

# Patenting vs. Secrecy for Startups and the Trade of Patents as Negotiating Assets\*

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*We analyze a sequential innovation model and show that narrow patent rights can facilitate a market in which startups' patents are traded as negotiating assets. In this market the trade of patents, on top of monopoly profits, conveys extra surplus from the patents' capacity to affect future tech-transfer negotiations. This surplus, which stems from a patent's potential ability to exclude infringers and the corresponding enforcement spillovers that patents confer, may incentivize innovations that would not have been possible under trade secrecy, improving social welfare. (JEL Codes: O31, O32, O34)*

*Keywords:* Patents, trade secrets, startups, takeovers.

## 1 Introduction

The term “patent paradox” refers to the increased use of patents, despite being perceived as having limited stand-alone value as incentives to innovate (Hall *et al.*, 2012). This phenomenon can be attributed to the array of roles patents may play. One role particularly relevant in this context is their use as bargaining chips by firms who employ many patents bundled into patent portfolios to gain a better hand in licensing negotiations, especially in industries where technology is cumulative (Hall and Ziedonis, 2001). As argued by Lanjouw and Schankerman (2004), patent portfolios endow such uses because patents confer “enforcement spillovers” that allow firms to exploit economies of scale, making it less costly to protect a patent when it is part of a bundle, in which case small firms like startups, that hold few patents, are at a disadvantage. In fact, for startup firms patents

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may even be a “liability” as they can invite infringement allegations from dominant firms with a portfolio of patents. Fear of evoking such highly costly legal disputes is known to force startups to redirect their research (Lerner, 1995) and may well have contributed to the tendency of startups to prefer trade secrecy over patenting as found in some studies, e.g., Graham *et al.* (2009). In a world of dominant firms and patent portfolios, is there a role for patents as incentives to innovate for tech-startups, or should these innovative firms, which play an outsized role in US net job creation (Hathaway, 2013), prefer secrecy instead? This is an important question because patents, unlike trade secrets, promote welfare enhancing diffusion and knowledge spillovers.

The use of patents as leverage in licensing negotiations stems from ownership contentions that arise due to the inherent difficulty (especially in cumulative innovation) of confining bordering technologies. Due to such contentions, when licensing or trading a patent whose ownership is potentially disputed by the prospective licensee, a startup may not be able to reap the full value of its patented technology because the negotiations take place in the shadow of infringement litigation (Shapiro, 2003). Nevertheless, we argue that trade secrecy may not be the best resort. Instead, we show that overt ownership of technology through patenting, together with appropriate channels for ownership trading, can work better to incentivize startups’ innovation activities. Specifically, we present an equilibrium analysis of a dynamic model that clarifies when and how patents may outperform trade secrets in promoting startup innovations. In the process, we also provide some policy implications.

Our main thesis is that when trading a patent its owner is potentially selling more than a monopoly right. Specifically, insofar as patents’ enforcing capacity spills over as mentioned above, when a patent is added to a patent portfolio it enhances the portfolio’s muscle in enforcing the rights of any given patent in the bundle. Such additional leverage correspondingly increases the portfolio’s ability to favourably barter a future technology transfer agreement against potential infringers. Thus, a transfer of patent rights does not only convey monopoly profits on the technology embodied in the patents’ claims (as trade secrets do), but also extra surplus from the patents’ capacity to affect future technology transfer negotiations. Therefore, when an innovator transfers a patent, even though its transfer price may not be able to capture the full monopoly profits (because of the risk of infringement), it may merit a markup reflecting the prospect of such extra future surplus. When a sequence of startups are expected to patent and transfer their technology to an incumbent, gradually increasing its future bargaining power, the dynamic feedback effects on this markup can be large enough so that the patent’s transfer price exceeds the value of a trade secret. In short, since patent portfolios do not only engender the threat

of infringement allegations but also elicit the use of patents as transferable negotiating assets, they can incentivise innovations that would not have been possible with trade secrets, increasing social welfare.

The aforementioned sequence of startup innovators who transfer their patents is not an exercise of intellectual curiosity. Actually, the general picture we portray is reminiscent of the unremitting streak of startup acquisitions by established incumbents that is now a familiar sight in the news (Arora, Belenzon and Pataconi, 2015). For example, as of 2015 Google has acquired more than 180 firms, most of them being startups. In fact, since 2010 (kindled by an active interest in robotics) Google has acquired 123 firms, which amounts to buying more than one firm a month. Cisco and Yahoo has been equally prolific with 121 and 114 acquisitions each, while G.E. and Siemens marginally lag behind with more than 100 acquisitions each. In line with the open innovation paradigm (Chesbrough, 2003), these takeovers are understood to serve in expanding a firm's technological horizon. However, our view of the takeover phenomenon is more nuanced because we approach the transfer of patents as a mechanism that also enhances the buyer's bargaining power in future deals. It thus seems that patents do not only facilitate a market for ideas, in the sense of Gans and Stern (2002), they also allow for a market for negotiating assets. As we explain, the prerequisite for such a market is relatively narrow patent rights.

The core mechanism is presented via a model of sequential innovation *à la* Scotchmer (1991), where the current innovation may be infringing on existing patents that are incorporated in a patent portfolio, generating a holdup problem for which two natural solutions exist: either to keep a trade secret, or to opt for a cooperative agreement between the initial innovator and latecomers (Green and Scotchmer, 1995). Specifically, we analyze a model in which an incumbent who owns a patent portfolio<sup>1</sup> faces a sequence of startups who innovate in a cumulative fashion, and negotiates (via Nash bargaining) a takeover agreement with them. What differentiates a patent from a trade secret is that patents can inadvertently invite property disputes. In this sense patents are handicapped relative to trade secrets and are susceptible to technology sharing negotiations, such as takeovers, under the threat of infringement litigation.

This disadvantage induces a sequence of events in the following manner in our dynamic equilibrium analysis. The more patents the incumbent owns, the more bargaining power it has in technology sharing negotiations because courts are more likely to argue in favour

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<sup>1</sup>Although in reality large firms' patent portfolios tend to range across many and frequently diverging technologies, for the purpose of this paper a patent portfolio means a subset of a firm's patents that are on a specific technological terrain. Examples abound, e.g., upon the invention of Nylon Du-Pond patented all the chemical formulae bearing resemblance to its core technology.

of the incumbent if it files an infringement suit against a startup. Hence, the incumbent capitalizes on the enhanced bargaining position that takeover deals, unlike other forms of settlement such as licensing, will bring in all potential future deals by incorporating the current startup's patented ideas to its own patent portfolio. Since this prospect of future surplus for the incumbent hinges on the current takeover, a part of the surplus accrues to the current startup, enlarging the startup's bargaining share. Consequently, patents can motivate R&D activities of startups that would not have taken place under trade secrets. Therefore, patents may turn their handicap over trade secrets into an advantage.

Our analysis suggests that for maximum benefit the incumbent's bargaining power should not accumulate too quickly, because if it did then the incumbent would become too powerful a litigant too quickly, killing off the innovation incentives for startups prematurely. Nor should it accumulate too slowly, for then the aforesaid dynamic effect feeding into the startup's bargaining share would be too feeble to adequately incentivize startup innovation. Insofar as bargaining power increases with portfolio size, this reasoning implies that the patent landscape should neither be overly condensed (being comprised by inordinate patent portfolios), nor too fragmented as in a patent thicket.

Overall, the need for balanced bargaining power the model prescribes to reflects the following key underlying idea of this mechanism: *for the transfer of benefits from the future to the present to materialize there must be a foreseeable sequence of impending innovations to be adequately incentivized and exploited.* In fact, in the absence of unfolding innovations trade secrets prevail. In terms of policy, therefore, patent protection must be sufficiently narrow in its scope so as to allow for derivative products and applications.

The idea that relatively weak IP protection is needed to promote innovations is not new. Bessen and Maskin (2009) argue for weak protection in order not to impede imitations by producers of differentiated products, which would permit innovative complementarities and thereby, improve prospects for future innovation. Furthermore, in a model of a single, multistage R&D race between firms with asymmetric R&D abilities at different stages, Fershtman and Markovich (2010) also examine when weak protection that allows free imitation is desirable. We focus on a different dynamic mechanism pertinent to startup innovators: weak protection promotes transfer of future innovation benefits to early innovators via the incumbent's strengthened future bargaining position when it enlarges its patent portfolio by takeovers.

Despite the prevalent use of trade secrecy, the choices between secrecy and patenting have been theoretically explored relatively recently in economics. Horstmann, *et al.* (1985) explore the signalling effect of patenting when an innovator chooses between patent and secrecy based on privately observed desirability of possible options available for its rival.

Anton and Yao (2004) extend the investigation to an innovator who decides both whether to patent or not and how much knowledge to disclose, and find that secrecy prevails for more significant innovations. In models where innovators choose between patenting and secrecy without knowing whether their rivals succeeded in the same innovation (no signalling motive present), Denicolo and Franzoni (2004), Kultti, *et al.* (2006, 2007) and Kwon (2012) investigate the effects of the patent system on innovation incentives, information spreading, and welfare. All of these papers study how patenting fares relative to secrecy for firms facing competition from similar rival firms in the product market. The current paper studies the choice of startups that are in a fundamentally different situation and focuses on dynamic effects of patent rights transfer negotiations.

