belief that the type is good with probability q. Bargaining in the second period remains unchanged. In particular, given Assumption 1 ($\pi - \pi_0 \geq \kappa$), an agreement is always reached if the innovation is of the good type. However, in the first period, the innovator is now uncertain about the quality of her invention. In this case we obtain the following result.

PROPOSITION 6: *If the innovator and the buyers share the same belief q that the innovation is good, a license is always signed in the first period for all values of q and n.*

If an agreement can be reached in the second period (i.e., Assumption 1 is satisfied), then an agreement will be reached in the first period regardless of the degree of uncertainty q and of the number of competitors n. The intuition is the following. If an agreement can be reached in the second period when the idea is good, then there is an even larger surplus that can be shared in the first period, since the buyers can develop the product at a lower cost than the innovator. That is, the innovator risks a greater loss from developing an idea that turns out to be bad than do the buyers, who have development costs of zero. With uncertainty and symmetric information, we find that the license is signed at the socially optimal time.

In Allain et al. (2011), we present a different interpretation of our model. Our result for the effect of competition on the timing of licensing is also valid in the absence of asymmetric information if the licensor and the licensees have different beliefs about the probability of success in the first period. A typical example is the case of overconfident innovators. We show that such a model will lead to similar predictions.

4 Robustness and Extensions

4.1 Model of auctions

As we previously noted, oligopsony models with homogenous buyers typically cannot capture the effect of competition between potential buyers on the price of an exclusive deal. We show below that a model of auction with some heterogeneity between buyers yields the same type of results as our bargaining model although, as argued below, the effect of the number of buyers on prices is less intuitive.

We consider a model where in both periods the innovator can choose to run a second price auction with a reservation price. If she does not run an auction in the first period, or if she runs an auction but fails to sell the license because the reservation price is not met, she can choose to pay the cost Δ (known to all players) and develop the product herself. We suppose that the profits that can be obtained from a good type innovation are identical for all buyers and known to be $\pi(n)$. However there is a fixed cost of production c that is drawn for each buyer from a distribution $c \sim F$ with support $[\underline{c}, \overline{c}]$.[8] The fixed cost must be incurred after observing the value of the invention (it will be paid only if the idea is good). Specifically, the value to a buyer of a bad idea is 0, but $\pi(n) - c$ if the idea is good. For simplicity, we assume that $\pi(n) - \overline{c} > \kappa$ and that $\pi_l = \pi_0 = 0$.

We show in the Appendix that the unique bidding strategy for the buyers in both periods is to bid their expected value for the good.[9] Furthermore, the innovator will run an auction in the first period if and only the extra profit she expects from waiting do not cover the development cost Δ, as expressed in the following result:

PROPOSITION 7: *An innovator with a good idea runs an auction in the first period if and only if*

$$\Delta \geq (1 - q)(\pi - E[c_{n2}])$$

where c_{n2} is the second lowest cost among the n buyers. Furthermore, if she runs an auction in the first period, she sets a zero reservation price and always sells a license.

We see that, if profits π do not depend on n, licensing delays become more likely as n increases. Indeed, the second period price mechanically increases as more draws are taken from the cost distribution. The same logic as in Proposition 3 then applies. The good innovator, who knows her quality, can fully extract this increase in the price in the second period. The buyers, though, only consider the added cost, corresponding to a higher price in period 2, if the innovator is good with probability q. The incentives of the innovator to delay are stronger than the incentives of the buyers to sign earlier. This basic intuition seems very general as long as the price in the second period is increasing with the number of potential buyers. Furthermore, if profits also depend on n, this creates a

[8] Our auction is therefore one with private values. We need to have private values for the price to vary with the number of buyers.

[9] A buyer with cost c bids $q(\pi - c)$ in the first period and $\pi - c$ in the second period.

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countervailing effect ($\pi(n)$ decreases and $-E[c_{n2}]$ increases), as in the previous sections. The total effect cannot be characterized without putting more structure on the profit function and on the distribution F, but this exercise could be easily conducted.

4.2 Milestone payments

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

However, we never observe contracts with pure milestone payments in our data on licensing contracts. Milestone-only contracts may not be feasible in the presence of a liquidity-constrained innovator. As well, such contracts may lead to moral hazard for buyers, who may not have sufficient incentives to develop the product. A detailed examination of these factors is beyond the scope of this paper. If we allow for two-part tariffs, or any tariff including a combination of conditional and non-conditional payment, and if we introduce an explicit constraint on how large the upfront payment needs to be, the effect of market structure on the date of licensing is still relevant. More generally, whenever contracts terms cannot completely offset the asymmetry, our results are still relevant and inefficient delays may arise.

5 Empirical analysis

5.1 Background on the pharmaceutical industry

The results of our theoretical model are tested on data from the pharmaceutical industry. We provide in this section some background on this industry and explain in particular why the theoretical assumptions we made appear particularly reasonable in this context.

The pharmaceutical industry is indeed a very good illustration of the process we captured in our model. There appears to be an increasing division of labor between small

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biotechnology firms and large pharmaceutical companies. 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). Biotechnology companies seem to have a comparative advantage in achieving early stage discoveries, while large pharmaceutical firms are considered more efficient in conducting later stage clinical testing. They can in particular exploit their relationships with medical practitioners who participate in running clinical trials or prescribe their other products. They also may benefit from economies of scale and scope in the administration of clinical trials. Drug candidates are usually sold with exclusive licensing contracts.[10] Negotiations to sign the licenses appear to fit quite closely the sequential bargaining model we use. They typically involve an exclusive period during which the licensor may not hold discussions with any other potential licensee.

An essential element of the model is that the seller is better informed about the prospects for the drug candidate than the potential buyers. The empirical literature attempting to assess the extent of adverse selection in this industry obtains mixed results. 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. Failure rates alone do not establish asymmetric information, since both the buyer and seller may agree that a project has a high probability of failure and agree on a low price for the sale of the idea. However, there is at least casual evidence that industry practitioners worry about buying a lemon. We find it plausible that the licensing firm has some additional information about the value of its drug candidate, even if considerable uncertainty exists. In particular, it may know more about possible shortcomings: it may have internal information that suggests problems or limitations, but that cannot be credibly disclosed. Some indirect evidence for this point is the observation that pharmaceutical firms prefer to license late-stage candidates, despite paying much higher fees: "To reduce the risk of licensing a drug that ultimately fails to win approval from the US Food and Drug Administration (FDA), these companies make low offers to biotechnology firms during preclinical testing...pharma companies often don't commit substantial resources until clinical trials demonstrate the drug's safety and efficacy in

[10]Even though direct acquisitions of the company also occur, we will focus in the empirical analysis on the licensing channel.

humans. While this delay is understandable, it can cost companies tens of millions of dollars in higher fees and royalty payments to the biotechs for every compound." (Kalamos et al. (2002))

We emphasize that, as we pointed out in section 3.3, if our assumption of asymmetric information is incorrect but the other elements of our model are appropriate, we should not expect to find any effect of market structure on the timing of licensing. Our results can thus be seen as indirect evidence that such asymmetries do exist. In our empirical analysis (see section 6.3), we examine the effect of market structure in cases where the severity of asymmetric information may differ. Moreover, we also show in Allain et al. (2011) that market structure would have a similar effect on delay in a model with over-confidence, rather than information asymmetry. While we do not attempt to distinguish these explanations empirically, they can be considered as two separate contributions of this paper.

