Waiting for the payday? The market for startups and the timing of entrepreneurial exit ♣

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Abstract

While many technology startups are set up for exit through acquisition by large corporations, they strategically choose when to sell out to maximize their expected payoffs. Early acquisitions reduce execution errors but fewer potential buyers may make them less attractive for startups. The timing of a technology-based acquisition depends, however, on complementary decisions by buyers, because early acquisitions require investment in absorptive capacity. In this paper, we build a model to capture this complexity and the related tradeoffs. Counterintuitively, we find that the early market for startups is inefficiently thin when startups have to make a large sunk investment to develop further the invention for a late acquisition. Under these circumstances, the availability of venture capital or the location in a technology cluster, by helping startups survive through later stages, increase the gap between value creation and value capture. Instead, when startups can freely move between the early and the late market, there are too many early acquisitions and too much investment in scientific research by incumbents. Venture capital improves matters by reducing early acquisitions.

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Given the much extended path to self-sustaining positive cash flow from operations, the responsible entrepreneur and VC are charged with asking themselves the same question at each step along the way: ... Do we sell now?

William Janeway, Warburg Pincus. https://medium.com/the-wtf-economy/enterprise-software-death-and-transfiguration-99eb1d3fc4c0

1. Introduction

The division of innovative labor between small startups and established incumbents has grown in importance.[1] Inventions begin their journey to commercialization in startups. After a period of incubation and development, the invention can be passed on to an incumbent, typically with an incumbent buying the startup.[2] There are natural inflection points in the lifecycle of a startup, when it can be acquired or can choose to persist and move the technology closer to commercialization (Graebner and Eisenhardt, 2004; Allain et al. 2016). In this paper, we analyze at what stage the original inventor is acquired, and whether this is too early or too soon as compared to what would maximize value creation. An early acquisition can be thought as taking place at the invention stage. The acquirer invests to develop the invention, and subsequently, to scale-up and commercialize. Alternatively, the inventor can invest in development itself, and if successful, present the acquirer with a more fully developed innovation.

The timing of sale matters for two reasons that pull in opposite directions. On the one hand, startups are often less efficient at developing inventions. To anticipate our model, startups have a greater likelihood of failing even if the underlying technology is good. For instance, they may not hire the right people, develop the product for the wrong market, or try to develop it for too many markets and succeed at none, or simply run out of money (e.g., Arora and Nandkumar, 2011). Established firms have developed routines for commercializing inventions that are less prone to execution failures.[3] These firms already possess sales and marketing channels, manufacturing capability, logistics and distribution, and other complementary resources (Teece,

[1]Arora, Cohen and Walsh (2016) show that nearly 50% of US manufacturing firms that introduced an innovative product between 2007 and 2009 obtained the invention externally, and that startups were disproportionately important as sources of invention.

[2] Out of the 83 startups in the US medical device industry, which had an exit in Cunningham (2017), 71 were acquired. Mathisen and Rasmussen (2016) similarly point to acquisitions as the most frequent exit strategy for successful Norwegian startups.

[3] Incumbents may be worse at commercializing disruptive inventions, which do not fit their existing models (Christensen, 1997).

1986). Instead, startups have to create them from scratch. Mistakes and missteps are only natural. On the other hand, early stage markets tend to have fewer buyers than later stage markets. If the value created by a startup is idiosyncratic to a buyer, having more potential buyers increases total value. This sets up a tradeoff for the startup: Create and capture more value by getting acquired when the startup and its invention is more mature, but run a greater risk of failing due to poorer execution.

There is another important player in this process, namely the potential buyer. Buying early stage startups requires absorptive capacity—the ability to evaluate the technology and the ability to develop the nascent technology and use it (Cohen and Levinthal, 1989). Buyers may have to be structured differently to absorb nascent startups as compared to later-stage startups with more mature organizations and technology (Arora, Belenzon and Rios, 2014). Naturally, startups wishing to sell at an early stage will do better when there are more early stage buyers and vice versa.

The timing of startup sale is a relevant decision in practice both for the seller and the buyer. Foursquare, a local search-and-discovery service mobile app based in New York City, was offered $100 million by Yahoo, as well as by Facebook, one year after its launch in 2010, but both of these offers were turned down. Receptos, a San Diego-based biotechnology company, waited 7 years from its foundation before it accepted a multibillion offer from Calgene that outbid AstraZeneca, Teva and Gilead. However, the counterfactual is unclear. Failure rates among technology startups are extremely high, so we do only observe a few successful stories.[4] For instance, Maine and Thomas (2017) provide the example of an MIT startup, BIND, which raised several rounds of capital to apply its nano-particle drug delivery to new therapies. Though it managed to IPO in 2013, it had to file for bankruptcy in 2016 following a failed clinical trial. It was acquired by Pfizer shortly thereafter for its intellectual property assets. Arguably, BIND would have been better off being acquired at an earlier stage instead of investing in building an organization and clinical trials.

[4] Failure rates of startups are as high as 90% in some industries. Remarkably, biotech companies' success probability in stage III of drug development is lower than the success probability of large pharmaceutical firms in comparable conditions (Guedj and Scharfstein, 2004; Arora et al., 2009).

Despite the importance of the timing of startup sale, there is a dearth of work addressing this phenomenon and the few existing studies we are aware of have predominantly adopted the seller's perspective (Allain et al, 2016; Luo, 2014). One notable exception is Arora, Belenzon and Rios (2014) who empirically analyze the differences in organization structure between corporations that tend to buy early stage ventures and those that focus on acquisitions of larger and more established firms. No one has investigated the interdependence between the two. In this paper, we build a parsimonious model of the equilibrium between early buyers and sellers.

We assume that if incumbent firms decide to participate to the early market they need to invest in absorptive capacity. Startups might go late, despite the execution risks, because in the late market the larger number of buyers promises a higher valuation, other things equal. A crucial determinant of the market outcome is whether startups have to make a strategic choice between going early versus late (Gans et al., 2016) or they are instead flexible and can be sold in both markets. For instance, a strategic choice is required when startups have to make large investments to develop the invention, that are valuable only to later acquirers and that are sunk if the startup is sold early.[5] In this case, startups have no flexibility and are forced to commit to go early versus late before they can view offers from potential buyers.[6] If, however, the investment required to develop the invention is fungible, the startup that enters the early market has always the option to reject all early offers and wait for the late market. The outcomes in the two cases differ in important ways.

We start by assuming that a startup has no flexibility and has to choose whether to go early or late. We find that the number of incumbents that invest in absorptive capacity and the probability of the startup selling early are positively related. As expected, we show that early deals increase

[5] As Gans, Stern and Wu (2016) argue, entrepreneurship implies choosing between alternatives, and once choices are made, some options are extinguished. Interviews by one of the authors with venture capitalists have confirmed that early vs late is a real strategic decision for startups. Indeed, many venture capitalists advise startups to avoid investing in capabilities that are not valuable to acquirers like, for instance, marketing, regulatory affairs, and sales. Instead, a late acquisition can be treated by the buyer as a "stand alone" business, thereby requiring less integration.

[6] Alternatively, early vs late becomes a strategic choice when a significant amount of external finance is required to fund the investment. In this case, the startup has to decide whether to raise the money or not. By not raising the money, the startup *de facto* commits to go early. Conversely, if the startup does raise the money but sells early, the time and effort spent on raising money has little value for the buyer.

when the cost of absorptive capacity relative to the number of startups shrinks, and when there are fewer late stage buyers.

We also find some less expected results. Counterintuitively, when startups have to make large sunk investments to develop the invention, they tend to sell too late. The intuition for this finding is that the difference between value creation (social) and value capture (private) enlarges when there are fewer buyers. As the late market has more potential buyers than the early market because of the cost of developing absorptive capacity, startups go late even when there are considerable execution risks. An important implication of this result is that the availability of venture capital, by helping startups survive through later stages, paradoxically makes things worst by reducing early deals more than it is desirable in terms of value creation.

We then analyze the opposite case where startups observe the offers from early buyers, and decide whether to sell early or wait for the late market. Thus all startups have full flexibility and potentially participate in both markets. Somewhat counter-intuitively, this results in startups accepting too many early offers relative to what would maximize value creation. Compounding the problem, too many incumbents invest in absorptive capacity required to participate in the early market. Venture capital, in this case, plays a positive role by reducing the number of inefficiently early deals and reduces the efficiency gap between value creation and value capture.

When we compare different types of innovation, we find that the relationship between the degree of radicalness (which we model as startups with higher idiosyncratic uncertainty about their market value) and the timing of startup sale is more complex than usually suggested in the literature. Greater uncertainty, which is typically associated with more radical innovations, complicates the negotiations around the terms of the deal (Jeong and Lee, 2015), increases the risk of misappropriation (Luo, 2014) and the chances of biases in the assessments of the value of the invention (Allais et al., 2016). Thus, the resolution of uncertainty delays the time of technology transaction.[7] In our model, although startups with radical inventions prefer, other things equal, to postpone the time of the deal as suggested in extant literature, buyers have greater incentives to invest in absorptive capacity, which in turn makes the early market more

[7] To the extent that the time of an IPO can be equated to the time of a startup's sale, Ferreira, Manso and Silva (2014) show that firms engaged in more explorative research, a presumption for more radical innovations, find optimal to retard their IPO decision.

attractive for startups. The second effect dominates when the cost of absorptive capacity relative to the number of startups is small and when there are fewer late stage buyers. In this case, radical inventions are likely to be acquired early rather than late.