The incentive effects of patents for cumulative innovations are more delicate because promoting early innovations by stronger protection means discouraging later innovations due to a holdup problem, and vice versa. Scotchmer is one of the first researchers who investigated this issue theoretically and shows that *ex ante* profit-sharing agreements can resolve the issue more effectively by internalizing externalities between innovators in the investment decisions (Scotchmer, 1991; Green and Scotchmer, 1995). Bearing in mind that *ex ante* agreements are usually collusive and impractical, we argue that takeovers may work better than other *ex post* agreements as a device to transfer future profits to the current innovator when a series of small innovators operate under uncertain property rights *à la* Lemley and Shapiro (2005).

The literature that studies the effects of patent landscape fragmentation on the innovation activities of small firms is still at its infancy. MacGarvie and Cockburn (2009), studying startup software firms, find that the ones that operate in a dense landscape saw their initial acquisition of venture capital delayed relative to firms in markets less affected by patents. This negative effect is not unique to the US. In terms of EPO patents, Graevenitz *et al.* (2012) show that an increase in density decreases patent applications by owners of smaller portfolios. The effects of low fragmentation have been tested on German service and manufacturing firms by Muller, MacGarvie and Cockburn (2008) and Schwiebacher (2011). However, both papers offer a transaction cost based explanation, arguing that high fragmentation can hamper innovation activities when firms have to negotiate licensing agreements with many patent holders.

The paper is organized as follows. Section 2 outlines the salient features of the model and provides a review of the facts and assumptions that we employ. Section 3 puts forward a basic description of the game, and a simple static model that acts as a benchmark that allows for comparisons with the dynamic model. The dynamic analysis and the resulting theoretical results are included in Section 4. Sections 5 and 6 describe the simulation of

the unique equilibrium of the dynamic model, the resulting comparative statics, and the main policy prescriptions. Section 7 concludes.

## 2 The relevant facts and assumptions

Our argument is buttressed by two asymmetries. The first one is between patents and trade secrets (TS). Crudely put, by disclosing the embodied technology, patents are handicapped towards TS, because disclosure can inadvertently invite infringement allegations. In terms of a territorial metaphor, one can think of a patent as a property deed that demarcates a technological territory, allowing its owner to protect it from trespassers. By demarcating her territory the owner fully discloses the particulars of her technology, making public what she claims as her own. Unfortunately, as the borders of a technology, unlike land, cannot be fully outlined and fenced, disclosure can invite property disputes in the form of trespassing (infringement) allegations from patentees who hold foggy property deeds in neighboring technologies. By contrast, aspiring to keep the details of their technology hidden, TS owners try to avoid revealing the characteristics of their technology to outsiders. In doing so, they do not visibly demarcate their territory via a property deed. Hence, as long as the TS remains a secret, it cannot invite infringement allegations.

However, sometimes TS are more of a wishful thinking. For example, pharmaceutical technologies are often partially unmasked via re-engineering, and this unveiling can potentially invite infringement allegations.<sup>2</sup> Under such circumstances, since the owner lacks a property deed, proving the borders of the underlying technology is cumbersome and the innovator fares better by owning a patent.<sup>3</sup> Lacking better terminology, we label a technology that reveals (via re-engineering) enough to invite infringement allegations as a “revealing” technology. Correspondingly, a technology is “non-revealing” if the TS successfully conceals the technology. In the model we assume that a technology will be non-revealing with a commonly known probability  $\theta \in (0, 1)$ , and revealing with a probability  $1 - \theta$ . In principle, this formulation is similar to Henry and Ruiz-Aliseda (2012) who assume that imitators can re-engineer a technology by paying a fixed cost.

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<sup>2</sup>The case of Adrenalin (Patent No. 730,176 of 1903) and its rival product Adrin is an early case in mind: *Parke-Davis & Co. v. H. K. Mulford Co.*, United States Circuit Court for the Southern District of New York, 189R 95 (C.C.S.D.N.Y. 1911).

<sup>3</sup>Even though, most national patent laws provide for prior user rights (allowing TS holders who were secretly using a process that is subsequently patented to continue to use it), they tend to be narrow in scope in that they do not allow for use in another jurisdiction and often do not cover improvements in the process. Consequently, the TS holder is at a disadvantage even if she was the first to invent.

The second asymmetry is between startups and incumbents. Incumbents are defined as established firms that own patent portfolios that can be used in resolving patent disputes (as in Lanjouw and Schankerman 2004). By contrast, startups are fledgling entities that hold only one asset, their IP, and lack the expertise and funds to spend on legal jousting. Hence, they are unable to impose their might onto other startups via infringement allegations, with a view to gradually building a patent portfolio and compete one-to-one against incumbents.<sup>4</sup> <sup>5</sup> Therefore, incumbents have a comparative advantage in resolving patent disputes that startups lack. We model this comparative advantage as an increased probability of winning an infringement lawsuit. Alternatively, it can be viewed as an enhanced bargaining power of the incumbent in a generalized Nash bargaining model, or as a lower litigation cost. As all three effects inevitably increase the incumbent’s bargaining share in forthcoming takeover deals, our results are not sensitive to this change.

In order to avoid exacerbating the asymmetry between incumbent and startup, we assume that justice is swift, there are no preliminary injunctions, and that the incumbent does not hold any essential “blocking” patents. Assuming otherwise would have endowed the incumbent with a better bargaining hand, a fact that (in our model) can be captured via a greater probability of prevailing in court. Specifically, prolonged court cases strengthen the incumbent’s hand, rendering out-of-court agreements more attractive.<sup>6</sup> Preliminary injunctions, by halting the use of the technology, equally enhance the plaintiff’s negotiating power.<sup>7</sup> In similar terms, the assumption that the incumbent holds an essential patent would likewise strengthen the plaintiff’s hand because the startup cannot commercialize the technology absent a license from the incumbent.

As to the forms of technology transfer that pertain to our argument, patents can deserve a markup only if they are transferred in a way that allows the incumbent sole ownership. To illustrate this point, focusing on the forms of technology transfer that find the most use, we compare technology transferring methods that lead to a comprehensive transfer of patent rights with methods that only license the use of the technology. Specifi-

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<sup>4</sup>In such occasion the startup must compete in its role as a litigant with the incumbent. Thus, its infringement suit against a future startup will be met by simultaneous allegations from the incumbent. As the startup has to defend its acquisition against the incumbent and its sizable patent portfolio, standard due diligence procedure requires the termination of takeover attempts due to outstanding legal obligations.

<sup>5</sup>The startups we have in mind are not like the young Intel, or Google, who (as startups) invented game changing technologies that allowed them to compete against behemoths.

<sup>6</sup>Swift trials allow the model to abstain from elaborating on damages. The yardstick used by courts in deriving damages is either the accumulated royalties resulting from a hypothetical licensing agreement, or the foregone profits from the sale of the infringing good. Both of these are minimal if justice is swift.

<sup>7</sup>Lanjouw and Lerner (2001) and Lemley and Shapiro (2007) explain how the plaintiff’s bargaining is enhanced through preliminary injunctions.

cally, we consider i) startup takeovers, ii) patent sales, iii) exclusive licensing, iv) exclusive cross licensing, and v) patent pools. Takeovers and patent sales are indistinguishable as they both lead to a full transfer of rights. By contrast, licensing and cross licensing both allow the use of the technology without a full transfer of rights. A patent pool is akin to cross licensing as both firms have access to all the patents in the pool, but the ownership is separated. Accordingly, for brevity, we henceforth focus our analysis on takeovers and exclusive licensing agreements and correspondingly assume that a technology sharing agreement takes the form of a takeover, or licensing.

As a last note, we do not consider the usual counter accusation of invalidity because our emphasis is on the ability of portfolios (and not individual patents) to endow the incumbent with a comparative advantage in patent enforcement. Consequently, the possible invalidation of one (or a few patents) will only diminish the incumbent's patent enforcement capacity, merely reducing the value of filing a lawsuit for the incumbent. For the substance of our analysis to change, the possibility of invalidation must be comprehensive enough as for the incumbent's expected payoff from filing a lawsuit to become negative.

### 3 A static benchmark

Even though our argument is dynamic we first introduce a static model that illustrates how patents may be handicapped relative to TS. This static model acts as benchmark that allows for comparisons with the dynamic model that follows, which outlines how patents can turn their handicap into an advantage.

We consider two firms operating under a single line of cumulative technology. Firm 1 is an established incumbent, holding a patent portfolio. Firm 2 is a startup innovator who aims to innovate in this line of technology and needs to decide whether to invest in an R&D project that costs  $c$ . We assume that  $c$  is a random variable whose value is 0 or  $C > 0$  with probabilities  $\eta \in (0, 1)$  and  $1 - \eta$ , respectively. The realized value of  $c$  is firm 2's private information but  $\eta$  is common knowledge.<sup>8</sup> This is in line with Bessen and Maskin (2009) and amounts to assuming the existence of *Silicon Valley* startups that, contrasting their high-cost counterparts, innovate with minimum cost.

The assumption that startups are the only ones engaging in R&D is made for expositional ease and our insights apply equally when both firms engage in a per period R&D

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<sup>8</sup>The lower value of  $c$  being 0 is for purely expositional ease. Our results are intact so long as  $c$  is less than  $\bar{\pi}_2(1)$  to be defined shortly in equation (2). In order to illustrate our core insight with clarity, we abstract from additional informational asymmetries and risk aversion. For the purpose of this paper, adding such features would complicate the analysis without much extra insights to be gained.



race and the startup wins the race. In this case, if the incumbent and the startup can win the race with identical probabilities, it is relatively straightforward to see that the dynamic effects of a takeover deal support our main message, namely, that the future benefit of a takeover deal can motivate the startup’s innovation activity that would not take place otherwise. If the incumbent is less likely to win, then it may find it optimal to save its own R&D cost and pursue a takeover deal of the startup’s innovation instead.