The last important element of the model is that verifiable information is revealed during the development process. This is particularly true in this industry, since drug development involves several distinct phases which are clearly defined and controlled by regulatory agencies such as the FDA in the United States or the European Medicines Agency (EMA). During the discovery phase, firms identify drug candidates for further development in targeting a disease or indication. These are tested in animal subjects during the preclinical phase. At this point, clinical trials in humans begin. Phase I trials involve a small number of healthy volunteers to establish a drug candidate's safety. Phase II trials focus on the efficacy of the drug candidate in treating patients with the disease and begin to identify side effects. Phase III trials are much larger studies that continue to gather data on safety and efficacy. Verifiable evidence of a drug candidate's quality is produced at each phase and presented to the regulatory agencies.

The existence of a different type of information asymmetry is also possible: buyers might have superior knowledge of the downstream market and profit potential. However, this type of asymmetry is unlikely to decrease as the product is developed. It is therefore not obvious how it could explain the systematic effect of market structure on the timing of licensing that we uncover in our model and demonstrate in the pharmaceutical industry.

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5.2 Data

We draw our sample of licensing contracts from Recombinant Capital's rDNA database. It contains detailed information on all licensing deals in the pharmaceutical industry signed since 1973, including financial details (total value, up-front and milestone payments, royalty rates) for a subset of the agreements. 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. Since the rDNA database contains no information on potential licensees or any other market level data, we exploit additional data sources called R&D Focus and MIDAS, produced by IMS Health. MIDAS provides us with annual data on total revenues by disease from 15 countries from 1993-2007. The R&D Focus database tracks all drug candidates, or projects, in development since the early 1990s. From this source, we not only add additional information about the development status of each licensed product, but we can determine the experience (in developing drugs, as well as marketing approved products) in different anatomical therapeutic classes (ATCs), of both the licensor and licensee. This will allow us to build different definitions of potential buyers of a license as well as important control variables.

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

We restrict our analysis to contracts involving R&D on drug candidates that have not yet been approved for launch, excluding co-marketing alliances. We focus on exclusive deals with no geographic restriction, and on deals that are signed in the discovery, preclinical or clinical phases of development. In order to match each deal to market-level variables for which we have data, we include deals from 1990-2007. 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 practice, this requires us

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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. In addition, we concentrate on deals that involve a specific drug candidate (or candidates, in some cases) rather than those for the use of a technology platform (which are rarely exclusive agreements). This process results in 2335 matches. We have the least success in matching very early stage deals and those where the stage at signing is missing.

Important for our definitions of potential buyer and downstream market is a drug's Anatomical Therapeutic Chemical classification (hereafter therapeutic class).[11] Therapeutic classes correspond to disease markets, and are coded at different levels of specificity. For example, the broadest level is a single letter, such as group C for cardiovascular system therapies. C02 refers to the subgroup of antihypertensive therapies, and C02A is the narrower set of centrally-acting antiadrenergic agents. Drugs within a therapeutic class may be considered as substitutes, but drugs within the same narrow class are closer substitutes than those in the same broad class, and substitution is unlikely across therapeutic classes. For example, "acne" (D10) is a separate market from "diabetes" (A10), and human insulins (A10A) are closer substitutes than oral antidiabetics (A10B) in the treatment of diabetes. We exclude the therapeutic class V7 (defined as "All other non-therapeutic products") because the set of products assigned to this class are not therapeutic substitutes.

Drug candidates are often assigned to multiple therapeutic classes because they can treat different diseases. In addition, most drug candidates have more than one firm listed as co-developers. When counting the number of firms in a therapeutic class, we consider all firms that are involved in the development of a project, and we include all projects that are assigned to the therapeutic class. Thus, our measures of the number of firms in a therapeutic class are very inclusive.

Table 1 provides summary statistics for the key variables in our analysis. We examine only drug candidates that were licensed between 1990 and 2007, not the set of all drug

[11] 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."

candidates that were ever (or are currently) available for licensing. Our estimates therefore apply only to a selected sample. All variables are measured as of the date a license was signed. The definitions of incumbents and entrants are described in section 6.4.

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Table 1: Summary statistics

Variable	N	Mean	StdDev	Min	Max
Late signing (post-preclinical)	2066	0.287	0.452	0.0	1.0
Log(months since start of preclinical)	1814	1.120	1.816	0.0	5.594
Licensor market experience (no. drugs marketed)	2047	3.204	13.654	0.0	198.0
Licensor development experience (no. drugs in development)	2047	6.383	16.437	0.0	302.0
Licensor deal experience (no. deals previously signed)	2047	1.491	2.468	0.0	17.0
Licensor is publicly traded	2066	0.150	0.357	0.0	1.0
Licensor is based outside US	2066	0.424	0.494	0.0	1.0
Firms are co-located (same country of headquarters)	2066	0.424	0.494	0.0	1.0
Licensor is not in VentureXpert data	2047	0.488	0.500	0.0	1.0
Licensor's round of venture financing	1026	3.693	2.680	1.0	20.0
Licensor's funding in last round of venture financing	1026	10.901	18.653	0.0	150.0
Licensor's cumulative venture financing	1026	28.516	33.106	0.0	244.590
Licensor's age	1048	8.227	5.601	0.0	20.0
Total revenues in therapeutic class (millions of US$)	1672	4.273	4.772	0.000	30.563
Total venture funding for industry (units of US$)	2065	9.147	4.230	0.000	16.671
Potential buyers	2047	42.399	27.726	0.0	113.0
Incumbents that sign at least one license	2047	22.778	19.951	0.0	80.0
Entrants that sign at least one license	2047	19.620	15.059	0.0	94.0
Incumbents, all firm types	2047	63.512	59.092	0.0	243.0
Entrants, all firm types	2047	35.915	33.867	0.0	230.0
Incumbents that are large and public	2047	8.128	5.085	0.0	20.0
Entrants that are large and public	2047	7.671	5.350	0.0	24.0

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5.3 Empirical specification

We want to test our theoretical predictions on the link between market structure and the timing of licensing. We present two main categories of results. First we use our baseline model, which treats all potential buyers as symmetric. In this case, as described in section 3, the theoretical model predicts an inverted-U shape relationship between number of potential buyers and delay in licensing. We test this prediction using as main explanatory variables both the number of potential buyers and this number squared. Second, we use the model of section 3.2.3, which differentiates incumbents with stakes on the markets and potential entrants. The explanatory variables of interest in this case are the number of incumbents and the number of entrants.

Our theoretical model assumes that potential buyers are identical, or differ only in incumbency. In reality, of course, potential buyers vary in size, existing portfolios of products, and many other factors. The empirical approach we adopt does not allow for buyer characteristics to enter except through our definition of the set of potential buyers, which we discuss below. Our focus is not on the identity of the buyer, but rather on the timing of the sale.

For both sets of analysis we use the same empirical methods: logit, ordered logit and a hazard rate model. The first approach is to define an "early" stage of licensing, such as the discovery and preclinical phases, and a "late" stage as Phase I, II and III clinical trials. Because regulators are directly involved beginning in Phase I, we consider this stage to be the point at which information about quality is verifiable. As well, this is the point at which testing involves human subjects and more complicated study design. An alternative is to treat each of these distinct phases as a "period" and assume that a similar trade-off exists between signing in stage i and delaying until stage $i+1$ for each stage i; the difference is that rather than disappearing completely, the informational asymmetry shrinks as each development stage is completed. We can think of the condition for signing a license described in Proposition 2 as an unobserved latent variable y^*. Two natural empirical models are the logit (for early vs. late) and ordered logit (for each phase of development). 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:

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

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.

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. 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 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 preclinical phase on the same variables as used in the ordered logit. 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.