We briefly assess the contribution of our paper vis-à-vis existing work in the following section. Section 3 describes the baseline model, while Section 4 presents our main findings. Section 5 discusses some extensions and Section 6 contains our conclusive remarks. Proofs of formal propositions are in the Appendix.

2. Background literature

Our contribution falls within the literature on markets for technologies and ideas (Arora et al., 2001; Gans and Stern, 2003). Compared to existing work in this research stream, our paper offers three novel elements. First, we analyze the timing of technology transactions, a dimension that has been mostly overlooked, and, as we argued in the introduction, has profound implications for firms' choices and value creation. Second, our research foresees technology acquisitions as the outcome of both demand and supply. Usually, the two sides of technology markets have been studied in isolation (Arora and Gambardella, 2010; Gans and Stern, 2010; Laursen et al., 2010). Specifically, we analyze the interaction between the decision to invest in scientific capabilities by large corporations and the choice of when to sell by startups. We show indeed that such considerations lead to insights and conclusions that could not have been reached with extant approaches. Finally, we analyze how the market outcomes differ from the value maximizing outcomes.

Given the complexity of these interrelated actions and choices, we develop below a formal model. Compared to a more conceptual approach, it has at least three advantages: it explicitly clarifies the main assumptions driving the results; it provides precise mechanisms and implications that could potentially be tested empirically; and it allows us to define more clearly the boundary conditions of our theory.

To the best of our knowledge, there is only a handful number of papers explicitly modeling the timing of technology transactions. Luo (2014) develops a model where a screenwriter must decide whether to sell a storyline for a movie or a complete script, i.e. to time the sale early or late in the development process. Earlier ideas are subject to greater information asymmetry and enjoy weaker IPRs protection, as startups with functioning products and services are better protected than a mere technology. She finds that both the best and the worst ideas are sold later, but for two different reasons. High-quality ideas generate more value and the seller captures a larger share in the late market where expropriation risk is muted. Instead, low-quality ideas cannot be sold in the early market because the buyer prefers to delay its investment till more information about the true value of the storyline is revealed to the market. Our model is different because we take a market perspective rather than a transaction perspective. In addition, our results do not rely on asymmetric information between sellers and buyers. Finally, we analyze the equilibrium in the market for technology and study its efficiency.

The work by Allain et al (2016) is probably the closest to ours. They build a model to study how the decision about the timing of technology licensing in the pharmaceutical industry depends on the number of buyers. They assume that sellers are overconfident about the quality of their technology and thereby delay licensing in the hope that additional (positive) information is revealed to the market. Delaying, however, is not costless as the seller has to incur in a fixed cost, which is value destroying. Akin to our model, the price of the technology is the outcome of a second price auction. They find that a larger number of buyers increases the value captured by the seller and thus makes the startup keener to delay the deal, but it also increases competition and thus reduces buyers' willingness to pay, which makes later deals less appealing. Combining these two effects, they show that a larger number of buyers from neighboring drug classes always increases delays, while incumbent buyers in the same drug class might reduce delays, under certain conditions.[8]

Our paper introduces three key differences with respect to Allain et al. (2016): First, we endogenize entry by buyers in the early market and we model the market for startups in the early and late stage. Thus, we allow the number of early buyers and the likelihood of the startup selling early to be jointly determined in equilibrium. Second, we analyze when technology transactions are made inefficiently too late. By contrast, in Allain et al. (2016), an early sale is always efficient but the startup either participates in an early market or in the late market (with the same number of buyers). Third, we also distinguish cases where the startup has to commit ex-

[8] This is consistent with the basic assumption in our model, namely that experienced buyers, who presumably are more likely to participate in the early market, increase the likelihood of an early deal, whereas an increase in inexperienced buyers reduces the likelihood of an early deal. Unlike Allain et al. (2016), we do not model product-market competition among buyers.

ante (i.e. before observing the offers) to go early or not, versus the case analyzed by Allain et al. (2016), where the startup observes the offers in the early market and then decides whether to accept them or wait.

Two other papers have looked at the timing of technology licensing and studied how it depends on features of the patent system. Gans, Hsu and Stern (2008) show that licensing deals occur earlier when patent rights are more clearly defined. Indeed, they show empirically that there is a bulk in the probability to license a patent around grant date. Along the same line, Hegde and Luo (2016) argue that mechanisms that make information about technology public reduce the time to license of patented technology. They provide a model to show that when firms are forced to publish their patented information, licensing is more likely even if the patent has not been granted yet. Together these two papers show that technology transactions occur at an earlier stage when patent rights are better defined and there is more information available about the technology.

In all these papers, some type of asymmetric information plays a crucial role. Instead, our paper assumes that information is symmetric, and focuses on how the number of early buyers and sellers is jointly determined.

Our paper is also related to the literature on technology entrepreneurship. There is an extensive literature on the nature of the exit, especially between an IPO and an acquisition. The literature has typically examined the motives and characteristics of entrepreneurs, or agency problems between founders and investors (e.g., Cumming and Mackintosh, 2003). Bayar and Chemmanur (2011) theoretically study the choice between IPO and acquisition using differences in post exit product market competition. Chemmanur et al. (2016) find that larger, better financed, human capital intensive firms are more likely to IPO as compared to being acquired. These findings are related to our model insofar as IPOs are more likely to be later exits than acquisitions.

3. The baseline model

Our goal is to model transactions in the technology markets, which can occur at two different moments in time: *early*, when the technology is nascent and needs to be developed further; and *late*, when the technology is already developed. One could think about selling a patent or a prototype versus selling a functioning technology or selling a business concept versus selling a company with a product. The key characteristics of early deals are that only buyers who have the absorptive capacity to evaluate and use the nascent technology participate. On the plus side, early acquisitions permit greater efficiency in scale-up.

Technology transactions can also occur in different forms. In some cases, arms' length contracts are enough to transfer both nascent and developed technologies. In other cases, technology is transferred through corporate acquisitions. In our model, a startup holds only one technology and there is no difference between the acquisition of the technology through a contract or the acquisition of the firm. However, the way in which we present it through the rest of the paper is as if the technology transaction necessarily requires the acquisition of the venture.

We now describe each side of the market and the decisions companies can make.

Buyers or incumbent firms

We assume that there is an exogenous number, n, of incumbent firms (buyers) that can acquire as many startups as they like. This implies that buyers are not capacity constrained and that the technologies they can acquire are not substitutes. We revisit this assumption later.[9]

Buyers can always be active in the late market where they acquire developed technologies in more fully formed ventures. However, to take part to the early market, buyers need "absorptive capacity", that is, the ability to understand, assimilate, develop and integrate the nascent technology (Cohen and Levinthal, 1989). Absorptive capacity is the outcome of investments in basic research and scientific capabilities (Rosenberg, 1990), which we model as a fixed cost, T.[10] We denote by m the number of buyers active in the early market. Buyers that have invested in absorptive capacity can both acquire startups in the early market and in the late market.[11]

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[9]This is plausible in the pharmaceutical industry where success probabilities are very low. Therefore, the likelihood that two competing drugs make it to commercialization is quite low. In the extreme case where a firm can only acquire one startup, the model becomes a matching model (Roth and Sotomayor, 1992): either a marriage model (Gale and Shapley, 1962) or an assignment game (Shapley and Shubik, 1972).
[10]Investing in basic research and scientific capability makes it possible to generate invention internally. Given our assumptions of unlimited capacity for buyers and non-substitute technologies, the benefits from internally developed technologies can be modeled as a reduction of T.
[11]There might be organizational reasons for which it becomes difficult to develop nascent technology and integrate fully developed technology at the same time. For instance, an organization that invests in basic research might develop NIH syndrome and resists the acquisition of finished technology. More generally, firms tend to favor either buying early stage startups or more mature firms (Arora et al., 2014). Specifically, firms such as Microsoft that are research intensive are more likely to buy early stage startups compared to less research intensive firms such as Cisco, which buy later stage firms. In biotech, research intensive firms such as Merck focus on early stage biotech firms, whereas Pfizer, whose strength is in

Sellers or startup firms

We denote by *s* the total number of startups, which we assume to be exogenously given. Startups can either sell in the early market (i.e. "go early") or "wait" for a late deal. If they sell in the early market, potential buyers are those firms that have invested in basic research and are therefore able to integrate and develop nascent technology. Instead, if they wait, buyers will compete for their technology in the late market.

Suppose a startup has to invest K_0 in order to reach the late stage (to move from a prototype to a technology or from a business concept to a company). If it invests K_0, it will reach the late stage with probability p. Its value to the i^{th} buyer then is $w+\nu_i$. where w is a common component, and ν_i is an idiosyncratic component. The common component represents the part of the value of the technology on which all buyers agree. The idiosyncratic component is buyer-specific. It represents heterogeneity in the value of the technology, and the specific fit with the buyer's existing products and capabilities. For instance, buyers might be heterogeneous in terms of geographic markets, distribution channels, potential for cannibalization of existing products, breath of applications of the innovation, etc. The ex-ante value of selling to the i^{th} buyer in the late market is therefore $p(w+\nu_i) - K_0$. We assume therefore that the buyer does not need any additional investment in case of a late acquisition. For instance, the target is treated as a "stand alone" business, thus requiring little integration.