If firm 2 decides against investing in R&D, the market stays unchanged and the game ends with payoffs normalized as 0 for both firms. If firm 2 invests  $c$ , it develops a new technology that has a full commercial value of  $V > 0$ .<sup>9</sup> Upon development, firm 2 observes whether the invented technology is revealing or not and must accordingly decide whether to obtain one single-claim patent as a testimony to its innovativeness or keep a TS; to highlight different dynamic effects between the two options (in the next section) with minimal confounding factors, we assume that patenting is free.<sup>10</sup> Given the cumulative nature of technology, if revealed, firm 2’s technology will be perceived as potentially infringing on one or more of the incumbent’s patents. This will be the case if firm 2 obtains a patent on its technology, or if a revealing technology is kept as TS. This description on the nature of technology is common knowledge. We start our analysis by examining the role of patents.

### 3.1 Patents

Consider the case that firm 2 patents its technology, exposing it to potential infringement allegations by the incumbent as explained above. There are three options that the incumbent may take at this point as described below.

The first option for firm 1 is to file a suit alleging that 2’s technology is infringing on its patents, the outcome of which is uncertain. We model infringement litigation as follows: the court finds firm 2’s technology infringing (firm 1 wins) with a commonly known probability  $p \in (0, 1)$ , invalidating 2’s single-claim patent and thus, depriving its ownership of the ideas in the revoked patent claim; or finds it non-infringing (firm 2 wins) with probability  $1 - p$ , confirming 2’s sole legal right to commercialize the new technology. We interpret a higher  $p$  as reflecting a stronger stance of the court toward IP protection.<sup>11</sup> Regardless of the outcome, going through the legal battle is costly for both

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<sup>9</sup>Our results extend straightforwardly to the cases that investing  $c$  leads to an innovation with a known probability less than (rather than equal to) 1.

<sup>10</sup>Our main results continue to hold as long as the cost of patenting is not too large relative to  $V$ .

<sup>11</sup>In modeling  $p$  we have the current US paradigm in mind, where courts have set out tough legal standards for infringement cases, rather than the USPTO which seems to have relaxed its patentability

parties involved, which we reflect by assuming that litigation incurs a monetary equivalent cost of  $\ell > 0$  for both the plaintiff and the defendant.

As to the eventual outcome ensuing the court's decision, we assume that the payoff to the losing party is zero (not counting the litigation cost  $\ell$ ) and the winner solely commercializes the new technology. In the case that the startup wins, this means that it reaps a profit of  $V$ . If the incumbent wins, we assume that it reaps a profit of  $bV \leq V$ , where  $b \in [0, 1]$  is an exogenous value. Firm 1 may be unable to capture the whole value of  $V$  for various reasons in this case. For example, there could be residual tacit knowledge not apparent in the document yet needed for realization of the full value of the ideas. Or, the revoked patent may contain ideas which are of merit to users yet judged failed to fulfill the substantial requirements of patentability; such ideas are effectively in the public domain and any third party can free ride on them. It should be noted that our main results hold regardless of the value of  $b$ , as will be shown below both analytically and by simulation.

The second option is for firm 1 to seek a technology sharing agreement with firm 2, which can take the form of a takeover, or licensing. This agreement is the result of licensing negotiations that are carried out under the shadow of litigation (as in Shapiro 2003). Such out of court settlements are not unusual. In fact, for infringement cases trials are actually rare, with 95% of all cases being settled out of court (see Lanjouw and Schankerman 2004).

In line with the literature, we model such an agreement as a Nash bargaining<sup>12</sup> where the disagreement/threat points are the expected surpluses when firm 1 files an infringement lawsuit. We present our analysis presuming that the two firms have equal bargaining powers, but our main qualitative results remain intact for a wide range of unequal bargaining powers.<sup>13</sup> If a deal is reached, as the ownership of the patent *per se* does not alter

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standards.

<sup>12</sup>E.g., Green and Scotchmer (1995), Chang (1995), and Crampes and Langinier (2002).

<sup>13</sup>Our core results remain valid unless the incumbent has all the bargaining power, i.e., makes a take-it-or-leave-it offer and does not try to negotiate. In practical terms, this latter case implies double ultimata that seem to depart from contemporary norms. Specifically, it suggests that if firm 2 is not successfully arm-wrestled in accepting the take-it-or-leave-it-offer (the first ultimatum) the incumbent will issue a second ultimatum by filing the case in a court of law. Considering current legal practice (and the use of juries) the use of such an overt bullying threat must be detrimental to one's chances of winning a court battle. More importantly, and in relation with the residual tacit knowledge that the incumbent is interested in, firms like Cisco (the champion of startup takeovers) do not issue ultimatums but bargain. That is, given that the tacit knowledge the acquiring firms are usually interested in takes the form of a network of clients whose needs the startup firm knows and understands, an ultimatum is not conducive to the startup's voluntarily disclosure of such knowledge. In addition, such an ultimatum would hurt the

the maximum value of the technology,  $V$ , a takeover and a licensing agreement are indistinguishable and in both cases firm 1 commercializes the technology as the sole patent holder, reaping the full value  $V$ .

The third option is for firm 1 to do nothing, in which case firm 2's payoff is  $V$  from commercializing the technology and firm 1's payoff is 0. As will be verified shortly, this option is worse than pursuing a technology agreement *à la* Nash bargaining. Summing up, in the static model a strategy of firm 2 is whether to invest in R&D or not, and that of firm 1 is whether to file a suit, to seek a Nash bargaining outcome, or to do nothing. The structure of the game is common knowledge.

At this point we derive the Nash bargaining outcome when the incumbent seeks a technology sharing agreement with firm 2. Conditional on firm 2 having developed and patented a new technology, the disagreement/threat points are the expected surpluses from an infringement lawsuit, i.e.,  $d_1 = pbV - \ell$  and  $d_2 = (1 - p)V - \ell$  for firms 1 and 2, respectively. Since  $V$  is the maximum possible industry profits from the technology, the Nash bargaining set is defined as  $B = \{(\bar{s}_1, \bar{s}_2) \in \mathfrak{R}_+^2 \mid \bar{s}_1 + \bar{s}_2 \leq V\}$  where  $\bar{s}_i$  denotes the bargaining share of firm  $i = 1, 2$  (the bar above  $s_i$  is designatory of the static framework). Since  $B$  is compact and convex, there is a unique Nash bargaining outcome  $(\bar{s}_1, \bar{s}_2)$  that solves  $\max_{(\bar{s}_1, \bar{s}_2) \in B} (\bar{s}_1 - d_1)(\bar{s}_2 - d_2)$ , expressed as the following functions of  $p$ :

$$\bar{s}_1 = \frac{V + d_1 - d_2}{2} = \frac{p(b+1)}{2}V \quad (1)$$

$$\bar{s}_2 = \frac{V - d_1 + d_2}{2} = \frac{2 - p(b+1)}{2}V. \quad (2)$$

Note that  $\bar{s}_1 > 0$  because  $V + d_1 - d_2 = (1 + pb)V - (1 - p)V \geq (pb + p)V > 0$ . Thus, the strategy of doing nothing is strictly dominated by that of pursuing Nash bargaining for the incumbent. For this reason, the strategy of doing nothing will not be discussed further in the dynamic sequel. Moreover, since  $\bar{s}_1 > d_1$  and  $\bar{s}_2 > d_2$  hold, both firms will find it optimal to pursue a technology sharing agreement *à la* Nash bargaining, instead of litigation. Anticipating such an agreement, firm 2 innovates if  $\bar{s}_2 > c$ .

### 3.2 Trade Secrets

Consider the case that firm 2 decides to keep its innovation as a TS. There are two sub cases: the TS is either revealing or not. If it is revealing (which happens with probability  $1 - \theta$ ), then the incumbent has the same three options as before. Nonetheless, in case of litigation, since a patent is better in demonstrating to a court the borders of 

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acquirer's reputation that may be valuable for future takeover deals.

what the patentee claims as her own, firm 2 stands a worse chance in exhibiting how its technology diversifies from 1's patented technology, i.e. firm 1's probability of prevailing in court increases. Hence, the expected outcome of litigation is better for the incumbent compared to the previous case under patents. As this provides stronger threat points for the incumbent, when a technology agreement is sought, the Nash bargaining outcome is better (worse) for the incumbent (startup) compared to the case of a patented technology. Doing nothing is the worst option for the incumbent as before. To sum up, both litigation and a technology sharing agreement *à la* Nash bargaining provide a worse outcome for firm 2 if it holds a revealing TS. Consequently, it is optimal for firm 2 to patent its technology when it turns out to be revealing.

If the technology is non-revealing (which happens with probability  $\theta$ ) the incumbent is incapable of filing an infringement lawsuit. Therefore the incumbent cannot arm-wrestle the startup into licensing negotiations in the shadow of litigation, and a technology sharing agreement cannot materialize.<sup>14</sup> Thus, the incumbent has no option but to do nothing (its payoff is 0), and the startup garners a payoff of  $V$  when it keeps a non-revealing technology as a TS.