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 main focus, we include a number of controls that might also affect licensing behavior. These include the extent to which a licensor faces capi-

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tal 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), market experience (measured as the number of drugs the licensing firm has successfully launched). Because the availability of financing may vary over time, we also include annual commitments by venture capitalists within the biotechnology and medical industries. All specifications also include therapeutic class fixed effects, to control for differences in demand as well as development costs that are likely to vary by disease, and a control for the size of the therapeutic class market, measured as total annual revenues from 15 countries for drugs assigned to that therapeutic class.

6 Results

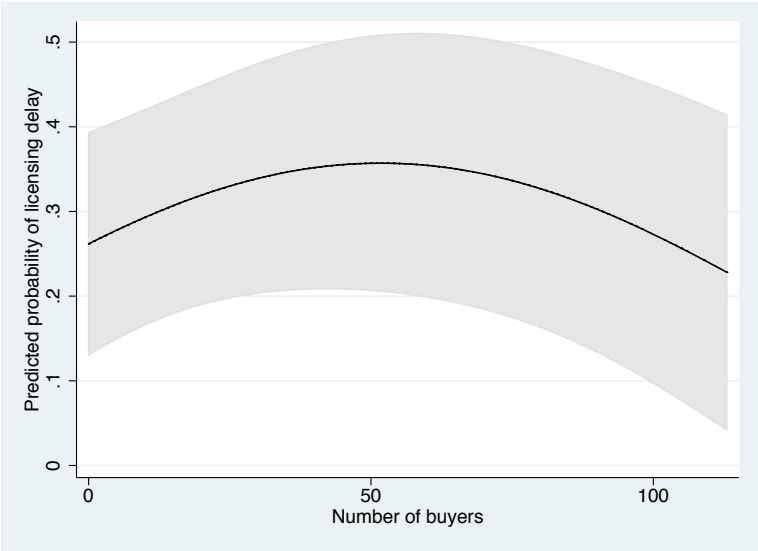
We test separately the predictions of our baseline model and those of the model differentiating entrants from incumbents. Most of our robustness checks, such as varying the definition of potential buyers, will be presented in this second case.

6.1 Baseline model

Our starting point in this section is the condition for signing in the first period given in Proposition 2. We have shown that this condition is easier to meet when additional competition has little impact on downstream profits. This condition is less likely to hold in a very concentrated market for standard models of downstream competition, such as Cournot competition and differentiated Bertrand, although we have not established that this is a general result. We examine the relationship between market structure and the timing of a license by using the number of potential buyers and its square as the main explanatory variables. A positive coefficient on the number of buyers and a negative coefficient on the squared term would suggest that the effect of increased competition on license timing has an inverted-U shape, as in the examples we presented.

We define the set of potential licensees of an innovation as those with existing products in the same broad disease area, or 2-digit ATC, as the drug candidate licensed. Relative to firms in other disease areas, firms meeting this definition are likely to have a good understanding of the market potential and to be well-positioned to evaluate the scientific

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



validity of a drug candidate available for license. In addition, such firms have pre-existing relationships with doctors who treat the disease, who may enroll patients in clinical trials as well as prescribe the drug once it is approved. In other words, these firms should have relatively lower costs of conducting clinical trials and marketing the product. However, firms may use licensing as a means of entering a disease area, and some firms focus exclusively on internal development; indeed, any definition of potential licensee risks excluding some actual buyers and/or including some that are not true competitors for the license. For our baseline results, we focus on those firms that buy at least one license; this essentially means that we don't consider firms that mostly sell drug candidates (usually small biotechs) as potential buyers. Robustness checks with respect to the definition of potential buyers are presented in section 6.4.

Table 2 presents our baseline results for the three econometric models described above. Competition appears to have an inverted U-shaped effect on the timing on licensing. This effect is illustrated in Figure 2, which graphs the predicted probability of late signing (using the estimates of the logit model) as the number of buyers changes with continuous variables at their means for a US-based licensor that is not publicly traded. The mean number of buyers using our very inclusive definition is 42, and the peak of the inverted U is around 55.

Our main focus is on the effect of market structure on the timing of licensing, for which our model proposes clear and testable predictions. We do not want to insist too

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Table 2: Baseline results

Variable	Logit	M-Logit	Hazard
Intercept	-2.2233**	-1.6605**	-0.1384
	(0.5437)	(0.4523)	(0.4369)
Buyers	0.0161*	0.0140*	0.0240**
	(0.0097)	(0.0080)	(0.0080)
Buyers squared	-0.0002**	-0.0002**	-0.0002**
	(0.0000)	(0.0000)	(0.0001)
Total venture funding for industry	0.0225	0.0429**	0.0476**
	(0.0219)	(0.0184)	(0.0186)
Total revenues in therapeutic class	0.0363**	0.0327**	0.0161
	(0.0138)	(0.0119)	(0.0124)
Licensor market experience	0.0076	-0.0015	0.0115
	(0.0108)	(0.0096)	(0.0096)
Licensor development experience	-0.0047	0.0059	-0.0118
	(0.0107)	(0.0095)	(0.0095)
Licensor deal experience	-0.0193	-0.0471**	-0.0057
	(0.0235)	(0.0203)	(0.0205)
Licensor is publicly traded	0.5088**	0.4202**	0.6539**
	(0.1776)	(0.1537)	(0.1562)
Licensor is based outside US	0.0530	0.1234	-0.0053
	(0.1286)	(0.1086)	(0.1094)
Firms are co-located	-0.5903**	-0.4604**	-0.4542**
	(0.1282)	(0.1066)	(0.1050)
Licensor is not in VentureXpert data	0.4952**	0.5358**	0.4344**
	(0.2068)	(0.1730)	(0.1675)
Licensor's cumulative venture financing	0.0046	0.0053*	-0.0023
	(0.0035)	(0.0030)	(0.0032)
Licensor's funding in last round of venture financing	-0.0097	-0.0106**	0.0042
	(0.0059)	(0.0051)	(0.0050)
Licensor's round of venture financing	-0.0226	-0.0185	0.0306
	(0.0382)	(0.0331)	(0.0326)
Licensor's age	0.0711**	0.0712**	0.0792**
	(0.0157)	(0.0134)	(0.0139)
Number Obs	1633	1633	1449
Log L or R^2	-935.4465	-2084.579	.085

much on the interpretation of the coefficients on the other explanatory variables, though controlling for them could be important. The interpretation of the effect of being in the same location is unambiguous: it will tend to decrease asymmetric information, and thus, consistent with our theoretical model, lead to earlier licensing. But many of the other variables can reflect several competing effects. A high value of q (i.e high chance of having a successful drug) may be accompanied by a lower Δ (smaller efficiency difference with potential buyer). For instance, older firms or those that are publicly traded might have better products (higher q), but also be less liquidity constrained or have already access to cheaper ways of conducting clinical trials (lower Δ). Our reduced-form empirical approach limits the interpretation of the coefficients on these measures.

6.2 Entrants and incumbents

In reality, potential buyers of a license may not be equally exposed to downstream competition and its countervailing effect on licensing delay. Firms that market a product in the same narrow disease area are most affected by downstream competition, while those that are active in related diseases are less so. We refer to the former as incumbents in the market, and the latter as entrants. We estimate the model of section 3.2.3 that differentiates between incumbents and entrants. We showed that the number of entrants unambiguously delays licensing. While the effect of the number of incumbents is ambiguous, but we showed that in general we should expect an increase in the number of incumbents to reduce delays in licensing. We therefore use the number of entrants and incumbents as the main explanatory variables in the following specifications. We expect a negative coefficient on the number of incumbents and a positive coefficient on the number of entrants.