At the early stage, before the investment is made, if the startup is acquired by a buyer *i*, the buyer will also invest K_0 and with probability γ will gain value $(w + \nu_i)$.[12] The early buyer's net value is therefore $\gamma(w + \nu_i) - K_0$. The startup is less efficient at developing the technology so that $p < \gamma$, and this inefficiency is orthogonal to the likelihood of success of the early buyer. Specifically, let $p=\gamma\theta$, so that an idea has a lower probability of surviving to the late stage if developed by the startup than by an incumbent that buys the startup. Startups are heterogeneous in their ability to make the transition from a nascent technology to a developed technology. We envision this as an

marketing and sales rather than in research, tends to make larger acquisitions. In this case, buyers are either active in the early market or in the late market and thus their respective number is m and $n - m$. The results are unaffected as long as n-$m > m$.

[12]Acquiring early when the technology is not yet fully developed facilitates its integration into existing products and technologies (Karim and Mitchell, 2004; Luo, 2014; Allain et al., 2016) and avoid its development in a direction that is less compatible with the platforms and products of the buyer (Graebner et al. 2010). The results are unchanged if we allow integration benefits from an early sale.

execution capability (recruiting, manufacturing, sales, marketing) independent of the quality of the underlying technology. This implies that θ differs across startups.

The ex-ante value of selling to the i^{th} buyer in the late market is therefore $\gamma\theta\,(w+\nu_i) - K_0$. It is convenient to write this normalized by success probability (or quality) of the underlying idea as $\theta(w + \nu_i) - K$, where $K = K_0/\gamma$. All startups draw θ from the same distribution $q(\theta)$, and their draws as public knowledge. For tractability, we assume $q(\theta)$ is uniform over $[b, 1]$, where $1 \geq b \geq 0$.

Cost of trying to find an early buyer and the possible need for commitment

For a startup, finding an early buyer can take the focus away from developing the business. Entrepreneurs have many demands on their time. The technology has to be developed, engineers and team members to be recruited, and customers to be wooed. These take effort, and they take time. As a rough rule of thumb, raising a round of financing can take six months. Looking for potential acquirors during this time can be a big distraction if the entrepreneur also wants to continue to develop the business. Moreover, some of the investments being made to develop the business may not be valuable to early acquirors. In some cases, developing the business for the later stage may additionally require greater secrecy, which may not be compatible with trying to sell the startup.

In other words, a startup that wishes to try both the early and late market may incur additional costs relative to startup that chooses one or the other market (see appendix for more details). These costs are likely to depend upon the industry and technology and other features of the environment. We analyze two polar cases. In one, startups have to commit to either going early or late. If they try the early market, this will delay other investments needed for the startup to progress to the late market, and therefore, if the startup does not get acquired in the early market, it must exit the market.[13] This is a reasonable description of the biotech world where development beyond lab and into animals is expensive, and moving into humans is especially expensive. Moreover, acquirers will not derive value from the branding, marketing, sales and regulatory capability built up during this process.

[13] A different motivation for this assumption is that the timing of exit is a strategic choice (see also Gans, Stern and Wu, 2016). A firm that intends to go late will need to raise capital ex ante and hire experienced executives. An early sale, with its lower multiples, will not be consistent with such investments.

The other case is where startups can costless get offers from all the early buyers, and decide whether to accept one or to reject all and continue to develop the business and try the late market. This is likely to occur in many software oriented sectors, where market success is uncertain but technical success is far less so. Startups are flexible; they have always the option to reject all early offers and wait for the late market. For instance, Dropbox started as a solution to a file-sharing problem and grew organically. It reportedly rejected a buyout offer from Apple and remains independent.

Early and late markets

We model the functioning of technology markets as a sealed-bid second price auction (also, known as Vickrey auction) where bidders submit written bids without knowing those of the other participants. The buyer submitting the highest bid ends up acquiring the startup paying the second-highest bid. Auctions provide a convenient micro-foundation, but our results would hold as long as the startup is assigned to the buyer with the highest valuation (in the given market).

We assume that the idiosyncratic component v_i is drawn from a distribution function $H(v)$, for each startup. For tractability, we assume $H(v)$ is uniformly distributed over $[-a, +a]$, so that ν is mean zero and its variance increases with a.[14] The variance of the idiosyncratic component is related to the degree of *radicalness* or novelty of a technology. The intuition is that technologies that constitute a radical step from the status quo generate a more disperse set of realized values. Instead, incremental technology, while they can still be very valuable, display greater convergence about their market value.

Timing

We assume that actions and decisions follow a four-stage game. See table 1 below. In stage I, incumbents decide about investing in absorptive capacity to be active in the early market. In stage II, nature draws the type, θ_j, corresponding to each startup that then chooses between going early versus going late, if it has no flexibility. If the startup is flexible, it will be present in both markets, so it does not have to make a strategic choice. In stage III, if the startup has decided to go early or is flexible, with probability 1, it will receive bids from those m buyers that have

[14] The Uniform distribution is tractable and it is a standard assumption (see, for instance, Ellison et al. 2004). Our results also hold if ν has a generalized extreme value (GEV) distribution.

invested in absorptive capacity. Profits are realized for those startups that have committed to go early, while in the case of flexibility profits are realized if a bid is accepted by the startup. In stage IV, if the startup has chosen to go late or has rejected all bids in the early market, with probability θ_j, it will advance to the late stage and receive bids from all *n* buyers.

Table 1: Timing of the game for the two cases

Case 1: K is large, λ = 0 → strategic choice between early and late			
Stage I	**Stage II**	**Stage III**	**Stage IV**
Incumbents decide about investing in absorptive capacity	Startups decide about going early versus going late	Profits are realized in the early market for all startups going early	Surving startups are sold in the late market
Case 2: K is small, λ = 1 → startups are flexible			
Stage I	**Stage II**	**Stage III**	**Stage IV**
Incumbents decide about investing in absorptive capacity	Startups are flexible	Profits are realized in the early market for those startups that accept the bids	Surving startups are sold in the late market

4. Solving the model

We solve the game backwards by looking at stages III and IV. Because we have assumed unlimited capacity for the buyers, the payoff for each technology deal (i.e., for each startup sold in the market) is independent of the number of sellers. In a sealed-bid second price auction, each buyer bids its private value and the expected price is equal to the expected value of the second-highest bid. Because we have no transaction costs, it also corresponds to the expected payoff of the seller. Instead, for a buyer the expected payoff is the difference between the expected value of the highest bid and the expected price paid for the startup.

Let $v(k, z)$ represent the idiosyncratic component of the k^{th} highest bid out of z bids. Thus, $v(1, z)$ represents the idiosyncratic component of the highest bid with z bidders and $v(2, z)$ the second highest. $V(k, z)$ denotes the expectation of $v(k, z)$.

The following results are from the theory of order statistics:

Lemma 1. Let $H(v)$ be the cumulative distribution function of the idiosyncratic component of buyers' evaluation for a given startup and z the number of buyers. The cumulative distribution functions of the idiosyncratic component of the highest and the second highest bid are respectively: *F( ) = H*^{z} and *G( ) = z H*$^{z-1}$ *- (z – 1) H*^{z}.

Proof: Application of Theorem 5.3.1 in Arnold et al. (1992: 111).

Lemma 2. $\frac{1}{z}[V(1,z) - V(2,z)] = [V(1,z) - V(1,z-1)]$.

Proof: By application of Lemma 1.

Lemma 3. Let $H(v) \sim U(-a, +a)$. Then, $V(1,z) = a\frac{z-1}{z+1}$, $V(2,z) = a\frac{z-3}{z+1}$, $\frac{1}{z}[V(1,z) - V(2,z)] = \frac{2a}{z(z+1)}$.

Proof: By direct substitution.

We can now move to stage II of the game and solve for the decision about the timing of technology transactions by startups.

4.1. Case 1: Strategic choice (K is large, λ = 0)

In this case, the startup has to make a strategic choice between going early versus going late before observing the potential bids in the early market. Thus, its decision is based on expectations of profits in the two markets. Denote the type that is exactly indifferent between selling early and late by $\tilde{\theta}$. Then, $\tilde{\theta}$ is characterized by:

$$\pi_S^E = \tilde{\theta}\pi_S^L. \qquad (1)$$

where π_S^E and π_S^L are the expectations of the profits of the startup in the early and late market. A startup sells early if $\theta \leq \tilde{\theta}$ and late if $\theta > \tilde{\theta}$. So we can obtain:

$$\tilde{\theta} = \frac{\pi_S^E}{\pi_S^L} = \frac{w + V(2,m)}{w + V(2,n)}$$

Notice that the expected profit of the startup is increasing in the number of buyers/bidders, both in the early and the late market. Thus, while an early acquisition increases value because of reduced risks of execution or greater integration benefits (which could be modeled as a parameter scaling up buyers' evaluations—see footnote 12), it might lead to a lower price for the startup because of the lower number of potential buyers in the early market. Note also that absent integration benefits, $\tilde{\theta}$ is meaningful only if $n > m$.

The expected numbers of startups sold early is $\mathrm{s_E} = \mathrm{s}\int_0^{\tilde{\theta}} \mathrm{q}(\theta)\mathrm{d}\theta$ and $\mathrm{s_L} = \mathrm{s}\int_{\tilde{\theta}}^{1} \theta\, \mathrm{q}(\theta)\mathrm{d}\theta$ is the expected number of startups sold late.