### 3.3 Static equilibrium

As we have argued above, if firm 2 patents its technology then a takeover deal will ensue generating payoffs  $\bar{s}_1$  and  $\bar{s}_2$  for firms 1 and 2, respectively. If the technology is revealing, therefore, firm 2 finds it optimal to patent it because 2's payoff from keeping it as a TS is worse than  $\bar{s}_2$  due to its more vulnerable position in case of litigation. If the technology is non-revealing, on the other hand, firm 2 would opt for TS over patenting if  $V$  is larger than  $\bar{s}_2$ , which is the case because the value of  $\bar{s}_2$  is  $V$  when  $p = 0$  and decreases as  $p$  increases. Therefore, the startup always keeps a non-revealing technology as TS. Thus, the subgame-perfect equilibrium of the static game is summarized as below.

**Proposition 1:** *In the static model, the startup innovates as long as  $\bar{s}_2 + \theta(V - \bar{s}_2) \geq c$  and protects its technology by keeping it as a TS if non-revealing and by patenting it if revealing. In the latter case, Nash bargaining ensues over a patented innovation, leading to a takeover or licensing.*

To recapitulate, in the static model we exemplified how patents may be handicapped relative to TS. In particular, TS dominates patenting whenever the technology is non-

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<sup>14</sup>This assumption is not essential: qualitatively the same result will prevail if we assume that a technology-sharing agreement is possible in this case, too, but at worse terms for the startup than when it is protected by a patent.

revealing. Putting this into perspective, patents should be prevalent in industries where TS fail in concealing the technology. In subsequent sections we demonstrate that patents can fare better than TS even when the technology is non-revealing; and that this has the added effect of incentivizing innovation activities by startups who would not innovate otherwise.

## 4 A dynamic approach

In this section we extend the analysis to a fully dynamic model of infinite periods. In each period the static game of Section 3 is played as the stage game between a long-lived incumbent (firm 1) and a new potential startup (firm 2) that arrives at the market. The key difference from the static model is that the incumbent's patent portfolio may grow via takeovers, lending implications on future bargaining outcomes.

If the incumbent acquires new patents through takeover deals, the technological territory covered by its patent portfolio expands and thus the likelihood increases that it will prevail in future patent-infringement suits. In this regard, we assume that legal power increases as the portfolio size gets bigger, but at a decreasing rate. That it increases at a decreasing rate is a logical consequence of the fact that the chance of prevailing in court is bounded above by 1. To capture this we re-define  $p$ , the probability of firm 1 winning an infringement suit, as a function of the degree of IP protection, denoted by  $z \in (0, 1)$ , and the size of 1's patent portfolio, measured by the number of patents in its portfolio. In particular, an increase in  $z$  (which can be considered as patent breadth) implies a tougher stance on infringement, increasing  $p$ .

To facilitate presentation, we make two indexing conventions. First, since the continuation game from any period is fully described by the size of firm 1's portfolio at the beginning of that period, with slight abuse of terminology we index the period by the size of firm 1's portfolio. Second, since what matters in the analysis is the accumulation of patents on top of the incumbent's initial portfolio, we index the size of the initial portfolio as the base size of 1, and each patent added to it increases the portfolio size by one. Hence, period 1 designates the initial period (of the base portfolio size of 1) and period  $t > 1$  designates any period prior to which firm 1's portfolio size has reached  $t$  but no higher, i.e., firm 1 has added  $t - 1$  patents to its initial portfolio. In other words, period  $t$  denotes any period in which the incumbent starts with a stock  $t$  of patents in its portfolio. So long as firm 1 has added one patent every period from the initial period, our indexing coincides with the natural indexing of periods by natural numbers. Two consecutive periods are indexed the same, however, if the incumbent's portfolio did not

grow in the first of the two periods; see below. For expositional clarity we do not model expiration of patents, the effect of which is discussed at the policy section. On account of the above,  $p$  is a function of  $z$  and  $t$ , which we denote as  $p_z(t)$ . As discussed earlier, we assume that

$$\partial p/\partial z > 0, \quad \partial p/\partial t > 0, \quad \text{and} \quad \partial^2 p/\partial t^2 < 0.$$

Note that the incumbent's portfolio may not grow from one period to the next (in which case we index the two periods the same as explained above) either because firm 2 did not innovate in the first period,<sup>15</sup> or because it did but the incumbent did not buy the innovation.

The order of moves in each period  $t$  is as follows. First, a startup (firm 2) arrives and decides whether to innovate or not contingent on its R&D cost which is 0 and  $C$  with probabilities  $\eta$  and  $1 - \eta$ , respectively. If firm 2 does not innovate, nothing happens until the next period starts. If firm 2 innovates, it observes whether the developed technology is revealing or not, and decides whether to patent it (with zero cost) or to keep it as TS.

If firm 2 patents, firm 1 must decide whether to file a suit or pursue an agreement *à la* Nash bargaining. If a suit is filed, both parties incur a legal cost of  $\ell$  and, as a result, with probability  $p_z(t)$  firm 1 wins and gets a surplus of  $bV$  while with probability  $1 - p_z(t)$  firm 2 wins and gets a surplus of  $V$ . The losing party has a surplus of 0. If an agreement is pursued, the Nash bargaining outcome results over the total producers surplus of  $V$ , plus, in case of a takeover, the additional benefits that would accrue to firm 1 in future deals due to its enlarged portfolio. To avoid the replacement effect, as in Bessen and Maskin (2009), we assume that  $V$ , the profits that can be generated from commercializing the new technology, are incremental values.

If firm 2 keeps its technology as a TS, what happens next depends on whether the technology is revealing or not. If revealing, then firm 1 has the same options as above, where litigation results in firm 1 winning with a higher probability than  $p_z(t)$ , which provides the threat points for a Nash bargaining outcome when an agreement is sought. If non-revealing, firm 2 obtains a payoff of  $V$  from commercializing the technology and firm 1 gets 0.

The startup in each period maximizes its expected surplus of that period, net of innovation cost when relevant. The incumbent maximizes the expected present value of its profit stream with a discount factor  $\delta \in (0, 1)$ .

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<sup>15</sup>In the context of sequential innovation literature where innovation  $n + 1$  cannot be introduced until innovation  $n$  has been, this means that the introduction of innovation  $n$  is delayed at least by one period (rather than innovation  $n$  is skipped).

## 4.1 Equilibrium

We now present a formal analysis of the dynamic model and characterize the unique (subgame-perfect) equilibrium. Two points to note. First, we only focus on takeovers as the means of a technology sharing agreement because they dominate licensing agreements that do not bring future benefits by expanding the incumbent's portfolio; the payoffs from licensing are given by equations (1)-(2) of the static model. Second, as the dynamic model (via the expansion in the incumbent's patent portfolio) provides greater payoffs than the static model, and bearing in mind that the payoffs from litigation and from doing nothing are given by the static model (because there is no expansion in the incumbent's portfolio), similar to the static model, a technology sharing agreement is always preferable to litigation and doing nothing. Thus, in outlining the equilibrium conditions we do not focus on litigation and on doing nothing when technology transfer is feasible (i.e., apart from the case of non-revealing TS).

In the static model we explained that patents are handicapped relative to TS, because of the incumbent's superior position in potential infringement lawsuits owing to its accumulated patent portfolio. The core insight of this section is that the very same reason may render patenting more attractive than TS in a dynamic environment (at least in early stages of the innovation process) and as a result, motivate startup innovations that would not have been possible otherwise. To illuminate this result, we consider environments in which high cost startups would never innovate in the static model. As the startup's bargaining share,  $\bar{s}_2$ , obtains a maximum value of  $V$  when  $p = 0$ , this is the case if

$$C > V \tag{3}$$

which we assume from now on. Since  $V$  captures only the producers surplus, the above inequality does not mean that high-cost startups should not innovate. It is socially efficient for them to innovate so long as the total social surplus, which also includes the consumers surplus, exceeds  $C$ .

Consider an arbitrary equilibrium of the dynamic game. Let  $X(t)$  denote firm 1's value at the beginning of period  $t$ , which is the discounted sum of its expected payoff stream from period  $t$  onward. If a startup innovates and patents its technology in period  $t$ , there will be a takeover as a result of Nash bargaining by the same reasoning as in the static game. As the bargaining outcome is always positive for the startup, a low-cost startup always innovates and then patents when the technology turns out to be revealing. Thus, let  $Q(t) > 0$  denote the probability that a takeover takes place in period  $t$ . Then,

$$X(t) = (1 - Q(t))\delta X(t) + Q(t)(s_1(t) + \delta X(t + 1)) \tag{4}$$

because firm 1's value in the next period is the same as that in the current one if there is no takeover deal in the current period, while if there is a takeover, firm 1 captures the bargaining surplus over the current innovation,  $s_1(t)$ , plus the next period's value which is  $X(t+1)$ .