Using a similar logic to our definition of potential buyers discussed above, we now define incumbents as firms with drugs in the same 3-digit ATC as the licensed drug, while entrants are firms with drugs in the same 2-digit ATC as the licensed drug, but not in the same 3-digit ATC. Both definitions include only firms that buy at least one license in our data. The results are presented in table 3; the specifications include all the additional explanatory variables as in our baseline case, but we report only the coefficients for incumbents and entrants. Across all specifications, the predictions of our theoretical model are confirmed: an increase in the number of incumbents (resp.

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Table 3: Results with incumbents and entrants

Variable	Logit	M-logit	Hazard
Incumbents	-0.0169**	-0.0232**	-0.0116**
	(0.0050)	(0.0042)	(0.0042)
Entrants	0.0113**	0.0080**	0.0145**
	(0.0041)	(0.0034)	(0.0035)
Number Obs	1633	1633	1449
Log L or R^2	-926.4657	-2069.873	.095

entrants) decreases (resp. increases) licensing delays. To assess the importance of the effect of competition, we calculate the average elasticity of the probability of late signing with respect to incumbents and entrants. The percentage change in the probability of late signing for a one-percent change in the number of incumbents is -0.31, and the corresponding figure for entrants is 0.17.

6.3 Asymmetric information

In our model, inefficiencies arise only in the presence of asymmetric information. To confirm the importance of this factor, we test our model on different sub-samples for which we expect information asymmetries to be high or low. Asymmetric information is difficult to quantify, but we argue that it is likely to be greatest in the case of licensors that have yet to establish themselves as capable of producing good drug candidates or as trustworthy partners. Nicholson et al. (2005) show that these firms receive the largest discount from new partners, for example, and cite deal experience as a means of signalling quality. We therefore define "high asymmetry" licensors as those with fewer than 3 deals prior to its current one; we obtain similar results using a definition based on development experience. An alternative definition is based on a firm's status as a public or private firm. Public firms are subject to greater scrutiny and required by law to disclose specific information to shareholders. Therefore, we might expect public licensors to have less private information as well as less subject to liquidity constraints. We estimate our models using this split as well.[12]

Table 4 indicates that our results are strongest for the subset of deals where asymmetric information is likely to be high (as above, we report only a subset of coefficients

[12]Note that this split can also possibly separate firms according to their degree of over-confidence.

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Table 4: Results comparing information asymmetry

Variable	High asym.	Low asym.	Private	Public
Incumbents	-0.0245**	-0.0031	-0.0202**	0.0048**
	(0.0059)	(0.0112)	(0.0056)	(0.0000)
Entrants	0.0086*	0.0180*	0.0116**	0.0103**
	(0.0045)	(0.0109)	(0.0000)	(0.0000)
Number Obs	1254	379	1388	245
Log L	-697.9432	-200.6718	-760.5830	-144.2832

but include the same set control variables as in the previous sets). Licensing agreements involving licensors with an established history of partnerships do not yield statistically significant coefficients on competition. Similarly, competition has a very small, although significant, effect on licensing agreements involving publicly traded licensors. We interpret these findings as additional support for our model: if the effect of competition were the same in both high asymmetry and low asymmetry cases, this would suggest that informational asymmetry is not an underlying mechanism driving the timing of licensing.

6.4 Alternative definitions of potential buyers

An important concern in the empirical analysis is that our key variables of interest, those for buyer competition, may be measured with error because we can't observe for certain which firms may have considered a license for a particular drug candidate. In this section, we explore alternative definitions of potential buyers. Our previous definition was based on the argument that firms with market experience in related areas would have the highest valuation for, and best ability to evaluate, potential drug candidates. Levine (2007), in her paper on licensing of biotechnology drugs, defines a potential buyer as any firm that markets a biotechnology product in the US, and allows their valuation to depend on their experience in different disease areas. We consider non-US markets and do not distinguish prior marketing of a biotechnology product from that of small molecule drugs, but our previous definition also restricted the set of potential buyers to those that actually buy a license at least once in our data. In this section, we consider two alternative definitions of potential buyers to check the robustness of our findings.

First, we define incumbents and entrants as before except without the restriction that

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Table 5: Results with first alternative definition of potential buyers

Variable	Logit	M-logit	Hazard
Incumbents	-0.0035**	-0.0058**	-0.0025*
	(0.0016)	(0.0013)	(0.0013)
Entrants	0.0058**	0.0045**	0.0068**
	(0.0017)	(0.0014)	(0.0015)
Number Obs	1633	1633	1449
Log L or R^2	-927.4660	-2072.446	.095

Table 6: Results with second alternative definition of potential buyers

Variable	Logit	M-logit	Hazard
Incumbents	-0.0254	-0.0496**	-0.0031
	(0.0211)	(0.0177)	(0.0175)
Entrants	0.0232*	0.0106	0.0337**
	(0.0127)	(0.0104)	(0.0105)
Number Obs	1633	1633	1449
Log L or R^2	-932.5247	-2081.531	.087

firms that buy a license at least once in our data set. This set includes many firms that may not be seeking to license in external drug candidates. For example, a small firm that co-developed a drug with a much larger partner, but that has no marketing capabilities of its own, is counted as a potential buyer under this definition. Table 5 presents the results from our three econometric models using this alternative definition. We again find a negative and significant coefficient on the number of incumbents and a positive and significant coefficient on the number of entrants. Second, we define incumbents and entrants as in the previous section except that we restrict buyers to be large, publicly traded firms (those we believe are most likely to have the necessary commercialization and marketing skills). The results, presented in table 6, are weaker in terms of statistical significance, though of the expected signs. Because most big firms are active in a large set of disease areas, there is less variance in the number of potential buyers across therapeutic classes for us to identify the effect of competition. As before, both tables report only the coefficients relevant to market structure, but all specifications include the same control variables as the baseline case.

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7 Conclusion

In this paper we analyze, both theoretically and empirically, inefficiencies in the transfer of technologies. We focus in particular on a question that has been largely neglected in the literature, the effect of competition on the timing of technology transfers. One of the important conclusions is that a decrease in the number of incumbents and an increase in the number of entrants on the market may inefficiently delay the signature of a license contract, or more generally, that competition has two countervailing effects on the efficiency of markets for technology.

We present a model of sequential bargaining that incorporates a number of elements that characterize markets for technology in practice. Of particular importance is the asymmetry of information between the buyer and seller of an idea. Despite the complexity that it shares with other models of sequential bargaining, we are able to obtain testable predictions that are confirmed by our empirical analysis. Empirically, our results on the effect of competition on licensing of pharmaceuticals are economically significant: the percentage change in the probability of late signing for a one-percent change in the number of incumbents is -0.31 and the corresponding figure for entrants is 0.17.

The ambiguous effect of competition on delays in licensing appears to be robust: we obtain similar results with a bargaining model and with an auction model. Though the pharmaceutical industry is particularly well-suited for our application, our results should be relevant in any industry where the division of labor in the innovative process exists, where early stage innovators have better information on the quality of their innovation than later developers, and where innovators face a higher cost of providing information about quality through the development process than do potential buyers. For example, ideas generated in a university setting may be difficult to transfer because academic scientists may face a very high cost of proving their quality.

Our model is not specifically designed to analyze the issue of mergers, but our results suggest that merger reviews in highly technological areas should consider this additional effect of the merger on upstream licensing markets. The pharmaceutical industry has undergone significant consolidation in recent decades, particularly between the large multinationals that are the typical buyers of licenses. However, there is much concern regarding a slowdown of innovation in this industry that the widespread use of licensing has failed to reverse. This paper highlights some frictions in licensing and the role of

competition that may at least partially explain these patterns.