We can now consider stage I of the game and look at buyers' investment decision in absorptive capacity. Notice that, because we have assumed unlimited capacity, such decision is independent of the profit they make in the late market. Instead the benefits from participating in the early market are a function of both the number of buyers that have invested and the expected number of startups to acquire. Ignoring again integer constraints, the number of incumbents *m* investing in absorptive capacity and participating in the early market is given by:

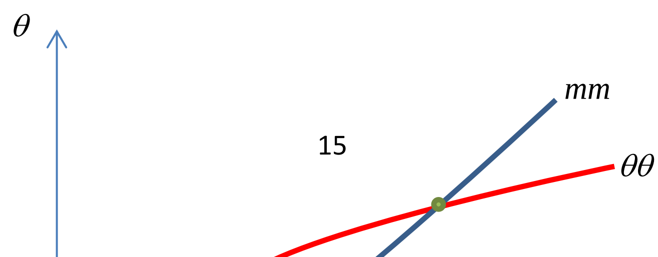
$$\mathrm{S_E}\pi_B^E = T \tag{2}$$

where π_B^E is the expectation of the profit of the buyer per each startup available in the early market, which is equal to $\left[\frac{V(1,m)-V(2,m)}{m}\right]$. Substituting equation (1) into (2), and $H(v){\sim}U(-a,+a)$ and $q(\theta){\sim}U(b,1)$ the equilibrium number of early buyers, m*solves the following equation:

$$\frac{2a}{m(m+1)}\left(\frac{w+a\frac{m-3}{m+1}}{w+a\frac{n-3}{n+1}} - b\right)\frac{1}{1-b} - T_s = 0 \tag{3}$$

where T_s=T/s is the buyers' fixed investment in absorptive capacity per startup. Figure 1 provides a graphical representation of the equilibrium in θ and *m*. Equation (1) defines the $\theta\theta$ curve, while equation (2) defines the *mm* curve. Both curves are positively sloped, $\left.\frac{d\theta}{dm}\right|_{mm} = \frac{1}{w+V(2,n)}\frac{\partial V(2,m)}{\partial m} > 0$ and $\left.\frac{d\theta}{dm}\right|_{\theta\theta} = -\frac{Q(\theta)}{q(\theta)}\frac{\frac{\partial \pi_B^E}{\partial m}}{\pi_B^E} > 0$, but while the $\theta\theta$ curve is concave, the *mm* curve is convex. Stability requires that the *mm* curve is steeper, thus $-\frac{Q(\theta)}{q(\theta)}\frac{\frac{\partial \pi_B^E}{\partial m}}{\pi_B^E} > \frac{1}{w+V(2,n)}\frac{\partial V(2,m)}{\partial m}$.

Figure 1: Stable and unstable equilibria



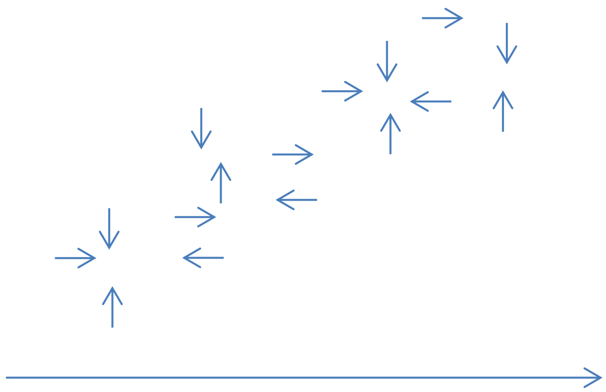


Table 2 summarizes the comparative statics with respect to the exogenous parameters of the model at the stable equilibrium.

Table 2: Comparative statics (positive increment in the parameter)

Parameter	Economic interpretation	Channel	Effect on the number of firms investing in AC	Effect on the timing decision of startups
n	Total number of late buyers	$\theta\theta$ curve: $\tilde{\theta}\downarrow\rightarrow m^*\downarrow$	Reduction	Go late
T_s	Cost of investment in AC per startup	mm curve: $m^*\downarrow\rightarrow\tilde{\theta}\downarrow$	Reduction	Go late
w	Common component of buyers' evaluations	$\theta\theta$ curve: $\tilde{\theta}\uparrow\rightarrow m^*\uparrow$	Increment	Go early
Increase in b	Availability of VC reduces execution risk	mm curve: $m^*\downarrow\rightarrow\tilde{\theta}\downarrow$	Reduction	Go late

Most of these comparative statics are straightforward. A reduction in the cost of investment in absorptive capacity makes entry in the early market cheaper for incumbents and thus more attractive to go early for startups. A larger number of incumbents makes the late market more attractive for startups as they might expect to capture more value by selling in a thicker market. Policies that stimulate entry into entrepreneurship and promote firm formation like, for instance, training, access to mentoring and expertise, or a reduction of bureaucratic red tape (Hellmann and Veikko, 2017), generate a bigger early market because incumbents have more opportunities to recover the fixed cost of their investment in absorptive capacity. A larger common component makes the expected profit of the startup less sensible to the number of buyers and thus tilts its choice toward the early market, which avoids execution risks. Instead, the comparative statics with respect to the idiosyncratic component, which proxies for the degree of radicalness of the invention, is less straightforward and we analyze it below in a dedicated subsection.

An interesting result is about changes in execution risk. As we shall discuss below, greater availability of venture capital (VC) leads to a reduction in execution risk or, equivalently, to an increase in the probability of reaching the late stage. We can thus model the availability of VC by an increase in b. Greater availability of VC makes the early market thinner directly (more startups choose to go late), and indirectly by reducing the incentive of prospective buyers to invest in absorptive capacity. More in general, any policy that favors the survival of startups to later stages can be reinterpreted as an increase in b.

We can summarize this discussion in the following proposition:

Proposition 1: The number of incumbents investing in absorptive capacity and the number of startups sold in the early market increase when: the cost of investment in absorptive capacity relative to the number of startups declines, the total number of buyers declines, execution risk increases (i.e. less availability of VC) and the invention has a larger common value.

Proof: By noticing that both curves in Figure 1 are positively sloped and that each of these changes either affects only one curve or affects both curves in the same direction.

4.1.1. Value creation vs value capture

In this section, we study the value creation properties of the equilibrium solution we derived in the previous section. Specifically, we ask whether startups go too early or too late as far as value creation is concerned, and whether too few or too many incumbents invest in absorptive capacity. We start by looking at startups and what would be the division between early and late markets, which leads to the greatest level of value creation. This requires comparing expected value creation in the early and late market, respectively. It is straightforward to show that value creation is the highest if startups with $\theta \leq \hat{\theta}$ go early and startups with $\theta > \hat{\theta}$ go late, where:

$$\hat{\theta} = \frac{w+V(1,m)}{w+V(1,n)} \tag{4}$$

While startups care about value capture and thus the price they can secure in the early and late market, value creation requires looking at the highest bid because the auction is always efficient. Thus, startups' value capture versus value creation decisions about early and late markets differ to the extent that the highest and second highest bid vary with the number of buyers. The following lemma is useful.

Lemma 4. Let *H(v)* be the cumulative distribution function of the idiosyncratic component of buyers' evaluation for a given startup and *z* the number of buyers. If $H(v) \sim U(-a, +a)$ has a Uniform distribution, then $\frac{\partial \frac{w+V(1,z)}{w+V(2,z)}}{\partial z} < 0$. The ratio or difference between value creation and value capture shrinks with the number of buyers.

Proof. Notice that $\frac{\partial \frac{w+V(1,z)}{w+V(2,z)}}{\partial z} = \frac{\frac{\partial V(1,z)}{\partial z}[w+V(2,z)] - \frac{\partial V(2,z)}{\partial z}[w+V(1,z)]}{[w+V(2,z)]^2} < 0$ if $\frac{\partial V(2,z)}{\partial z} > \frac{\partial V(1,z)}{\partial z}$. With a Uniform distribution for the idiosyncratic component of buyers' evaluations $\frac{\partial V(2,z)}{\partial z} = a\frac{4}{[z+1]^2} > a\frac{2}{[z+1]^2} = \frac{\partial V(1,z)}{\partial z}$.

Lemma 4 implies that in thicker markets for technology not only there is greater value creation because of a better match, but the seller captures a larger fraction of the value created.

We can now derive the key proposition of this section, which holds under fairly general distributional assumptions. Prima facie, one would argue that startups tend to go inefficiently late when they are flexible and do not have to commit. Perhaps counterintuitively, we will show that when startups are forced to make strategic choices between going early versus going late or, equivalently, when scaling up the invention requires substantial, sunk investment, they systematically go too late.

Proposition 2: Startups tend to go inefficiently late, and the number of buyers that invest in absorptive capacity is also less than the number that maximizes value creation.

Proof*:*

We prove it through a series of results.

Result 1. Too few startups go early for a given number of early buyers, *m*.

Proof: Notice that, $\hat{\theta} > \tilde{\theta} \leftrightarrow \frac{w+V(1,m)}{w+V(1,n)} > \frac{w+V(2,m)}{w+V(2,n)} \leftrightarrow \frac{w+V(2,n)}{w+V(1,n)} > \frac{w+V(2,m)}{w+V(1,m)}$. Using lemma 4, i.e. $\frac{\partial \frac{w+V(1,z)}{w+V(2,z)}}{\partial z} < 0$, and $n > m$ complete the proof.[15] Intuitively, the difference between value creation and value capture tends to shrink with the number of buyers. Thus, there is greater inefficiency in the early market because there are fewer potential buyers.

Result 2: The equilibrium number of buyers in the early market conditionally maximizes value creation, i.e. it maximizes value creation given the decisions of the startups.