In the Nash bargaining of period  $t$ , the total surplus that a startup's innovation generates is maximized when firm 1 commercializes it, adding it to its portfolio. The total surplus it brings forth in this case is  $V + \delta(X(t+1) - X(t))$ , which is the size of the pie on the bargaining table. If the case is litigated, since both parties must accept the court's decision, there is no takeover deal.<sup>16</sup> Therefore, the threat points are the court outcomes minus the legal costs, i.e.  $d_1 = p_z(t)bV - \ell$  and  $d_2 = (1 - p_z(t))V - \ell$ . Since the Nash bargaining set in this case is  $B(t) = \{(s_1, s_2) \in \mathfrak{R}_+^2 \mid s_1 + s_2 \leq V + \delta(X(t+1) - X(t))\}$ , the Nash bargaining outcome  $(s_1, s_2)$  that solves  $\max_{(s_1, s_2) \in B(t)} (s_1 - d_1)(s_2 - d_2)$  is,

$$s_1(t) = \frac{p_z(t)(b+1)}{2}V + \frac{\delta(X(t+1) - X(t))}{2} \quad (5)$$

$$s_2(t) = \frac{2 - p_z(t)(b+1)}{2}V + \frac{\delta(X(t+1) - X(t))}{2}. \quad (6)$$

Plugging  $s_1(t)$  back into equation (4) and rearranging, we get

$$X(t+1) - X(t) = \frac{2(1-\delta)}{3Q(t)\delta}X(t) - \frac{p_z(t)(b+1)}{3\delta}V, \quad (7)$$

a difference equation that characterizes the sequence  $X(t)$ . In addition, plugging (7) into (6), we get

$$s_2(t) = \frac{1-\delta}{3Q(t)}X(t) + \frac{3-2p_z(t)(b+1)}{3}V. \quad (8)$$

At this point, observe that given the values of innovation cost  $c \in \{0, C\}$  and the payoff  $V$  of keeping a non-revealing technology as TS, in light of (3), in equilibrium one of the following three cases must hold in each period  $t$ :

- [I]  $s_2(t) \geq C$  and both high-cost and low-cost startups innovate and always patent their technology.
- [II]  $V \leq s_2(t) \leq C$  and a low-cost startup always innovates and patents its technology when it is non-revealing (for certain if  $V < s_2(t)$ ) as well as when it is revealing;

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<sup>16</sup>The legal annals are not unfamiliar with awkward cases, and a takeover after the court has decided on the merits of the case could have taken place. We do not examine such an outcome, because in this context it is irrational, plus it is impossible to define the outside options of the firms after the threat of litigation has materialized.



and a high-cost startup may innovate if  $s_2(t) = C$  but with a probability less than 1 (and always patents its technology).<sup>17</sup>

[III]  $s_2(t) \leq V$  and only low-cost startups innovate and keep their technology as TS if it is non-revealing (and patent it if revealing).<sup>18</sup>

To explain the equilibrium heuristically, note that as the portfolio size gets arbitrarily large, the extra value of an additional patent gets negligible and therefore,  $X(t+1) - X(t) \rightarrow 0$  as  $t \rightarrow \infty$ . Because

$$\lim_{t \rightarrow \infty} s_2(t) = \frac{2 - p_z(\infty)(b+1)}{2}V < V \quad (9)$$

from (6), case [III] above holds for all sufficiently large  $t$ , say  $t \geq T^*$  for some  $T^* < \infty$  to be pinned down below. Hence, the equilibrium sequence  $X(t)$  for  $t \geq T^*$  solves (7) when  $Q(t) = \eta(1 - \theta)$ , which is an increasing and convergent sequence as formalized in the next result. Although the solution to (7) when  $Q(t) = \eta(1 - \theta)$  is pertinent only for  $t \geq T^*$  as a part of equilibrium, it proves useful to present the solution sequence, denoted by  $X^*(t)$ , for all natural numbers  $t \geq 1$ .

**Proposition 2:** *The sequence  $X^*(t)$  that solves (7) when  $Q(t) = \eta(1 - \theta)$  is unique, monotonically increases at a decreasing rate, i.e.,  $X^*(t) - X^*(t-1) > X^*(t+1) - X^*(t) > 0$  for all  $t > 1$ , and converges to*

$$X^*(\infty) = \frac{\eta(1 - \theta)p_z(\infty)(b+1)}{2(1 - \delta)}V \quad \text{as } t \rightarrow \infty. \quad (10)$$

*Proof:* See Appendix A.

Let  $s_2^*(t)$  denote the startup's bargaining share when  $X(\cdot) = X^*(\cdot)$ , i.e.,

$$s_2^*(t) := \frac{2 - p_z(t)(b+1)}{2}V + \frac{\delta(X^*(t+1) - X^*(t))}{2}.$$

Note that  $s_2^*(t)$  strictly decreases in  $t$  because  $p_z(t)$  increases while  $X^*(t+1) - X^*(t)$  decreases in  $t$ . Letting  $T^*$  be the smallest  $t$  such that  $s_2^*(t) \leq V$ , the equilibrium of the dynamic game is characterized as below.

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<sup>17</sup>We require "with a probability less than 1" here just to distinguish [II] from [I].

<sup>18</sup>It is not possible that  $s_2(t) = V$  and a low-cost startup patents its technology with a positive probability when it is non-revealing. The reason is, there would be a takeover of the patented technology in that case, enhancing the incumbent's current value  $X(t)$  via strengthened future bargaining power, which in turn would mean a reduced stake to bargain over because  $X(t+1) - X(t)$  shrinks and consequently, a reduced  $s_2(t) < V$ . See the proof of Proposition 3 in Appendix A.

**Proposition 3:** *There is a unique equilibrium of the dynamic game.*

(a) [I] or [II] holds for  $t < T^*$  while [III] holds for  $t \geq T^*$ , so  $X(t) = X^*(t)$  for  $t \geq T^*$ .

(b) For any  $\tilde{t} > 1$  there is  $\underline{\delta}(\tilde{t}) < 1$  such that if  $\delta > \underline{\delta}(\tilde{t})$  and [I] holds in some period  $t \leq \tilde{t}$ , then [I] holds in all periods 1 through  $t$ .

*Proof:* See Appendix A.

Roughly speaking, the proof starts from the observations that  $X^*(t)$  is the lower bound of the incumbent's values because  $Q(t)$  is bounded below by  $\eta(1 - \theta)$ , and that  $X^*(t)$  is increasing at a decreasing rate from Proposition 2. Thus, if  $X^*(t+1) - X^*(t)$  is not enough to induce high-cost innovation, i.e.,  $t \geq T^*$ , then high-cost innovation cannot be induced in any future period, say  $t' > t$ , because that would require a higher benefit from obtaining an additional patent in period  $t'$ , i.e.,  $X(t'+1) > X^*(t'+1)$ , which in turn would require  $X(t'+2) > X^*(t'+2)$  and so on, which is impossible as the value of  $X(\cdot)$  must converge to (10) in the limit. This establishes that  $X(t) = X^*(t)$  for all  $t \geq T^*$ . On the other hand, for any  $t < T^*$ , as  $X^*(t+1) - X^*(t)$  is large enough so that  $s_2^*(t) > V$  and  $X(t+1)$  is no lower than  $X^*(t+1)$ , it follows that  $s_2(t)$  must exceed  $V$  and even non-revealing innovations will be patented, establishing that [I] or [II] prevails for  $t < T^*$ . Furthermore, if  $s_2(t)$  exceeds  $C$  so that even a high-cost startup innovates in some  $t < T^*$ , then it can be shown recursively that the same holds for all preceding periods for  $\delta$  close to 1.

Thus, the dynamic equilibrium typically goes through a few phases. Initially, both types of startups innovate, always patenting their innovation; in the next phase, only low-cost startups innovate and patent their innovation even when it is non-revealing; then in the final phase, only low-cost startups innovate and keep a TS when non-revealing. This transition of phases stems from the insight that when the incumbent's patent portfolio is small, a large impact of a takeover on future bargaining outcomes boosts the size of the pie to be bargained over, increasing the startup's bargaining share enough to motivate even high-cost startups to innovate (who would not due to (3) in the absence of such dynamic effects). As this process continues, the future benefit of the enlarged portfolio size diminishes reducing the startup's share, so that high-cost startups stop innovating at some stage and then low-cost startups stop patenting when their technology turns out to be non-revealing.

## 5 Simulation and comparative statics

Even though our argument seems intuitive, its recursive nature and its discontinuity at  $T^*$  makes it impossible to visualize its fine details. In remedying this we now simulate the recursive model. What we aim to demonstrate is a) that the sequence  $X(\cdot)$  converges and behaves in the fashion described above, and in doing so uncover the model's comparative statics, and b) that the dynamic effects in fact motivate high-cost startups to innovate who wouldn't do so otherwise. The algorithm we run is outlined in Appendix B. In this instance, our aim is to run the algorithm for expositional purposes and for values that lead to a relatively high  $T^*$  in order to illustrate our main point. By changing the parameter values (throughout their parameter range) we find different values of  $T^*$  without altering the qualitative properties of the equilibrium.

For the simulation, we need to fix the function  $p_z(t)$  representing the incumbent's probability of winning an infringement lawsuit. We argued earlier that  $p_z(t)$  increases at a decreasing rate in  $t$ , and increases in  $z$ . Although empirical estimates are rather scarce on this measure, such properties are in line with the findings of Lanjouw and Schankerman (2004) that the marginal protective power of portfolio size is positive but slowing down. We capture this by setting  $p_z(t) = 1 - (1 - z)^t$ . To provide an example, when  $z = .01$  a firm with a portfolio made up of 100 patents stands a 63% chance of winning its case, and an increase of 1 patent raises this by .36%. Note that by changing  $z$  we can affect the speed of convergence of  $p_z(t)$  to 1; we elaborate on this point in the next section.