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8 Appendix (not to be published)

Proposition 1

Consider the case where all negotiation failed before the last sequence in the second period. Consider the bargaining session with the last buyer. If a license is signed at a price p, the buyer receives $\pi - p$ and the innovator p, whereas if the negotiation fails they respectively receive π_0 (as the current negotiation is the last one, no license will be signed if it fails) and κ. As ϵ converges to zero, Binmore et. al. (1986) show that the bargaining outcome is defined by the Nash bargaining solution where the surplus is split equally. Under Assumption 1, $\pi - \pi_0 \geq \kappa$, and thus there is room for an agreement. The continuation equilibrium is thus such that a license is indeed sold to the last buyer at a price $p_2(1)$ defined by:

$$p_2(1) - \kappa = \pi - p_2(1) - \pi_0 \;\Rightarrow p_2(1) = \tfrac{1}{2}(\pi - \pi_0 + \kappa)$$

Consider now the previous negotiation rounds in the second period. When ϵ converges to zero we show the following recursive property:

$\mathbf{P_k}$: *When there are $k > 1$ buyers left in the sequence, a license is sold at a price $p_2(k)$, where:*

$$\mathbf{p_2(k)} = \left(\frac{\mathbf{1}}{\mathbf{2}}\right)^{\mathbf{k}} (\kappa + \pi_\mathbf{l} - \pi_\mathbf{0}) + \left(\mathbf{1} - \left(\frac{\mathbf{1}}{\mathbf{2}}\right)^{\mathbf{k}}\right)(\pi - \pi_\mathbf{l})$$

We first show this property for $k = 2$, i.e when there are only two buyers left in the sequence. Consider the negotiation between the innovator and the buyer before last ($k = 2$), assuming that all previous negotiations failed. Both firms anticipate that if they do not sign, bargaining with the last buyer will succeed: default options are thus π_l for the buyer and $p_2(1)$ for the innovator. If a license is signed, the price is determined by an equal split of the surplus and the recursive relation is therefore

$$p_2(2) - p_2(1) = \pi - p_2(2) - \pi_l$$

Using the value of $p_2(1)$ previously derived, we find:

$$p_2(2) = \left(\frac{1}{2}\right)(\kappa + \pi_l - \pi_0) + \left(\frac{1}{2}\right)(\pi - \pi_l)$$

The last step is to show that a license is indeed signed, i.e $\pi - \pi_l > p_2(1) \Leftrightarrow \pi - 2\pi_l + \pi_0 - \kappa > 0$. This condition is satisfied because of Assumption 1 and the fact that $\pi_0 > \pi_l$. Therefore, property P_2 is correct.

$\mathbf{P_{k-1}} \Rightarrow \mathbf{P_k}$: Consider the case where k buyers are left in the sequence. Because of property P_{k-1}, the buyer and the innovator know that a license will be signed with the next buyer in the sequence, if they fail to agree.[13] Therefore, an equal split of the surplus gives:

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

According to P_{k-1}

$$p_2(k-1) = \left(\frac{1}{2}\right)^{k-1}(\kappa + \pi_l - \pi_0) + \left(1 - \left(\frac{1}{2}\right)^{k-1})(\pi - \pi_l\right)$$

Replacement in the previous expression gives:

$$p_2(k) = \left(\frac{1}{2}\right)^{k}(\kappa + \pi_l - \pi_0) + \left(1 - \left(\frac{1}{2}\right)^{k}\right)(\pi - \pi_l)$$

The last step is to show that a license is indeed signed, i.e there is room for bargaining: $\pi - \pi_l > p_2(k-1)$. This is equivalent to $\pi - 2\pi_l + \pi_0 - \kappa > 0$, property already shown to be correct. We have thus shown that P_k is correct.

The result stated in Proposition 1 is property $\mathbf{P_k}$ for $k = n$ buyers initially in the sequence.

Proposition 2

Note first that there cannot exist a separating equilibrium with signature in the first period, as a buyer would not pay a higher price for a license with a bad type, and if the

[13] 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 $(1-\epsilon(k-1))\pi_l + \epsilon(k-1)\pi_0$. As ϵ converges to zero we obtain the reported disagreement points.

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price for the good type were higher a bad type innovator would always profitably deviate by mimicking a good type. We therefore focus on pooling equilibria. Note then that if $\Delta > p_2(n)$, then if no license is signed in the first period, the innovator does not develop the product. Thus, when the innovator negotiates with the last buyer in the sequence in period 1, her outside option is zero. Bargaining will therefore necessarily succeed in period 1. For the rest of the proof we thus concentrate on the case $\Delta \leq p_2(n)$. Note that the condition stated in Proposition 2 is $\Delta \geq \underline{\Delta}(n) = p_2(n) - q(\pi - \pi_l)$ where $\underline{\Delta}(n) < p_2(n)$ (see proof of Proposition 3). Thus if we show that the result of Proposition 2 holds for $\Delta \leq p_2(n)$ we have completed the proof.

Step 1: If the condition of Proposition 2 is satisfied then, in all PBNE, a license is signed in the first period

Suppose there exists a PBNE such that the license is signed in period 2. We know in period 2, bargaining immediately succeeds if the innovation is good, and the price paid is $p_2(n)$.

Consider the last bargaining session in period 1. Consider a round where the buyer makes an offer. If he offers a price $p' > p_2(n) - \Delta$ this offer is accepted by both types of innovators. Indeed the best the innovator can hope for in equilibrium is to obtain $p_2(n)$ in the following period and he will have to pay Δ to develop the product from period 1 to period 2. With this offer, the utility of the buyer is $q\pi + (1-q)\pi_0 - p'$.[14] If he waits for period 2, his expected utility is $q\pi_l + (1-q)\pi_0$. The condition given in Proposition 2 guarantees that there exists a price p', acceptable to both types of innovators ($p' > p_2(n) - \Delta$) such that: $q\pi + (1-q)\pi_0 - p' > q\pi_l + (1-q)\pi_0$. There is therefore no PBNE where the license is signed in period 2 since we can always construct a profitable deviation.

Step 2: If the condition of Proposition 2 is not satisfied then in all PBNE, the license is signed in the second period

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

[14] Note that in a PBNE beliefs must be consistent on the equilibrium path so that the buyer expects the quality of innovation to be good with probability q.

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Consider first inside this session a round where the innovator makes the offer. For a good type innovation she always asks for a price $p_t \geq p_2(n) - \Delta$ as she knows she can guarantee herself at least $p_2(n) - \Delta$ by developing the product herself. 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 buyer. If the buyer accepts the offer, he obtains an expected payoff of $q'\pi + (1 - q')\pi_0 - p_t$. However, he never accepts an offer that yields a smaller payoff than what he can guarantee himself if he rejects all offers and obtains his outside option $q'\pi_l + (1 - q')\pi_0$. So, if $q'(\pi - \pi_l) < p_2(n) - \Delta$ no equilibrium offer by the innovator is acceptable to the buyer.

Consider now a round where the buyer makes an offer. In equilibrium he offers a price p_t that is such that $q'\pi - p_t \geq q'\pi_l$. Furthermore, he knows that all offers lower than $p_2(n) - \Delta$ will be rejected by the good type innovator and might be accepted by the low type. Such an offer is never made in equilibrium. So if $q'(\pi - \pi_l) < p_2(n) - \Delta$, no equilibrium offer by the buyer is acceptable to the innovator.