Proof: Each early buyer's expected profit per startup must be at least as large as T_s. Specifically, $\boldsymbol{\pi_B^E} \geq \frac{\boldsymbol{T_s}}{\mathbf{Q}(\tilde{\boldsymbol{\theta}})}$. Using Lemma 2, we have that $\boldsymbol{\pi}_{\mathbf{B}}^{\mathbf{E}} = \frac{\mathbf{V(1,m)-V(2,m)}}{\mathbf{m}} = [\mathbf{V}(\mathbf{1},\mathbf{m}) - \mathbf{V}(\mathbf{1},\mathbf{m}-\mathbf{1})]$.
Notice that $[\mathbf{V}(\mathbf{1},\mathbf{m}) - \mathbf{V}(\mathbf{1},\mathbf{m}-\mathbf{1})] \geq \frac{\boldsymbol{T_s}}{\mathbf{Q}(\hat{\boldsymbol{\theta}})}$ is the entry decision that maximizes value creation, as the expected total value creation from an additional buyer in the early market has to be higher than the entry cost.[16]

Putting together results 1 and 2, the proof follows.

Below we analyze the conditions under which the difference between value creation decisions and value capture decisions is larger or smaller. To do so, let us call *efficiency gap* the ratio between $\hat{\boldsymbol{\theta}}$ and $\tilde{\boldsymbol{\theta}}$, that is:

$$\frac{\hat{\theta}}{\tilde{\theta}} = \frac{\frac{w+V(1,m)}{w+V(1,n)}}{\frac{w+V(2,m)}{w+V(2,n)}}. \tag{5}$$

Proposition 3. The efficiency gap declines with *m*, and increases with *n*.

Proof: $\frac{\partial \frac{\hat{\theta}}{\tilde{\theta}}}{\partial m} = \frac{\frac{\partial V(1,m)}{\partial \mathrm{m}}\tilde{\theta} - \frac{\partial V(2,m)}{\partial \mathrm{m}}\theta^*}{(\tilde{\theta})^2} < 0$ because $\hat{\theta} > \tilde{\theta}$ and $\frac{\partial V(2,m)}{\partial \mathrm{m}} > \frac{\partial V(1,m)}{\partial \mathrm{m}}$. : $\frac{\partial \frac{\hat{\theta}}{\tilde{\theta}}}{\partial n} =$
$\frac{\frac{-\frac{\partial V(1,n)}{\partial \mathrm{n}}[w+V(1,m)]}{[w+V(1,n)]^2}\tilde{\theta} + \frac{\frac{\partial V(2,n)}{\partial \mathrm{n}}[w+V(2,m)]}{[w+V(2,n)]^2}\hat{\theta}}{(\tilde{\theta})^2} = \frac{\frac{-\frac{\partial V(1,n)}{\partial \mathrm{n}}}{w+V(1,n)}\tilde{\theta}\hat{\theta} + \frac{\frac{\partial V(2,n)}{\partial \mathrm{n}}}{w+V(2,n)}\tilde{\theta}\hat{\theta}}{(\tilde{\theta})^2} = \frac{\hat{\theta}}{\tilde{\theta}}\left[\frac{-\frac{\partial V(1,n)}{\partial \mathrm{n}}}{w+V(1,n)} + \frac{\frac{\partial V(2,n)}{\partial \mathrm{n}}}{w+V(2,n)}\right] > 0$ because

[15] This result also holds for a variety of other distributions, including the GEV and exponential.
[16] The conditional efficiency of the early buyer decision holds for any arbitrary distribution.

$w + V(1, n) > w + V(2, n)$ and $\frac{\partial V(2,n)}{\partial \mathrm{n}} > \frac{\partial V(1,n)}{\partial \mathrm{n}}$.

This proposition is interesting and helps identify a number of factors that might exacerbate the efficiency gap. Obviously, m is endogenously determined by the incumbents' entry condition in the early market. However, because m^* is conditionally efficient we can study the effects of all exogenous parameters that affect m^* only through equation (2). Consider an increase in T or a decline in s. In both cases we have a greater inefficiency gap. Thus, the efficiency gap is particularly severe when the number of startups is small and when the cost of developing the required absorptive capacity for early acquisitions is large. As a consequence the early market is rather underdeveloped and the tendency to go too late by startups is reinforced. This suggests that when the cost of performing basic research, which is typically associated with absorptive capacity (Rosenberg, 1990; Arora and Gambardella, 1994) increases, not only we have fewer early acquisitions but this is a highly inefficient market outcome. Also, policies that stimulate the creation of startups, through for instance training or access to mentoring and expertise, have the effect of increasing the number of active buyers in the early market, and thus increase value creation.

Because m* depends, among other things, on the distribution of θ, any shift in this distribution might increase or reduce the efficiency gap. We shall focus here on a factor that has received quite a bit of attention in the innovation literature: availability of venture capital (VC). Entrepreneurial firms with VC funding have a higher likelihood of reaching an initial public offering as compared to those without it (Hsu, 2006). Venture capitalists are believed to offer more than merely financing – they also help the startup recruit suitable employees, and connect with potential customers or complementors. Puri and Zarutskie (2012), using US Census data, find that VC-backed companies grow faster at every stage of the investment cycle.

For a given supply of startups, we model an increase in the supply of VC as a shift in the distribution of θ to the right (first order stochastic dominance). This is consistent with the notion, supported by the literature, that venture capitalists help develop the startup's organization and reduce execution risk (Chemmanur et al., 2016). A shift in the distribution (an increase in b) increases the share of startups that go late. In turn, this implies that m^* falls (see Table 2). From Proposition 2 we conclude that greater availability of VC brings an increase in the efficiency gap, that is, startups are going inefficiently late, the more so if VC is abundant. Recall that we are considering the case in which startups have to make a strategic choice between going late versus going early, and it is perhaps under these circumstances that the role of VC is more salient. However, while VC might have many benefits, one possible undesired effect that our model elucidates is that, when scaling up an invention requires substantial, sunk investment, it might make things worse by delaying too much acquisitions. This would create too many "unicorns" raising and wasting lots of money. This result is in contrast with Hellmann and Veikko (2017) who show that funding policies, which presumably help increase startups' survival chances, are effective in reducing inefficiencies due to dynamic interlinkages between generations of entrepreneurs in which successful entrepreneurs accumulate both the expertise and the wealth to fund future generations of entrepreneurs.

Another potential interpretation of a first order stochastic shift in the distribution of θ is related to the geographical location of the startup. It is plausible to assume that startups located in a cluster have higher chances of survival, other things equal. For instance, Delgado, Porter and Stern (2016) show that companies located in clusters tend to be more resilient to downturns. Provided they come out with a valuable business proposition, startups located in a cluster have easier access to complementary resources, which would help them to reduce mortality in the transition from invention to innovation. Given Proposition 2, we can conclude that firms located in a cluster tend to go too late as far as value creation is concerned. It would be therefore advisable to devise policies that incentivize buyers to invest in absorptive capacity or startups to commit to the early market.

4.2. Case 2: Early investments are fully fungible (K is small, λ = 1)

If the investment to reach the later stage is small and fully fungible, startups are flexible and can entertain offers from buyers in the early market, while also investing to scale-up for the late market. In this case, we need to consider when the startup is willing to accept a given bid in the early market instead of waiting to receive bids in the late market, and how the bidding strategies of buyers change. After observing its θ, the startup will foresee that the expected profit in the late market is $\theta\big(w + V(2, n)\big)$, and thus it will accept any offer greater than that in the early market. We capture this by assuming that there is a reserve price $R^*(\theta) = \theta\big(w + V(2, n)\big)$ in the second-price auction.[17] This implies that the winning buyer pays $Max\{w + v(2, m), R^*(\theta)\}$, where $v(2, m)$ is the second highest valuation among all the early buyers.

Buyers too now take into account that they can buy in the late market if the startup is not sold in the early market, and this possibility modifies their bidding strategies. Lemma 5 below characterizes the optimal bidding strategy of an early buyer.

Lemma 5. *Define* $\underline{v}^*(\theta) = Max\{\theta\big(\pi(n) + w + V(2, n)\big) - w, -a\}$. *Then, there exists a symmetric equilibrium in the early market where the bidding strategy of buyer i is given by:*

i) *Bid its true valuation* $(w+v_i)$ *if* $v_i \geq \underline{v}^*(\theta)$;

ii) *Do not bid if* $v_i < \underline{v}^*(\theta)$.

The formal proof is contained in the Appendix. Here, we provide the intuition for the case in which $\underline{v}^*(\theta) = \theta\big(\pi(n) + w + V(2, n)\big) - w$. A buyer with a valuation equal to $w + \underline{v}^*(\theta)$ is indifferent between bidding and not bidding. The buyer can only make strictly positive profits if all other buyers have lower valuations. However, in this case, bidding $w + \underline{v}^*(\theta)$, and paying the reserve price, or not bidding, and competing for the startup in the late market, yield the same expected profit equal to $\theta\pi(n)$. Consider now a buyer with a valuation greater than $w + \underline{v}^*(\theta)$. Two situations can occur: Either there are competing buyers or not. If there are competing buyers, it is optimal to bid the true valuation in a second-price auction. If there are no competing buyers, it is also optimal to bid the true valuation and pay the reserve price.