For other parameter values, we normalize  $V = 1$  and set  $C = 1.0001 > V$  to satisfy (3), ensuring that innovation by high-cost startups may only be possible in a dynamic model. Furthermore, noting that  $\bar{s}_2(p) \leq \bar{s}_2(0) = 1$ , and that  $p_z(t)$  is constant at 0 for all  $t$  if  $z = 0$ , a  $C > 1$  ensures that IP protection (i.e.  $z > 0$ ) is necessary for the innovations that we envision.<sup>19</sup> Turning our attention to  $b$ , as the value of  $b$  proves not to affect  $T^*$  significantly, we report the simulation result for  $b = 1$  mainly, and also report comparative statics on  $b$ . With respect to  $\delta$ ,  $\theta$ , and  $\eta$ , we simulate the model for  $\delta = .97$  (the incumbent is patient),  $\theta = .1$  (frequently the innovation is easy to re-engineer) and  $\eta = .95$  (a very entrepreneurial environment) and we report comparative statics on  $\delta$ ,  $\theta$ , and  $\eta$ .

Using the above values of  $V$ ,  $C$ ,  $b$ ,  $\delta$ ,  $\theta$ ,  $\eta$  and for the aforementioned  $p_z(t)$  with a  $z = .01$  we commence the simulation by calculating the unique sequence  $X^*(t)$  of Proposition 2, that solves (7) when  $Q(t) = \eta(1 - \theta)$ , for  $t = 1, 2, \dots$  and the corresponding  $s_2^*(t)$  for  $t = 1, 2, \dots$ . Having the  $s_2^*(t)$  at hand we find the  $T^*$  which is the smallest  $t$  such

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<sup>19</sup>Recall that  $C > V$  does not mean that high-cost innovation is socially inefficient, because  $V$  does not capture the consumer surplus.

that  $s_2^*(t) \leq V$ . In this case  $T^* = 10$ . This routine corresponds to the first 3 steps of the algorithm we outline in Appendix B. In figure 1 we plot  $X^*(t)$  and  $s_2^*(t)$  respectively. By changing  $b$ ,  $\delta$ ,  $\theta$ , and  $\eta$  through out their parameter range we find that: i) a decrease in  $\eta$  leads to a lower  $T^*$ , ii) an increase in  $\theta$  provides a smaller  $T^*$ , iii) lowering  $\delta$  decreases  $T^*$ , and iv)  $b$  has no visible effect on  $T^*$ .

Having derived a  $T^* = 10$  we recursively shift our attention to  $t = 1, 2, 3 \dots T^* - 1$ . Specifically, we run steps 4 and 5 of the algorithm (see Appendix B) to find the values of  $X(t)$ ,  $s_2(t)$ ,  $\alpha(t)$ ,  $\beta(t)$  and  $Q_2(t)$  and in the process verify that  $s_2(t) > V$  and  $X(t) > X^*(t)$ . The results are included in Table 1.

Table 1					
$t$	$X(t)$	$s_2(t)$	$\alpha(t)$	$\beta(t)$	$Q(t)$
1	8.78772	1.07454	1	1	1
2	8.96204	1.06309	1	1	1
3	9.13314	1.05173	1	1	1
4	9.30104	1.04047	1	1	1
5	9.46573	1.02931	1	1	1
6	9.62722	1.01825	1	1	1
7	9.7855	1.00728	1	1	1
8	9.94057	1.00001	1	0.298882	0.964944
9	10.0999	1	0.219863	0	0.875887

Specifications: Iterations=250,  $z=.01$ ,  $\eta=.95$ ,  $\theta=.1$ ,  $b=1$ ,  $\delta=.97$ ,  $V=1$ ,  $C=V+.00001$

## 6 Policy implications

An interesting policy-relevant question naturally arises from our analysis: what is the optimal level of IP protection,  $z$ , and the optimal patent length that provide the innovation incentives for entrant firms for longest? In terms of  $z$ , the core logic of our analysis points to the following intuition: If  $z$  is excessive, the marginal protective power that an extra patent brings to the incumbent is large initially but quickly dwindles as a result of accumulating its power too rapidly, killing off the positive effect on entrant innovation prematurely. If  $z$  is feeble, on the other hand, the marginal protective power of an extra patent can be too small and its impact on the entrant's innovation incentives limited. We confirm this intuition by running the simulation of the previous section (for the same values of  $C$ ,  $V$ ,  $b$ ,  $\delta$ ,  $\theta$ , and  $\eta$ ) for various values of  $z$ , with a view to finding the levels of  $z$  under which high-cost innovations are induced for longest. We list the results in Table 2 below.

Table 2 lists  $T^*$  for values of  $z$  in  $\{0.0000001, 0.000001, 0.00001, 0.0001, 0.001, 0.01, 0.1, 1\}$ . To put these levels of IP protection into perspective we also list the probability of winning the case for a portfolio of 100 patents. For a  $z = 0.0000001$  this probability is 0.00001, while for a  $z = 1$  this probability is 1. Table 2 posts a non-linear relationship between  $z$  and  $T^*$ . Specifically, the lowest and highest  $z$  provide the same  $T^* = 1$ , with intermediate values providing higher levels of  $T^*$ . For example, a  $z = 0.001$ , which corresponds to  $p(t = 100) = 9.5\%$ , leads to the highest  $T^* = 14$ .

In terms of length, even though takeovers enlarge a portfolio, the term of a patent counterbalances this enlargement as patents exit the portfolio after a maximum period of 20 years. In view of this, consider the following practical example. If one sets the patent length as  $T^*$  then in every period (as long as the portfolio's patents are evenly spaced) one patent expires as a new patent is added. An interesting alternative interpretation of  $T^*$ , therefore, is the maximal patent length that, by constraining the incumbent's portfolio size below a threshold, would allow for innovation by high-cost startups *ad infinitum*.

Table 2		
$z$	$p(t = 100)$	$T^*$
0.0000001	0.00001	1
0.00001	0.0001	4
0.00001	0.001	13
<b>0.0001</b>	<b>0.01</b>	<b>14</b>
<b>0.001</b>	<b>0.095</b>	<b>14</b>
0.01	0.63	10
0.1	0.99	3
1	1	1

Specifications: Iterations=250,  $z=.01$ ,  $\eta=.95$ ,  
 $\theta=.1$ ,  $b=1$ ,  $\delta=.97$ ,  $V=1$ ,  $C=V+.00001$

## 7 Conclusions

We started our analysis under the presumption that patents are handicapped towards TS, only to reach an antipodal conclusion. The prevalence of patents rests on their capacity to create a conflict that they can also ameliorate. In broad terms, what we argue is that patents can be viewed as “liabilities” that can engender a costly conflict, and as “assets” that can pave the way for a resolution. This dual role (as assets and liabilities) endows

patents with a strategic capacity conducive to technology transfer.<sup>20</sup>

The prerequisite for the dominance of patents is comprehensive technology transfer and an intermediate level of IP protection that prolongs the sequence of events, facilitating the trade of patents as negotiating assets. The assumption of an intermediate  $z$  is an ingrained part of the cumulative innovation genre. It rests upon the conjecture, first noted by Scotchmer (1991), that if the first innovation is narrow in its scope (and allows for derivative products and applications) there will be no R&D incentives for the first innovator. Conversely, a first innovation that is overly broad may hinder subsequent innovation. A compromise must be inevitably reached between the first and second innovator. As the values of  $z$  in the simulation are at the low end of the spectrum, this compromise is shown to be in favor of the second innovator. This conclusion is a consequence of the weight that the model attaches to the view that for the present innovation to exist there must be a foreseeable sequence of future innovations that should be adequately incentivized. This perspective is akin to an “*if you built it, they will come*” mindset that rests on the established contemporary practice of startup takeovers.

In retrospect, in this paper we contribute to the patents versus trade secrets debate. We study how patents shape the R&D incentives of agents who (due to their *infant* nature) lack other means of protection, and argue that balanced patent portfolios that have been created with a strategic goal in mind can be welfare inducing by leading to more patenting and more innovation.

## Appendix A

*Proof of Proposition 2:* First, note that  $X^*(t)$  is bounded below (by 0) and above because maximum surplus in each period is bounded and  $\delta < 1$ . If  $X^*(t+1) \leq X^*(t)$ , then the right hand side of equation (7), with  $Q(t) = \eta(1 - \theta)$  and  $X$  replaced by  $X^*$ , would be non-positive and, furthermore, its value would strictly decrease when evaluated for  $t+1$  because  $X^*(t+1) \leq X^*(t)$  and  $p_z(t+1) > p_z(t)$ . This would mean that  $X^*(t+2) - X^*(t+1) < X^*(t+1) - X^*(t) \leq 0$ . Applying the same argument repeatedly, we deduce that if  $X^*(t+1) \leq X^*(t)$  then the sequence should decrease forever at an increasing rate after  $t$ , which is a contradiction because the sequence is bounded below.

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<sup>20</sup>Patents were not originally envisioned as strategic assets. Article 1.8.8 of the US Constitution describes patents as limited time monopolies bestowed to innovators as to promote science. Their ability to be used as bargaining chips (irrespective of the uses the embodied technology finds) is a relatively new one. It rests on a 1908 Supreme Court decision, *Continental Paper Bag Co. v. Eastern Paper Bag Co.*, which established the principle that patent holders have no obligation to use their patents in production.

Hence, we conclude that  $X^*(t+1) - X^*(t) > 0$  for all  $t$ . Since the sequence is bounded above, it further follows that it must converge. The limit value,  $X^*(\infty)$  in (10), is obtained by setting  $X^*(t+1) = X^*(t)$  and  $p_z(t) = p_z(\infty)$  in equation (7) and solving for  $X^*(t)$ .