Finally, in all equilibria, $q' = q$. Indeed, given that there is an exogenous probability of breakdown η before each session, a bargaining session between the innovator and the last buyer in the sequence is on the equilibrium path regardless of the equilibrium. Therefore, the last buyer 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, in any PBNE no license is signed in the subgame where the innovator negotiates with the last buyer in the sequence. In any PBNE, when the innovator bargains with the buyer who is the one before last in the random sequence, both know that the negotiations will fail in the last round of negotiations in period 1. The continuation values are then identical to those of the last and we find that the same condition applies to all potential buyers but the first one in the sequence. The outside option of the first potential buyer to negotiate is higher than that of his competitors, as he anticipate that he will be the one who signs a license in the second period: he therefore has even less incentives to buy a license in the first period than his competitors. Reasoning recursively we can conclude that if the condition is not satisfied, no agreement can be reached in period 1.

Existence of an equilibrium

We show here that under the condition of Proposition 2, there exists a pooling equilibrium where a license is signed in the first period and firms have passive beliefs.

Assume that:

$$p_2(n) - \Delta \leq q(\pi - \pi_l)$$

There exists an equilibrium where a license is signed with the first buyer to negotiate in the first period. The following strategies sustain this equilibrium:

- If negotiation starts with the $n-k+1_{th}$ potential buyer in the sequence, and if this buyer believes that the innovation is good with probability q':
  - In any round where the buyer makes the offer, it offers $p_1(k) \equiv q(\pi - \pi_l)(1 - \frac{1}{2^k}) + \frac{1}{2^k}(p_2(n) - \Delta)$;
  - In any round where the seller makes the offer, it offers $p_1(k)$;
  - In any round where the seller makes the offer, the buyer accepts the offer if and only if it is lower than or equal to $p_1(k)$;
  - In any round where the buyer makes the offer, the seller accepts the offer if and only if it is higher than or equal to $p_1(k)$.
- Initially, all potential buyers share the same prior belief regarding the quality of innovation (that it is good with probability q). We assume that out-of-equlibrium beliefs are passive (*i.e.* if a buyer receives an out-of-equilibrium offer, he does not modify its beliefs: see McAfee & Schwartz (1994).

Note that a bad innovator mimics the strategy of a good innovator. We show that there is no profitable deviation from this equilibrium candidate. If all negotiations fail in the first period, we have characterized in Proposition 1 the second period continuation equilibrium outcome. We consider now the first period.

There is no profitable deviation in this bargaining sequence:

- If the seller deviates by asking for a higher price $p_D \geq p_1(k)$ in a round where it makes the offer, with passive beliefs the buyer does not revise its beliefs. The buyer thus does not accept the offer.

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- If the seller deviates by asking for a lower price $p_D \leq p_1(k)$ in a round where it makes the offer, with passive beliefs the buyer does not revise its beliefs. The buyer accepts the offer but this deviation is not profitable for the seller, irrespective of its type, as it can obtain $p_1(k)$ in the next round.

- If the buyer deviates by offering a higher price $p_D \geq p_1(k)$ in a round where it makes the offer, the seller accepts the offer and it is not profitable for the buyer.

- If the buyer deviates by offering a lower price $p_D \leq p_1(k)$ in a round where it makes the offer, the seller will not accept the offer.

Proposition 3

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

$$p_2(n) = (\pi - \pi_l) - \frac{1}{2^n}(\pi - 2\pi_l + \pi_0 - \kappa)$$

Furthermore, Assumption 1 and $\pi_l \leq \pi_0$ imply that $\pi - 2\pi_l + \pi_0 - \kappa > 0$. Thus, $p_2(n)$ increases with n.

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

$$\begin{aligned} \Delta &\geq \underline{\Delta}(n) \\ \text{where } \underline{\Delta}(n) &= p_2(n) - q(\pi - \pi_l) \end{aligned}$$

We have

$$\underline{\Delta}'(n) = [\pi - 2\pi_l + \pi_0 - \kappa]\ \frac{\ln(2)}{2^n}$$

Therefore $\underline{\Delta}(n)$ is increasing in n.

Proposition 4

In the case where profits depend on n, we find:

$$p_2'(n) = (\pi'(n) - \pi_l'(n)) + \frac{\ln(2)}{2^n}(\pi(n) - 2\pi_l(n) + \pi_0(n) - \kappa) - \frac{1}{2^n}(\pi'(n) - 2\pi_l'(n) + \pi_0'(n))$$

Furthermore, we examine how the benchmark $\underline{\Delta}(n)$ varies with n

$$\underline{\Delta}'(n) = p_2'(n) - q\left[\pi'(n) - \pi_l'(n)\right]$$

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

$$\lim_{n\to+\infty} \underline{\Delta}'(n) = \lim_{n\to+\infty} (1-q)\left(\pi'(n) - \pi_l'(n)\right)$$

Under the condition of Proposition 4, $\lim_{n\to+\infty} \underline{\Delta}'(n) \leq 0$ and thus the probability of signing in period 1 increases in n.

Cost reducing innovation under Cournot competition

Assume that the n buyers initially produce a homogenous good at the same constant marginal cost c. They compete in quantities and demand is assumed to be linear: $D(p) = 1 - p$, where p is the price of the good. The outcome of a good type innovation is a new process that reduces the production cost to zero (a bad innovation does not modify the production cost). We also assume that the innovator's outside option is $\kappa = 0$.

The initial profits on the product market are $\pi_0(n) = \frac{(1-c)^2}{(n+1)^2}$. Signing a license for a good innovation results in asymmetric competition, as the cost of the licensee is lower than that of his competitors. If the innovation is good, the licensee thus receives $\pi(n) = \frac{(1+c(n-1))^2}{(n+1)^2}$ whereas his competitors receive $\pi_l(n) = \frac{(1-2c)^2}{(n+1)^2}$. Given these payoffs, Assumption 1 holds. Note that the innovation is drastic and the licensee becomes a monopoly if $c \geq \frac{1}{2}$. We only consider the more interesting case where $c < \frac{1}{2}$.

We can show that the condition of Proposition 4, $\pi'(n) \leq \pi_l'(n)$, is satisfied in this case. Therefore, for large values of n, the efficiency threshold $\underline{\Delta}(n)$ decreases in n (the condition for signing a license is easier to meet). Straightforward comparative statics reveal that the threshold decreases in q, and can even become negative for low values of n, in which case a license is always signed in the first period. Figure 3 plots the threshold in the case $c = 0.1$ for several values of q. The threshold has an inverted U-shape in n.

Bertrand competition with differentiated products

Consider another example based on a differentiated goods model. Assume that the n buyers initially sell n symmetrically differentiated goods with a constant marginal cost c.

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They compete in prices. Following Motta (2004), we derive a simple model of consumer preferences from Shubik & Levithan (1980): the consumer's utility is given by

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

where q_i is the quantity of good i consumed, μ is the degree of product substitution between the goods ($\mu \in [0, +\infty]$) and v is positive and larger than c. The demand for each good is thus: [15]

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

The innovation corresponds to the introduction of a new product. If no license is signed, the market is composed of n symmetric firms with differentiated products. If one firm, say n, signs a license with the (good) innovator, it introduces a new product. The competition game is now asymmetric, with the licensee selling two of the existing $(n+1)$ products. We derive below equilibrium prices and profits:

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

$$\begin{aligned} p_i &= c + \frac{n(v-c)}{2n+\mu(n-1)} \\ \pi_0(n) &= \frac{(v-c)^2(n+\mu(n-1))}{(2n+\mu(n-1))^2} \end{aligned}$$

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

Firm n's profit is now

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

[15] Note that in this model, aggregate demand is independent of the substitution between the products, and does not change with the number of products if all prices are equal.