A buyer's expected profit from its participation in the early market when bidding for a start-up of type θ is denoted by $\pi^{Early}(\theta)$ and is given by:

[17] Notice that this is a credible reserve price as the startup would not accept a lower price in the early market. In principle, startups could do even better by setting an optimal reserve price. However, any reserve price above $R^*(\theta)$ requires commitment on the side of the seller: If the highest offer were below the reserve price but above $R^*(\theta)$, it would be ex-post optimal to accept it. We assume that startups, which have a finite planning horizon, suffer from a commitment problem that prevents them from setting an optimal reserve price.

$$\pi^{Early}(\theta) = \int_{\underline{v}^*(\theta)}^{a} \left(\underbrace{G\left(\underline{v}^*(\theta)\right)\left((\mathrm{w} + \mathrm{v}_i) - \mathrm{R}^*(\theta)\right)}_{\text{The second highest valuation less than or equal to } \underline{v}^*(\theta)} + \underbrace{\int_{\underline{v}^*(\theta)}^{\mathrm{v}_i} g(x)(\mathrm{v}_i - \mathrm{x})\,\mathrm{dx}}_{\text{The second highest draw is above } \underline{v}^*(\theta) \text{ but below } \mathrm{v}_i} \right) \frac{1}{2a}\mathrm{dv}_i$$

where $G(x) = \left(\frac{x+a}{2a}\right)^{m-1}$ and $g(x) = \left(\frac{m-1}{2a}\right)\left(\frac{x+a}{2a}\right)^{m-2}$ are the cumulative distribution function and the density function of the second highest bid. A buyer acquires the startup and earns strictly positive profit from its participation in the early market if (i) it has the highest valuation v_i among the early buyers, and (ii) its valuation exceeds $\underline{v}^*(\theta)$. Integrating by parts, $\pi^{Early}(\theta)$ can be written as:

$$\pi^{Early}(\theta) = \int_{\underline{v}^*(\theta)}^{a} \left(G\left(\underline{v}^*(\theta)\right)\left(\mathrm{w} + \underline{v}^*(\theta) - \mathrm{R}^*(\theta)\right) + \int_{\underline{v}^*(\theta)}^{v_i} G(x)\,\mathrm{dx}\right)\frac{1}{2a}\mathrm{d}v_i. \quad (6)$$

The next lemma demonstrates that an early buyer's expected profit is decreasing in the number of competing buyers.

Lemma 6. $\pi^{Early}(\theta)$ *is decreasing in m.*

Proof. Since $\mathrm{w} + \underline{v}^*(\theta) - \mathrm{R}^*(\theta) > 0$ and *G(x)* is decreasing in *m*, it follows immediately that $\pi^{Early}(\theta)$ decreases in *m*. □

Integrating over the startups' set of types, the equilibrium number of buyers in the early market is given by the zero profit condition:

$$\int_d^1 \pi^{Early}(\theta)\, q(\theta) d\theta - T_s = 0 \quad (7)$$

It follows immediately from Lemma 6 that if the early market is viable there exist a unique number of buyers m^* that solves equation (7).

Proposition 4. *There are more early deals than it is efficient from the point of view of value creation, and too many buyers invest in absorptive capacity.*

While the formal proof can be found in the Appendix, we provide below the intuitive arguments behind this proposition. Notice that, from the standpoint of value creation, a startup should be traded in the early market if and only if the highest realized valuation $w + v(1, m)$ is greater than or equal to the expected value if the startup continues to the late market, $\theta\big(w + V(1, n)\big)$. However, it follows from Lemma 5 that the transaction takes place in the early market if and only if the highest valuation is greater $w + \underline{v}^*(\theta)$. Since $\theta\big(w + V(1, n)\big) > w + \underline{v}^*(\theta)$, it follows that too many deals take place in the early market for a given number of early buyers. This, in turn, attracts too many buyers to the early market. This inefficiency arises because the buyer with the highest valuation only considers its own payoff when evaluating the gains from trade in the early market. The buyer is willing to trade as long as it obtains at least its own expected profit in the late market. However, it ignores the expected profits that accrue to other buyers if the startup were to continue to the late market. From the point of view of value creation, this causes too aggressive bidding in the early market and the associated effects on the number of early deals and buyers.

Corollary 1. *The number of early deals and the number of buyers investing in absorptive capacity are value maximizing when $n \to \infty$.*

As the number of late buyers becomes very large, the profit in the late market goes to zero. Therefore, the negative externality that an early buyer's acquisition of a startup imposes on the potential late buyers disappears, and the market outcome is efficient.

Proposition 4 provides another important insight: When obtaining offers from early buyers is cheap and does not delay or distract the startup, the market equilibrium features too many early acquisitions of technology startups that it would be required to maximize value creation. As we discussed above, this is likely the case in many software-related industries. In these circumstances, availability of VC might actually make the equilibrium outcome more efficient.

4.3. Degree of radicalness

In this subsection, we shall explore the comparative statics with respect to a change in the degree of *radicalness* of the invention. Radical inventions have more unpredictable outcomes as the path toward a marketable product is longer, characterized by many twists and typically requires the orchestration of different complementary resources. Radical inventions change both the components and how the components interact and put them together in a new way to create a unique solution (Henderson and Clark, 1990). Radical inventions are both more likely to fail and more likely to lead to a blockbuster.

A natural way to model the degree of radicalness is through a, which parameterizes the variance of the idiosyncratic component. However, increases in the variance of the idiosyncratic component also increase the overall value created by the startup. To account for this, we keep expected value creation in the late market (i.e., $w + V(1, n)$) constant while increasing a.

We begin with the case in which the startup has to make a strategic choice between going early vs going late. To preview our most interesting finding below, consider that the conventional wisdom among innovation scholars is that that more radical inventions are sold later. Greater uncertainty, which is typically associated with more radical inventions, complicates the negotiations around the terms of the deal (Jeong and Lee, 2015), increases the risk of misappropriation (Luo, 2014) and the chances of biases in the assessments of the value of the invention (Allais et al., 2016). Both sellers and buyers might find convenient to wait for additional information. Consequentially, a startup with a radical invention takes some additional steps to develop it further before seeking suitable buyers. The resolution of uncertainty delays the time of technology transaction. While we find that this intuition partly applies to our model too, the results below highlight a more complex relationship between the degree of radicalness and the timing of technology sale. Under certain conditions, we show that greater radicalness makes early deals more likely and not less.

Specifically, an increase in radicalness has two effects pushing in opposing directions: first, it makes an early deal more profitable for buyers as it relaxes competition by increasing the degree of heterogeneity in valuations; second, it increases the payoffs of startups to wait (i.e., $\tilde{\theta}$ decreases) because when there is greater heterogeneity about the value of the technology the number of potential buyers becomes crucial. Interesting enough, these two effects are general and do not depend on any distributional assumptions. They reflect the additional richness of insights that can be drawn by modeling both the supply and the demand of technology. Obviously, to investigate under what conditions one effect dominates over the other, one needs to rely on distributional assumptions. Moreover, the answer will depend on the parameters of the model. For this reason, we resort to numerical simulations to study this issue. Allain et al. (2016) report that the number of potential buyers in biotechnology is between 10 and 113. The mean number of late buyers in their sample is 42. These authors do not report failure rates but do report that nearly 75% of the licensing deals in biotechnology are struck at the discovery or pre-clinical stage. However, Arora et al. (2009) report failure rates, for compounds entering clinical trials, of about 66%. In a separate study, Cunningham (2017) finds that the number of buyers of medical device startups is 30. Cunningham also reports failure rates of around 40%.

Intuitively, the decision of startups to go early versus go late crucially depends on the number of buyers active in each market. If the number of buyers in the early market, m^*, is relatively close to the total number of buyers, n, a change in radicalness has a very limited effect on startups' decisions. Thus, the comparative statics is driven by the effect on the expected profit of the buyers in the early market. Because n and m^* are close when n is relatively small and T_s tends to zero, an increase in radicalness brings about more early deals under these conditions. We thus find, somewhat unexpected, that by considering both the demand and the supply of markets for technology, greater radicalness leads to more and not less startups acquired early, and more incumbents investing in absorptive capacity.

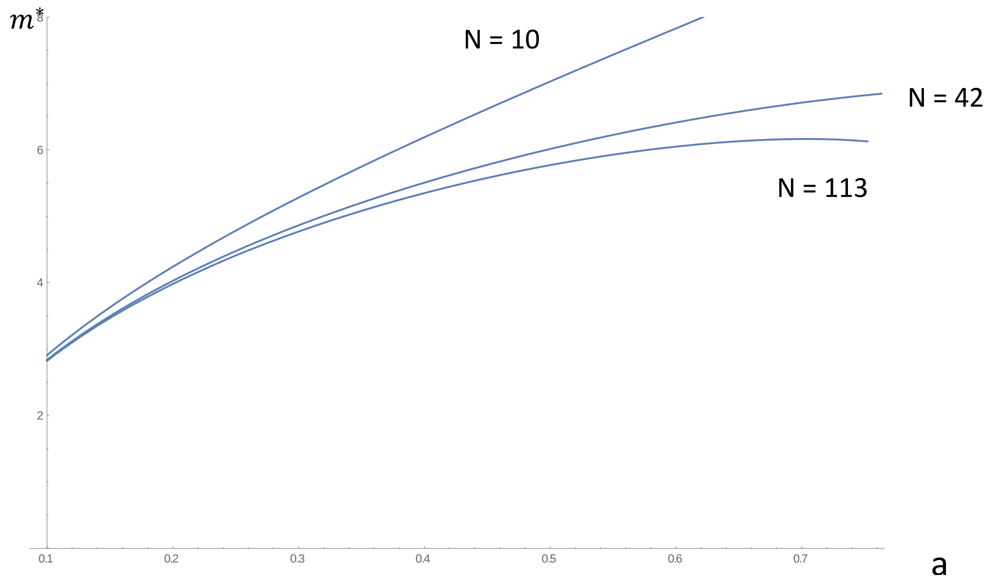
Instead, for larger values of n and T_s, the overall effect depends on the value of a. For small values of a, the common component w contains most of the value created by a startup. Since w is captured fully by startups both in the early and in the late market, $\tilde{\theta}$ is high. Then, the infra-marginal gain from an increase in a (more profit per deal) outweighs the marginal loss (fewer deals), an increase in radicalness attracts more early buyers. For parameter combinations where $\tilde{\theta}$ is relatively low (high values of a, n and T_s), m^* increases at a lower rate and may even be decreasing in the radicalness of the technology. Figure 2 reports how the number of firms investing in absorptive capacity, m^*, changes with the degree of radicalness, a, for three different numbers of incumbents. Result 1 below synthetizes the discussion.