To show uniqueness, suppose to the contrary that there are two sequences,  $\{X^*(t)\}$  and  $\{X^{**}(t)\}$ , that satisfy (7) with  $Q(t) = \eta(1 - \theta)$ , such that  $X^{**}(t') = X^*(t') + \gamma$  for some  $\gamma > 0$  and  $t'$ . By (7), we have  $X^{**}(t'+1) = X^*(t'+1) + (1 + \frac{2(1-\delta)}{3\eta(1-\theta)\delta})\gamma > X^*(t'+1) + \gamma$  and by repeating the same calculation,  $X^{**}(t) > X^*(t) + \gamma$  for all  $t \geq t'$ . This is impossible because both sequences should converge to the same limit as proved above, proving the uniqueness.

Finally, to show that  $X^*(t) - X^*(t-1) > X^*(t+1) - X^*(t)$ , note from equation (7) that

$$X^*(t+1) - X^*(t) - X^*(t) + X^*(t-1) = \frac{2(1-\delta)}{3\eta(1-\theta)\delta}(X^*(t) - X^*(t-1)) - \frac{(p_z(t) - p_z(t-1))(b+1)}{3\delta}V. \quad (11)$$

If  $X^*(t+1) - X^*(t) \geq X^*(t) - X^*(t-1)$  for some  $t$ , it would follow from equation (11) that  $X^*(t+2) - X^*(t+1) \geq X^*(t+1) - X^*(t)$  because  $0 < p_z(t+1) - p_z(t) < p_z(t) - p_z(t-1)$  due to the assumption that  $\partial^2 p / \partial t^2 < 0$ . Furthermore,  $X^*(t+1) - X^*(t)$  would increase in  $t$  by repeated application of the same argument. This is impossible because the sequence  $X^*(t)$  converges as shown above, hence we conclude that  $X^*(t) - X^*(t-1) > X^*(t+1) - X^*(t)$ . *Q.E.D.*

*Proof of Proposition 3:* We start by showing that in any equilibrium  $X(t)$  increases for all  $t$  sufficiently large. To prove by contradiction, suppose otherwise, i.e.,  $X(t+1) - X(t) \leq 0$  for arbitrarily large  $t$ , say  $t'$ . Then,  $s_2(t') < V$  by (6) and  $Q(t') = \eta(1 - \theta)$  by [III]. Note from possible cases [I]-[III] that  $Q(t) \geq \eta(1 - \theta)$  for all  $t$ . Therefore, the RHS of (7) is negative for  $t = t' + 1$ , i.e.,  $X(t'+1) - X(t') \leq 0$ . Applying the same argument repeatedly, we deduce that  $X(t+1) - X(t) \leq 0$  for all  $t \geq t'$  and thus,  $Q(t) = \eta(1 - \theta)$  for all  $t \geq t'$  by [III]. This would mean that  $X(t)$  for  $t \geq t'$  solves (7) when  $Q(t) = \eta(1 - \theta)$ , but this would contradict Proposition 2. This establishes that

$$X(t) \text{ strictly increases for all sufficiently large } t, \text{ say } t > T^o. \quad (12)$$

Moreover, from the fact that  $X(t)$  is bounded above by  $X(t) \leq V/(1 - \delta)$  because the maximum possible surplus for the economy (hence, for firm 1) is  $V$  in each period, it further follows that

$$\limsup_{t \rightarrow \infty} X(t+1) - X(t) = 0. \quad (13)$$

Below, we first show that any equilibrium must satisfy the properties of part (a) of

the Proposition, in the process of which we construct the unique equilibrium. Then, we prove part (b).

Supposing that an equilibrium exists, we verify that it satisfies the properties of part (a) of the Proposition. This verification consists of a few steps.

The first step is to show that [III] holds for  $t \geq T^*$ , i.e.,  $X(t) = X^*(t)$ ,  $s_2(t) = s_2^*(t)$  and  $Q(t) = \eta(1 - \theta)$  for all  $t \geq T^*$  where  $T^*$  is the smallest  $t$  such that  $s_2^*(t) \leq V$  as defined in the main text. It is straightforward from (13) and (6) that  $s_2(t) < V$  for all sufficiently large  $t$  and thus, from [III] that  $Q(t) = \eta(1 - \theta)$ . It further follows, therefore, that the  $X(t)$  solves (7) when  $Q(t) = \eta(1 - \theta)$  for all sufficiently large  $t$  and as a result, by Proposition 2, [III] holds for all sufficiently large  $t$ . Now, with a view to reaching a contradiction, suppose that there exists  $t \geq T^*$  that  $s_2(t) \neq s_2^*(t)$ . Without loss of generality, suppose that  $t$  is the largest such  $t$ . Note that  $s_2(t) < s_2^*(t)$  would mean  $Q(t) = \eta(1 - \theta)$  by [III] because  $s_2^*(t) \leq V$  for all  $t \geq T^*$  and thus,  $s_2(t) = s_2^*(t)$  by (6) and (7), a contradiction. Hence,  $s_2(t) \neq s_2^*(t) \leq V$  would imply that  $s_2(t) > s_2^*(t)$  which in turn would imply  $X(t) < X^*(t)$  by (6) and  $Q(t) < \eta(1 - \theta)$  by (7), but this is impossible because  $Q(t) \geq \eta(1 - \theta)$  always holds by [I]-[III]. This proves that [III] holds for all  $t \geq T^*$ .

Next, consider  $t = T^* - 1$ . Note, in particular, that  $s_2^*(T^* - 1) > V$ . Given  $X(T^*) = X^*(T^*)$ , from (7) we deduce that  $X(T^* - 1)$  is equal to  $X^*(T^* - 1)$  when  $Q(t) = \eta(1 - \theta)$  and strictly increases as  $Q(t)$  increases. Consequently, from (6) we deduce that  $s_2(T^* - 1)$  is equal to  $s_2^*(T^* - 1)$  when  $Q(t) = \eta(1 - \theta)$  and strictly decreases as  $Q(t)$  increases. We represent  $X(T^* - 1)$  and  $s_2(T^* - 1)$  as  $X(T^* - 1, q)$  and  $s_2(T^* - 1, q)$  to indicate their dependence on the value  $q \in [\eta(1 - \theta), 1]$  of  $Q(t)$ . Note that  $Q(t) = \eta(1 - \theta + \alpha\theta) \in [\eta(1 - \theta), \eta]$  if a low cost-startup innovates and patents with probability  $\alpha$  when non-revealing and a high-cost startup never innovates;  $Q(t) = \eta + (1 - \eta)\beta \in [\eta, 1]$  if a low cost-startup always innovates and patents and a high-cost startup innovates with probability  $\beta$  and always patent if innovates. The following two cases are possible.

(i) Suppose  $V < s_2^*(T^* - 1) \leq C$ . In this case, a high-cost startup would never innovate in period  $T^* - 1$  because  $s_2(T^* - 1, q) < C$  for all  $q \in (\eta(1 - \theta), 1]$ . If  $s_2(T^* - 1, \eta) \geq V$ , then  $s_2(T^* - 1, q) > V$  for any  $q \in [\eta(1 - \theta), \eta)$  and thus, a low-cost startup must innovate in period  $T^* - 1$  and always patent (i.e.,  $\alpha = 1$ ) in equilibrium. If  $s_2(T^* - 1, \eta) < V$ , then  $s_2(T^* - 1, q) = V$  for a unique  $q \in (\eta(1 - \theta), \eta)$ , say  $\hat{q}$ , and thus, a low-cost startup must innovate in period  $T^* - 1$  and patent with probability  $\hat{\alpha} \in (0, 1)$  when non-revealing in equilibrium, where  $\hat{\alpha}$  is the unique value of  $\alpha$  that solves  $\eta(1 - \theta + \alpha\theta) = \hat{q}$ .

(ii) Suppose  $C < s_2^*(T^* - 1)$ . If  $s_2(T^* - 1, 1) \geq C$ , then  $s_2(T^* - 1, q) > C$  for any  $q \in [\eta(1 - \theta), 1)$  and thus, both types of startup must innovate in period  $T^* - 1$  and always patent (i.e.,  $\alpha = \beta = 1$ ) in equilibrium. Consider the alternative case that



$s_2(T^* - 1, 1) < C$ . If  $s_2(T^* - 1, \eta) > C$ , then a low-cost startup must always innovate and patent while a high-cost startup must innovate and patent with probability  $\hat{\beta}$  in period  $T^* - 1$  where  $\hat{\beta}$  is the unique value of  $\beta$  that solves  $s_2(T^* - 1, \eta + (1 - \eta)\beta) = C$ . If  $V < s_2(T^* - 1, \eta) \leq C$ , then a low-cost startup must always innovate and patent while a high-cost startup must not innovate. If  $s_2(T^* - 1, \eta) \leq V$ , then a high-cost startup must not innovate while a low-cost startup must innovate and patent with probability  $\hat{\alpha}$  when non-revealing in period  $T^* - 1$  where  $\hat{\alpha}$  is the unique value of  $\alpha$  that solves  $s_2(T^* - 1, \eta(1 - \theta + \alpha\theta)) = V$ .