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

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

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

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

and the profits are

$$\begin{aligned} \pi &= \Pi_n = \frac{(c-v)^2(1+n+\mu(n-1))(2+\mu+2n(1+\mu))^2}{2(1+n)^2(2-\mu^2+n(\bar{1}+\mu)(2+\mu))^2} \\ \pi_l &= \Pi_i = \frac{(c-v)^2(1+n+\mu n)^3}{(1+n)^2(2-\mu^2+n(\bar{1}+\mu)(2+\mu))^2} \text{for } i \in \{1, ..., n-1\} \end{aligned}$$

Given these results, Figure 4 plots the efficiency threshold for $c = 0.1, \mu = 0.5$ and $v = 1$ for several values of q. Though the sufficient condition of Proposition 4 is not always satisfied, the efficiency threshold has an inverted U-shape in the example we give.

Proposition 5

Claim: *In equilibrium the license is signed in period 1 iff the following conditions are satisfied:*

$$\Delta > \widehat{\Delta}(n, e) = p_2^{E,I}(e, n) - q\pi_e$$

where $p_2^{E,I}(e, n)$ is the price in the second period where the license is sold to the first entrant at a price:

$$p_2^{EI}(e, n) = (1 - \frac{1}{2^e})\pi_e + \left(\frac{1}{2}\right)^{n+e}(2\pi_l - \pi_0 - \pi) + \tfrac{1}{2^e}(\pi - \pi_l)$$

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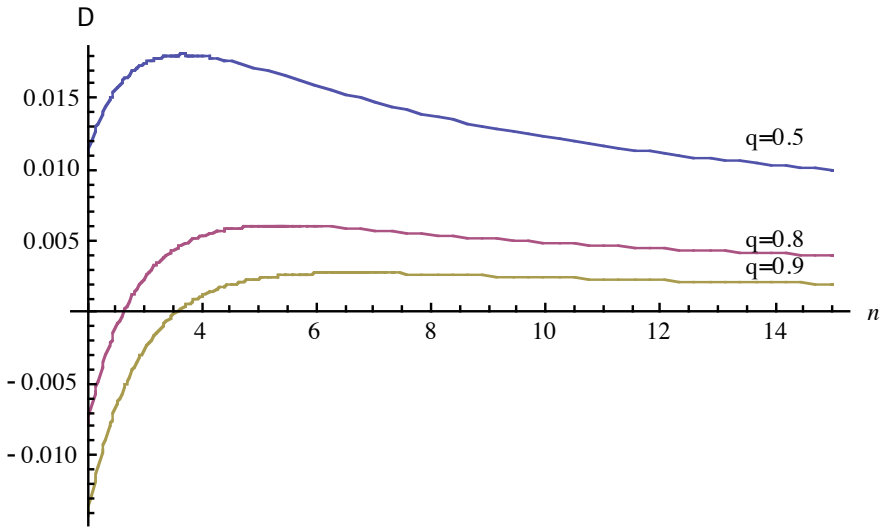

Figure 3: Cournot $c = 0.1$

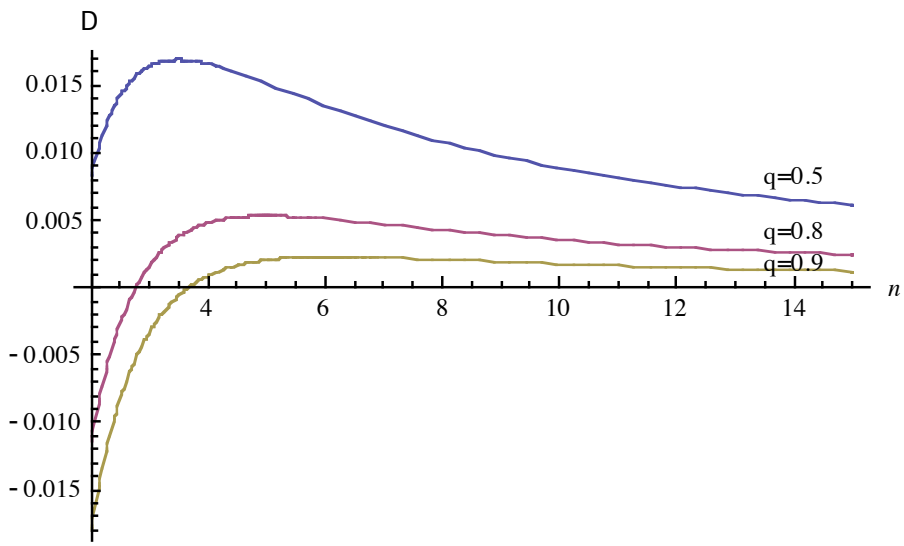

Figure 4: Bertrand $c = 0.1$, $\mu = 0.5$, $v = 1$

Proposition 5 is then a direct consequence. Indeed we have:[16]

$$\widehat{\Delta} = p_2^{E,I}(e,n) - q\pi_e = (1-q)\pi_e + \tfrac{1}{2^e}\left[\pi - \pi_l - \pi_e + \left(\frac{1}{2}\right)^n (2\pi_l - \pi_0 - \pi)\right]$$

We therefore have:

$$\frac{\partial\widehat{\Delta}}{\partial e} = -ln(2)\tfrac{1}{2^e}\left[\pi - \pi_l - \pi_e + \left(\frac{1}{2}\right)^n (2\pi_l - \pi_0 - \pi)\right] > 0$$

and

$$lim_{e\to+\infty}\frac{\partial\widehat{\Delta}}{\partial n} = (1-q)\frac{\partial\pi_e}{\partial n} < 0$$

Proof of the claim:

Second period The sequence of bargaining in both periods is e entrants followed by n incumbents. In period 2, if bargaining fails with the e entrants, under Assumption 1 a license will be signed with the first incumbent at a price $p_2^{EI}(0,n) = \left(\frac{1}{2}\right)^n(\pi_l - \pi_0) + \left(1 - (\frac{1}{2})^n\right)(\pi - \pi_l)$ (same reasoning as for equation (2) in Proposition 1).

Consider the second period negotiation with the last entrant. If bargaining fails, the innovator obtains $p_2^{EI}(0,n)$ and the entrant 0. If it succeeds, the innovator gets $p_2^{EI}(1,n)$ and the entrant $\pi_e - p_2^{EI}(1,n)$. The equal split of the surplus implies:

$$p_2^{EI}(1,n) = \frac{1}{2}(\pi^e + p_2^{EI}(0,n)) = \frac{1}{2}\pi^e + \left(\frac{1}{2}\right)^{n+1}(2\pi_l - \pi_0 - \pi) + \tfrac{1}{2}(\pi - \pi_l)$$

If it starts, negotiation with the last entrant succeeds since $\pi_e > \pi > p_2^{EI}(0,n)$ implies $p_2^{EI}(1,n) > p_2^{EI}(0,n)$. Note that $p_2^{EI}(1,n) < \pi_e$.