Result 1 (simulation): *Keeping expected value creation in the late market constant:*

(i) *In markets with few potential buyers (n) and low cost of absorptive capacity relative to the number of startups (T_s), the number of buyers investing in absorptive capacity is increasing with the degree of radicalness.*

(ii) *In markets with many potential buyers (n) and high cost of absorptive capacity relative to the number of startups (T_s), the number of buyers investing in absorptive capacity is increasing (decreasing) with radicalness for low (high) levels of radicalness.*

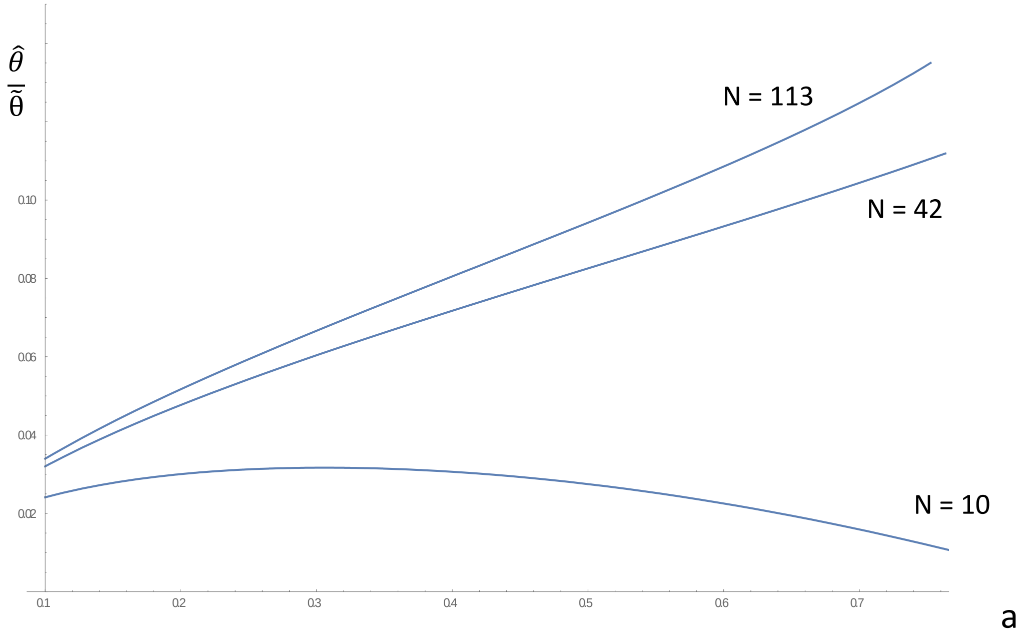
Figure 2: Comparative statics with respect to *a* when $w + V(1, n)$ is kept constant



The relationship between the degree of radicalness of the invention and the efficiency gap becomes even more complicated because it involves both direct and indirect effects. We will use again simulations to address this question. As above, we keep expected value creation in the late market (i.e., $w + V(1, n)$) constant while increasing *a*. A change in *a* has a direct effect on the efficiency gap through $V(i, n)$ and $V(i, m)$, *i = 1, 2*, and an indirect effect through a change in m^*, which we have analyzed above. First notice that it is possible to show analytically that for a given *m*, the efficiency gap is increasing in the degree of radicalness. So, the direct effect is positive. However, it follows from Proposition 3 (recall that the efficiency gap declines with *m*) that the positive direct effect is countered by a negative indirect effect in situations where m^* is increasing in *a*. The latter is more likely to be observed when *n*, T_s are small and *a* is large. Simulations (see Figure 3 below) show that the direct effect typically dominates, and the efficiency gap is increasing in *a*, except for low values of *n* where m^* increases steeply in *a*.

Result 2 (simulation). *Keeping expected value creation in the late market constant, the efficiency gap increases with radicalness if the number of potential buyers in the late market is high.*

Figure 3: Efficiency Gap - comparative statics with respect to a when $w + V(1, n)$ is kept constant



We now turn to the case in which the cost to develop the invention further is small and fungible, thus startups have full flexibility and can participate to both markets. TBD

5. Conclusions

Many technology startups devise strategies for being acquired by large incumbents (Gans, Hsu and Stern, 2002). In some cases, the acquisition is meant to take place at the idea stage, when the technology is still nascent. In others, technology companies push the technology development further and target a late acquisition. The choice of startups to be acquired early versus late is interrelated with the decision of incumbent companies to develop the capabilities to evaluate and absorb nascent technologies. Thus, the timing of technology transactions is influenced by the actions and characteristics of both sellers and buyers and depends on different environmental factors. In this paper, we built a parsimonious model to deal with this complexity.

An important novelty of our model compared to previous formal analyses of the time of technology sales is the consideration of interactions between sellers and buyers both in the early and the late market for technology. This allows us to derive some unexpected findings.

On the one hand, we show that when startups have to commit to developing their innovation internally (i.e., a late sale), too many choose to do so. Consistent with this, too few incumbents invest in absorptive capacity. As a corollary, we also show that startups might go inefficiently too late when VC is abundant and when they are located in technology clusters. Insofar as incumbents invest in research to acquire absorptive capacity, the rise of VC funded ventures might partially explain the decline in corporate research.

On the other hand, when startups are flexible, and can decide on internal development (i.e., can choose to sell later) after testing the early market, the early market sees too much activity. Too many startups accept early deals and too many incumbents invest to participate in the early market.

Finally, we show that more radical inventions are not necessary always traded in the late market as conventional wisdom would have suggested.

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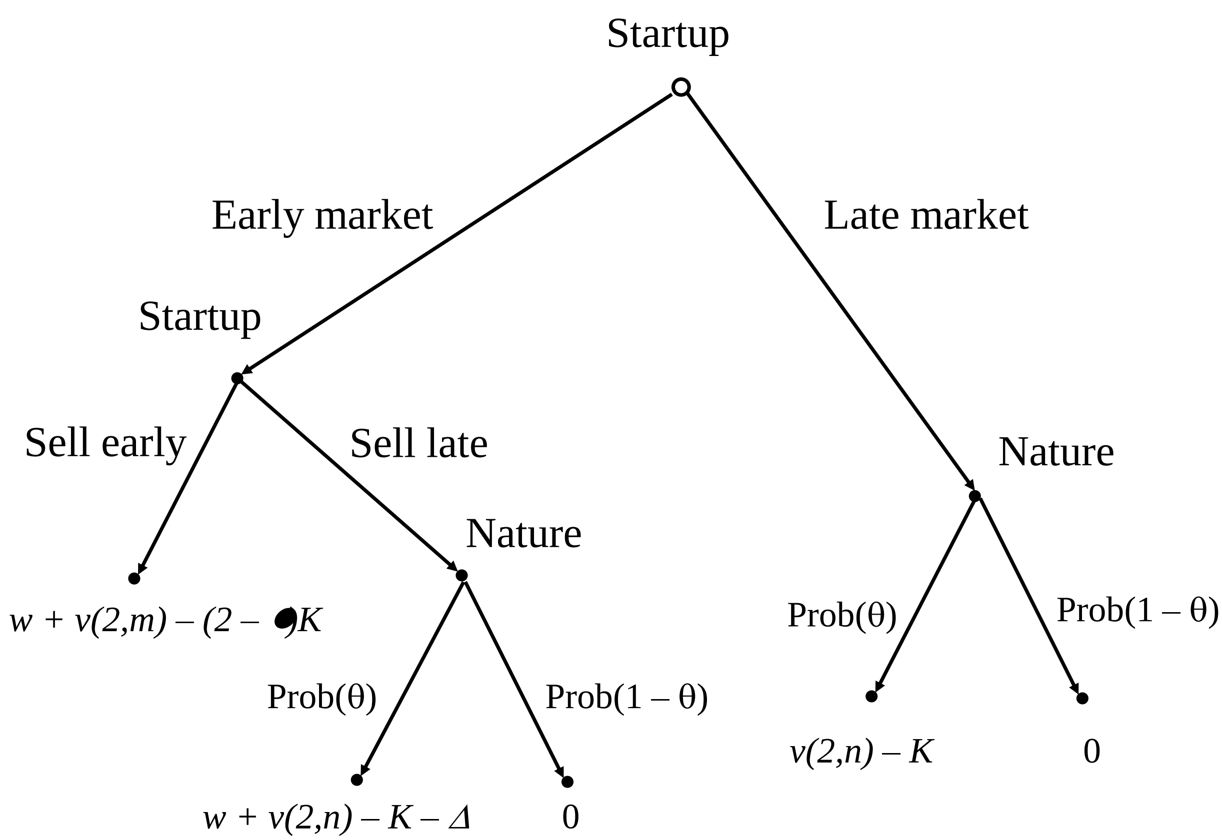
APPENDIX

In the figure below, we illustrate the decision tree of a start-up. Compared to the payoffs that we have in the paper, the only addition is an additional cost Δ that a startup incurs if it is sells late after an unsuccessful attempt to sell early. We can think of Δ as stemming from delays or information leakages: In addition, λ is the fraction of the early investment that would have to be duplicated by an early buyer.