We have shown above that [I] or [II] holds for  $t = T^* - 1$ . In particular,  $X(T^* - 1) > X^*(T^* - 1)$  and thus,

$$\tilde{s}_2(T^* - 2) := \frac{2 - p_z(T^* - 2)(b + 1)}{2}V + \frac{\delta(X(T^* - 1) - X^*(T^* - 2))}{2}$$

is larger than  $s_2^*(T^* - 2) > V$ . Therefore, we can apply an analogous argument as above (with  $\tilde{s}_2(T^* - 2)$  playing the role of  $s_2^*(T^* - 2)$ ) to deduce that [I] or [II] holds for  $t = T^* - 2$ . In addition, as  $X(T^* - 1) > X^*(T^* - 1)$  and the probability of takeover is higher than  $\eta(1 - \theta)$  in [I] and [II], it further follows that  $X(T^* - 2) > X^*(T^* - 2)$ . Consequently, we may apply analogous argument recursively to establish that [I] or [II] holds for all  $t < T^*$ . Note that  $s_2(t) > V$  and (6) ensure that  $X(t)$  increases in  $t$ . Note that we have constructed the unique equilibrium and that this construction proves part (a).

(b) Fix an arbitrary  $t > 0$ . Evaluate (7) for one period early to get an expression for  $X(t) - X(t - 1)$ , then add  $\frac{2(1-\delta)}{3Q(t-1)\delta}X(t)$  on both sides and rearrange to get

$$X(t) - X(t - 1) = \frac{2(1 - \delta)}{3Q(t - 1)\delta + 2(1 - \delta)}X(t) - \frac{p_z(t - 1)(b + 1)}{3Q(t - 1)\delta + 2(1 - \delta)}Q(t - 1)V. \quad (14)$$

Subtract (7) from (14) side by side to get

$$\begin{aligned} & X(t) - X(t - 1) - X(t + 1) + X(t) \\ = & 2(1 - \delta)X(t) \left( \frac{1}{3Q(t - 1)\delta + 2(1 - \delta)} - \frac{1}{3Q(t)\delta} \right) \\ & + \left( \frac{p_z(t)(b + 1)}{3\delta} - \frac{p_z(t - 1)(b + 1)}{3Q(t - 1)\delta + 2(1 - \delta)}Q(t - 1) \right) V \\ \rightarrow & \lim_{\delta \rightarrow 1} 2(1 - \delta)X(t) \frac{Q(t) - Q(t - 1)}{3Q(t)Q(t - 1)} + \frac{p_z(t) - p_z(t - 1)}{3}(b + 1)V > 0 \end{aligned} \quad (15)$$

as  $\delta \rightarrow 1$  where the inequality follows as long as  $Q(t) = 1$ , which is the case when [I] pertains in period  $t$ . Therefore, for each  $t > 1$  there is  $\delta(t) < 1$  such that if  $\delta > \delta(t)$  and [I] pertains in period  $t$ , then  $X(t) - X(t - 1) > X(t + 1) - X(t)$  so that  $s_2(t - 1) > s_2(t)$

by (6) and thus [I] pertains in period  $t - 1$  as well. For any  $\tilde{t} > 1$ , part (b) is proved by taking  $\underline{\delta}(\tilde{t}) = \max\{\delta(2), \delta(3), \dots, \delta(\tilde{t})\}$ . Q.E.D.

## Appendix B

We describe below the simulation steps used to calculate the unique equilibrium of the dynamic model reported in Section 5.

- (1) Fix the parameter values (try various values):  $C > V = 1$ ,  $\eta$ ,  $z$ ,  $\delta$ ,  $\theta \in (0, 1)$ .
- (2) Calculate the unique sequence  $X^*(t)$  of Proposition 2, that solves (7) when  $Q(t) = \eta(1 - \theta)$ , for  $t = 1, 2, \dots$ . Also calculate  $s_2^*(t)$  for  $t = 1, 2, \dots$ .
- (3) Find  $T^*$  which is the smallest  $t$  such that  $s_2^*(t) \leq V$ .
- (4) For all  $t \geq T^*$ , define  $X(t) = X^*(t)$  and  $s_2(t) = s_2^*(t)$ .
- (5) Consider  $t = T^* - 1$ . Define

$$\widehat{X}(T^* - 1, q) := \left( \frac{3q\delta}{3q\delta + 2(1 - \delta)} \right) X(T^*) + \left( \frac{3q\delta}{3q\delta + 2(1 - \delta)} \right) \frac{p_z(T^* - 1)(b + 1)}{3\delta} V$$

and

$$\widehat{s}_2(T^* - 1, q) := \frac{2 - p_z(T^* - 1)(b + 1)}{2} V + \frac{\delta(X(T^*) - \widehat{X}(T^* - 1, q))}{2}.$$

Verify that  $\widehat{s}_2(T^* - 1, \eta(1 - \theta)) > V$ .

- i) If  $V < \widehat{s}_2(T^* - 1, \eta(1 - \theta)) \leq C$ , calculate  $\widehat{s}_2(T^* - 1, \eta)$ . If  $\widehat{s}_2(T^* - 1, \eta) \geq V$ , then set  $\alpha(T^* - 1) = 1$ . If  $\widehat{s}_2(T^* - 1, \eta) < V$ , then set  $\alpha(T^* - 1) = \hat{\alpha} \in [0, 1]$  such that  $\widehat{s}_2(T^* - 1, \eta(1 - \theta + \hat{\alpha}\theta)) = V$ . Set  $\beta(T^* - 1) = 0$ .
- ii) If  $C < \widehat{s}_2(T^* - 1, \eta(1 - \theta))$ , calculate  $\widehat{s}_2(T^* - 1, 1)$ . If  $\widehat{s}_2(T^* - 1, 1) \geq C$ , then set  $\alpha(T^* - 1) = 1$  and  $\beta(T^* - 1) = 1$ .
- iii) If  $C < \widehat{s}_2(T^* - 1, \eta(1 - \theta))$  and  $\widehat{s}_2(T^* - 1, 1) < C$ , calculate  $\widehat{s}_2(T^* - 1, \eta)$ . If  $\widehat{s}_2(T^* - 1, \eta) > C$ , then set  $\alpha(T^* - 1) = 1$  and  $\beta(T^* - 1) = \hat{\beta} \in [0, 1]$  such that  $\widehat{s}_2(T^* - 1, \eta + (1 - \eta)\beta) = C$ . If  $V < \widehat{s}_2(T^* - 1, \eta) \leq C$ , then set  $\alpha(T^* - 1) = 1$  and  $\beta(T^* - 1) = 0$ . If  $\widehat{s}_2(T^* - 1, \eta) \leq V$ , then set  $\alpha(T^* - 1) = \hat{\alpha} \in [0, 1]$  such that  $\widehat{s}_2(T^* - 1, \eta(1 - \theta + \hat{\alpha}\theta)) = V$  and set  $\beta(T^* - 1) = 0$ .

Set  $Q(T^* - 1) = \eta(1 - \theta + \theta\alpha(T^* - 1)) + (1 - \eta)\beta(T^* - 1)$ . This is the probability with which an innovation is patented by the startup in period  $T^* - 1$ . Thus, define

$$X(T^* - 1) = \widehat{X}(T^* - 1, Q(T^* - 1)) \quad \text{and} \quad s_2(T^* - 1) = \widehat{s}_2(T^* - 1, Q(T^* - 1))$$

Verify that  $X(T^* - 1) > X^*(T^* - 1)$ .

- (6) Repeat all the steps of (5) above when  $T^*$  is replaced by  $T^* - 1$  everywhere, to determine  $Q(T^* - 2)$  through  $\alpha(T^* - 2)$  and  $\beta(T^* - 2)$  and thereby,  $X(T^* - 2)$  and  $s_2(T^* - 2)$ . Backwardly, repeat the steps of (5) when  $T^*$  is replaced by  $T^* - 2$  everywhere to determine  $X(T^* - 3)$  and  $s_2(T^* - 3)$ , then when  $T^*$  is replaced by  $T^* - 3$  everywhere to determine  $X(T^* - 4)$  and  $s_2(T^* - 4)$ , and so on until  $X(1)$  and  $s_2(1)$  are determined.

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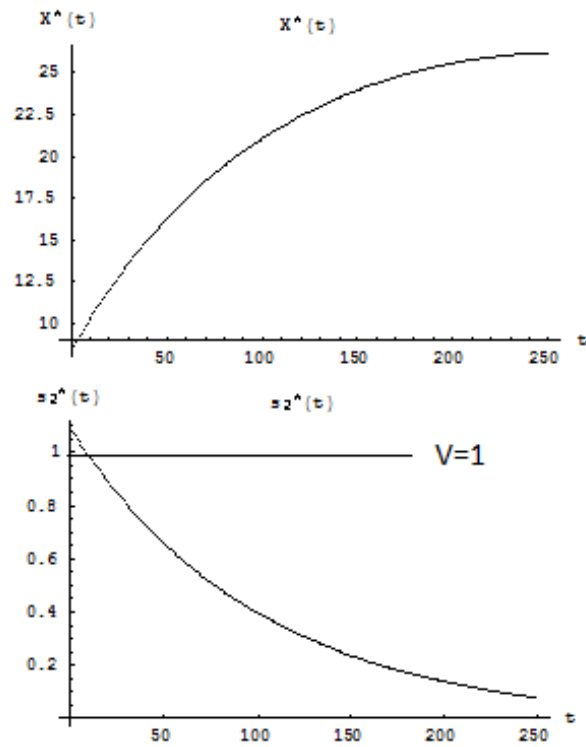


Figure 1: Specifications: Iterations=250,  $z=.01$ ,  $\eta=.95$ ,  $\theta=.1$ ,  $b=1$ ,  $\delta=.97$ ,  $V=1$ ,  $C=V+.00001$