Consider the second period negotiation with the entrant before last. If bargaining fails, the innovator obtains $p_2^{EI}(1,n)$ and the entrant 0. If it succeeds, the innovator gets $p_2^{EI}(2,n)$ and the entrant $\pi_e - p_2^{EI}(2,n)$. The equal split of the surplus implies:

$$p_2^{EI}(2,n) = \frac{1}{2}(\pi^e + p_2^{EI}(1,n)) = (1 - \frac{1}{2^2})\pi^e + \left(\frac{1}{2}\right)^{n+2}(2\pi_l - \pi_0 - \pi) + \tfrac{1}{2^2}(\pi - \pi_l)$$

Note that $p_2^{EI}(2,n) > p_2^{EI}(1,n)$. As a consequence, under Assumption 1, if negotia-

[16] Since $\pi^e > \pi$ and by Assumption 1, $2\pi_l < \pi_0 + \pi$

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tions start in the second period, signature occurs with the first entrant at a price

$$p_2^{EI}(e,n) = (1 - \frac{1}{2^e})\pi^e + \left(\frac{1}{2}\right)^{n+e}(2\pi_l - \pi_0 - \pi) + \tfrac{1}{2^e}(\pi - \pi_l)$$

First period

We now show that a license is signed in period 1 if and only if:

$$\Delta > \widehat{\Delta}(n,e) = p_2^{E,I}(e,n) - q\pi_e \tag{5}$$

First step: suppose condition (5) is satisfied and a license is signed in period 2.

We show that then, in any PBNE, there exists a deviation in the first period. Consider negotiation with the last entrant in period 1. If the negotiation fails, this entrant knows he will not sign a license and will make zero profits.[17] If he signs he expects a profit π_e: in a round where he makes an offer, he can offer a price larger than $p_2^{E,I} - \Delta$ and get a larger surplus than by waiting if condition (5) is satisfied; Such an offer will be accepted by both types of innovators, and this constitutes a deviation from the candidate equilibrium.

Second step: Suppose condition (5) is not satisfied. Then we show a license is signed in the second period.

Following the same logic as Proposition 2, we know that in this case, if $p_2^{E,I}(e,n) - \Delta > q(\pi - \pi_{le})$, no profitable deviation is possible in negotiation with the last incumbent in period 1. This condition is implied by the fact (5) is not satisfied since $\pi_e > \pi$. The same logic applies for all the previous incumbents who effectively become the last.

Given condition (5) we also know that none of the entrants other than the first will sign in period 1 either. Consider finally the negotiation with the first entrant in the sequence. If he signs in period 1, his expected reward is $q\pi_e$ while if he waits, his expected profit is $q(\pi_e - p_2(0,e))$. So if $q\pi_e - q(\pi_e - p_2(0,e)) < p_2(0,e) - \Delta$. Since $p_2(0,e) \leq \pi_e$, this condition is implied by by the fact (5) is not satisfied. We have shown that therefore there is no deviation in the first period.

Proposition 6

The proof is similar to the proof of Proposition 2 except that the buyer has no private information in the first period and believes his innovation is good with probability q. The

[17] Since the order is identical in the second period

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condition for signing in period 1 thus becomes

$$q(\pi - \pi_l) \geq qp_2(n) - \Delta$$

This is equivalent to

$$\Delta \geq \underline{\Delta}(n) = q(\pi_l - \pi + p_2(n))$$

In Proposition 1 we established that $p_2(n) < \pi - \pi_l$ and thus $\underline{\Delta}(n) < 0$ for all values of q and n.

Proposition 7

Second period

In the second period, the type of the inventor is known. The reservation price fixed by the innovator is κ, her outside option. The unique equilibrium is such that all buyers bid exactly their valuation (equilibrium bidding strategy in a second price auction). Thus in the second period

$$p_2(n) = \pi(n) - c_{n2} \tag{6}$$

where c_{n2} is the second lowest cost among n draws of the cost parameter.

First period

In the first period, the equilibrium is defined by:

- Bidding strategies for the buyers
- Reservation price r chosen by the good type innovator (bad type innovator always sets zero reservation price in first period)

For a given reservation price r, we show that the unique equilibrium is such that a player with cost c bids his valuation $q[\pi - c]$ if it is above r and bids zero if it is below.

If $q[\pi - c] < r$, in equilibrium, the buyer bids zero. Indeed, any bid above $q[\pi - c]$ would give a loss in expectation and any bid below is accepted only by the low type

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innovator since $q[\pi - c] < r$. In what follows we show that in the case where $q[\pi - c] > r$, the unique equilibrium strategy is to bid the valuation $q[\pi - c]$.

We first note that, for a buyer with cost c, bids strictly above $q[\pi - c]$ are dominated by bids equal to zero. We eliminate such strategies. After elimination of these strategies, we show that bidding exactly $q[\pi - c]$ is a dominant strategy for a player with cost c. Consider a bid $b < q[\pi - c]$. There are three cases to be considered:

Case 1 bid b is the highest bid. In that case bidding $q[\pi - c]$ does not change the outcome (outcome purely determined by the second highest bid).

Case 2 bid b is not the highest bid and the second highest bid is above the reservation price r. We denote b_1 the highest bid in that case. If $b_1 > q[\pi - c]$ deviating to bidding $q[\pi - c]$ has no effect. If $b_1 \leq q[\pi - c]$, the expected profits if a bid $q[\pi - c]$ is made is $q[\pi - c] - b_1 \geq 0$. Thus bidding $q[\pi - c]$ is preferable to bidding b that gives zero profits.

Case 3 bid b is not the highest bid and highest bid, denoted b_1, is below the reservation price (which means $b_1 \leq q[\pi - c]$). The profits if the buyer bids $q[\pi - c]$ are $q[\pi - c] - b_1 \geq 0$.[18] If $\pi - c$ is not the highest valuation among the n bidders, then the bidder would lose the auction in period 2 and strictly prefers bidding $q[\pi - c]$ this period. If he has the highest valuation, we denote $\pi - c_{n2}$ the second highest valuation. In the second period, if the innovation is good he will win the auction and make profits $\pi - c - (\pi - c_{n2})$. So, if he does not deviate, his expected profits are $q(c_{n2} - c)$. If he deviates and bids $q[\pi - c]$, his profits are $q[\pi - c] - b_1$. Since for a player with cost c, we eliminated the dominated strategy of bidding strictly more than $q[\pi - c]$, we know that $b_1 \leq q[\pi - c_{n2}]$. So when he bids $q[\pi - c]$ the bidder expects profits greater than $q[\pi - c] - b_1 \geq q[\pi - c] - q[\pi - c_{n2}] > q[c - c_{n2}]$.

We have therefore shown by elimination of weakly dominated strategies, that, for any reservation price r, the unique equilibrium is such that a player with cost c bids his valuation $q[\pi - c]$ if it is above r and bids zero if it is below.

We now show that if she runs an auction in the first period, the innovator chooses a zero reservation price. If the second highest bid is below the reservation price, the auction is run again in the next period. We note however that the incentives to wait are higher when the valuations are higher. Indeed, given the strategies of the bidders in the

[18] We assume that as long as the highest bid is above the reservation price, the sale occurs at the second highest bid, even if it is lower than the reservation price: assuming that the price paid is the reservation price would not qualitatively change our results.

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first and second periods, if the second highest bid is b in the first period, then the second highest bid would be b/q in the second (since in the first the players bid their valuation times the probability the type is good). So the innovator should accept the first period bid if:

$$b \geq \frac{b}{q} - \Delta \Leftrightarrow b \leq \frac{q}{1-q}\Delta$$

The incentives to wait are higher for higher valuations, so no reservation price is placed (for low values the innovator wants to sell now).

In the first period the innovator has to decide whether or not to run an auction. Her expected profit in an auction is $q[\pi - E[c_{n2}]]$. If she decides to wait for the second period to conduct the auction, she expects profits $\pi - E[c_{n2}] - \Delta$ if she is a good type, and zero otherwise. Thus a good innovator runs an auction in the first period if and only if

$$\Delta \geq (1-q)(\pi - E[c_{n2}])$$

As Δ is known by all potential buyers, running an auction in the first period if this condition is not satisfied signals a bad type innovator, and no buyer bids a positive price: such a deviation is therefore not profitable.

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