In the case of commitment, we want two things to be fulfilled: i) Some startups choose the early and some the late market, ii) those that go to the early market never continue to the late market after observing the bids. Let us focus on the second condition first. Since this condition has to hold for all possible bids in the early market, consider the extreme case of $v(2,m) = 0$. Hence, no startup continues to the late market if:

$$w - (2 - \lambda)K \geq \theta(w + V(2,n) - K - \Delta)$$

for all θ. Again, this condition is hardest to fulfill for $\theta = 1$. The condition thus becomes:

$$\Delta \geq (1 - \lambda)K + V(2,n)$$

This condition is harder to satisfy when there are large sunk cost ($\lambda = 0$), many buyers in the late market ($V(2,n)$ large), and small cost of trying the early market first in terms of delay and information leakage (Δ small).

Suppose that condition (1) holds. Then, a startup goes to the early market if and only if:

$$w - (2 - \lambda)K \geq \theta(w + V(2,n) - K).$$

Hence, we need this condition to hold for $\theta = d$ (the upper limit of θ) in order to have startups to sort:

$$w - (2 - \lambda)K \geq d(w + V(2,n) - K).$$

The case of no commitment corresponds to $\Delta = 0$ where there is no cost of trying the early market first.

Notice that all the sunk cost ($\lambda < 1$) does is to push startups to the late market. The key parameter for commitment is Δ. We might as well $K = 0$ in which case the conditions simplify to:

$$\Delta \geq V(2,n),$$

$$w(1 - d) \geq dV(2,n).$$

Then, we have the commitment cost when there is large cost of trying the early market first and the execution risk can be sufficiently high.

Proof of Lemma 6

In the construction of the equilibrium, we assume that buyers with a valuation v_i greater than or equal to $R(\theta)$ follow a symmetric bidding strategy $b(v_i)$ where $b'(v_i) > 0$. Also, it is assumed for now that $\theta\big(\pi(n) + w + V(2,n)\big) - w \geq -a$. A buyer of type $\underline{v}^*(\theta)$ bids $b\big(\underline{v}^*(\theta)\big)$ and wins only if all other buyers have valuations below $\underline{v}^*(\theta)$. Hence, whenever a buyer of type $\underline{v}^*(\theta)$ wins, it pays the reservation price $R(\theta)$. For a buyer of type $\underline{v}^*(\theta)$ the alternative to bidding $b\big(\underline{v}^*(\theta)\big)$ is not to bid. If all other bidders have valuations below $\underline{v}^*(\theta)$, the expected profit from not bidding is $\theta\pi(n)$, because the startup is sold in the late market. In equilibrium, the marginal type $\underline{v}(\theta)$ has to be indifferent between bidding and not bidding:

$$G(\underline{v}^*(\theta))\left(\underline{v}^*(\theta)+w-R(\theta)\right)+\left(1-G(\underline{v}^*(\theta))\right)0=G(\underline{v}^*(\theta))\theta\pi(n)+\left(1-\left(\frac{\underline{v}^*(\theta)}{2a}\right)^{m-1}\right)0 \Leftrightarrow$$

$$\underline{v}^*(\theta)=\theta\pi(n)+\ R(\theta)-w=\theta\big(\pi(n)+\ w+V(2,n)\big)-w$$

Consider now types $v_i > \underline{v}^*(\theta)$. Two situations can occur: Either there are competing buyers or not. If there are competing buyers, it is optimal to bid the true valuation. The startup is sold in the early market because there is at least one other buyer that bids above $R(\theta)$, and it follows from standard second-price auction logic that bidding the true valuation is optimal. In the other case, without competing buyers, it is also optimal to bid the true valuation. The start-up is then bought at the price $R(\theta)$, which (i) results in higher profits than buying in the late market as $v_i > \underline{v}^*(\theta)$, and (ii) $R(\theta)$ is the lowest price at which the startup can be acquired.

If $\theta\big(\pi(n)+w+V(2,n)\big)-w<-a$, a similar argument establishes that it is optimal for a buyer to bid its valuation for all v_i, and hence $\underline{v}^*(\theta)=-a$ in this case. □

Proof of Proposition 4

We first show that buyers overinvest in absorptive capacity. We next show that this behavior results in too many early deals from the point of view of value creation.

<u>*Claim 1*</u>*:* Buyers overinvest in absorptive capacity.

Suppose that a startup of type θ is sold in the early market for some $\mathrm{v}(1,\mathrm{m}) \geq \underline{v}(\theta)$. For now, it is assumed that $\underline{v}(\theta) \geq -a$. There is a reserve price $\mathrm{R}(\theta)$ in the auction representing the value of the outside option, and it is assumed that $\mathrm{w}+\underline{v}(\theta) \geq \mathrm{R}(\theta)$. Then, applying the same steps as in the derivation of $\pi^{Early}(\theta)$, the contribution of the marginal early buyer to value can be written as:

$$V^{Early}(\theta) \equiv \int_{\underline{v}(\theta)}^{\mathrm{a}}\left(G\left(\underline{v}(\theta)\right)\left(\mathrm{w}+\underline{v}(\theta)-\mathrm{R}(\theta)\right)+\int_{\underline{v}(\theta)}^{\mathrm{v}}G(x)\,\mathrm{dx}\right)\frac{1}{2a}\mathrm{dv}.$$

The value created is maximized for $\partial V^{Early}(\theta)/\partial\underline{\mathrm{v}}=0 \Leftrightarrow \underline{v}(\theta)=\mathrm{R}(\theta)-w$ if $-a<\mathrm{R}(\theta)-w$. Otherwise, $\underline{v}(\theta)=-a$. As argued in the main text, the reserve price in the early market that maximizes total value creation is $\widehat{\mathrm{R}}(\theta) = \theta\big(\mathrm{w} + V(1,n)\big)$. Hence, the value maximizing threshold is given by

$$\underline{\hat{v}}(\theta) \equiv Max\big\{\theta\big(\mathrm{w} + V(1,n)\big) - w, -a\big\}.$$

Plugging $\underline{\hat{v}}(\theta)$ into the profit function, we obtain:

$$V^{Early}(\theta) = \frac{1}{2a}\int_{\underline{\hat{v}}(\theta)}^{\mathrm{a}}\int_{\underline{\hat{v}}(\theta)}^{\mathrm{v}} G(x)\,\mathrm{dx}\,\mathrm{dv} \tag{A1}$$

Finally, arguing as in the proof of Lemma 6, it is immediate to show that $V^{Early}(\theta)$ is decreasing in *m*. Hence, the value maximizing number of early buyers is determined by the following equation:

$$\int_d^1 V^{Early}(\theta)\, q(\theta)d\theta - T_s = 0 \tag{A2}$$

Plugging $\underline{v}^*(\theta)$ into $\pi^{Early}(\theta)$ in equation (6), we obtain:

$$\pi^{Early}(\theta) = \begin{cases} \left(1 - H\left(\underline{v}^*(\theta)\right)\right) G\left(\underline{v}^*(\theta)\right)\theta\pi(n) + \frac{1}{2a}\int_{\underline{v}^*(\theta)}^{a}\int_{\underline{v}^*(\theta)}^{v_i} G(x)\,\mathrm{dx}\,dv_i & if\ \underline{v}^*(\theta) > -a \\ \frac{1}{2a}\int_{\underline{v}^*(\theta)}^{a}\int_{\underline{v}^*(\theta)}^{v_i} G(x)\,\mathrm{dx}\,dv_i & if\ \underline{v}^*(\theta) = -a \end{cases} \tag{A3}$$

Comparing equations (A2) and (A3), and using $\underline{v}^*(\theta) \le \underline{\hat{v}}(\theta)$, we obtain $V^{Early}(\theta) \le \pi^{Early}(\theta)$. Furthermore, $V^{Early}(\theta) < \pi^{Early}(\theta)$ for θ sufficiently large as $-a < \underline{v}^*(1) < \underline{\hat{v}}(1)$. Using equations (7) and (A3), this implies that $m^* > \hat{m}$.

<u>*Claim 2*</u>*:* Too many early deals.

The expected number of deals in the early market is given by $\int_d^1\big(1 - H(\underline{\mathrm{v}}^*(\theta))^{m^*}\big)\, q(\theta)d\theta$, which is greater than the number of the value maximizing number of deals $\int_d^1\big(1 - H(\underline{\hat{v}}(\theta))^{\hat{m}}\big)$ since $\underline{v}^*(\theta) \le \underline{\hat{v}}(\theta)$ and $m^* > \hat{m}$. □

Proof of Corollary 1

The market outcome is value maximizing in the limit for $n \to \infty$ since $\underline{\hat{v}}(\theta) \to \underline{v}^*(\theta)$ and $\widehat{\mathrm{R}}(\theta) \to R^*(\theta)$ for $n \to \infty$. □