How to incentivise internal innovation in the face of competition?

Andreea Livadariu, 422169

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Erasmus School of Economics

Erasmus University Rotterdam

Supervisor: Dr. J Delfgaauw
Second assessor: Dr. BSY Crutzen

Abstract

This paper studies how between-firm competition affects firms' ability to provide employees with incentives to innovate. In a relatively simple moral hazard framework, it derives the optimal dynamic contract to induce employees to pursue innovative work methods rather than using known work methods. Subsequently, it analyses the firms' choice of action to engage in, as well as the associated efficiency of the chosen method. Results show how, if a worker is to explore new production methods, he may need to be rewarded for early failure, which can be impossible for a firm operating under competition. This is caused by the lower expected profits, as well as by the increased competition for shareholders imposing constraints on the liquidity of a firm. Stakeholders would be more difficult to attract to any one firm, the more firms there are in the industry, implying that firms should avoid making losses in early stages. Thus, under certain conditions, less competition may prove to be beneficial for the overall efficiency of the market, while in other cases more competition could be more efficient.[1]

[1]For printed versions of this paper, the use of coloured ink is highly recommended.

Introduction

A perfect competition is traditionally thought to lead firms to the best allocation of resources, to the cheapest means of production, and the market to the lowest prices possible. The first fundamental theorem of welfare economics stipulates that resources, under a set of particular assumptions, are most efficiently allocated under a competitive equilibrium. This has seen significant empirical support over the years (e.g. Vickers, 1995). Competition also tends to 'weed out' the most inefficient firm and strengthen the position of more productive ones, as well as force firms to become more productive in order to survive in the economy, thus raising the aggregate efficiency. However, there has been a lot of discussion on whether and when competition may hurt or aid research and development (R&D). So, what if that much competition is in fact not the best alternative? Vickers (1995) elaborates on some cases in which increased competition can lead to lower productive or dynamic efficiency. Some of these differences in results between models may also stem from the fact that the standard theory concerning innovation fails to include the structure of R&D into consideration (Stiglitz, 1986).

This is also a recent topic of debate in the Spitzenkandidaten series of the European Parliament. In the beginning of 2019, the race to become the President of the European Commission took place once again. On March 26th, Yanis Varoufakis, former Greek Minister of Finance and candidate at the time, kicked off the debate with his agenda on, among other topics, competition policy. In his speech, Varoufakis denied the idea of governmental support for European 'champions', arguing that natural competition, innovation, and risk-taking are the main drivers of efficiency and growth of firms in Europe, deeming it necessary for European firms to be able to compete with other huge economies (Sevon, 2019a). Varoufakis' views were also shared by some of his opponents, such as Luis Garicano or Jan Zahradil (Sevon, 2019d and 2019e). Other candidates, such as Bas Eickhout and Manfred Webber, however, disagreed, arguing that European competition rules should be adjusted to aid, at least in some cases, with the protection of European Champions in strategic sectors, thus decreasing competition (Sevon, 2019b and 2019c).

These stark differences in views, all accompanied by compelling arguments, regarding the optimal competition law once again spark questions regarding the effects of competition on the growth and innovation abilities of firms within a given economy. The link between competition and innovation has long been a heated debate among scholars, as the theory seems to contradict what actually takes place in practice (see e.g. Gilbert, 2006b). However, something all scholars agree on is the fact that innovation is desired in the economy (as long as it is more productive than the existing technology).[2]

Until recently, most empirical work seemed to point towards the fact that innovation increases with competition (for instance, Geroski, 1995 or Blundell et al., 1999), perhaps even beyond the static gains observed in the short run, as firms will aim to maintain their edge by further capitalising

[2]This is also why the case of Microsoft v. Commission of 2007 was an intensely debated topic, as the regulations imposed by the European Commission, although increasing market competition, restricted protection for intellectual property rights. The Commission accused Microsoft of abusing their dominant position in the market concerning their licensing practices and ordered them to release critical information about their products. This shift in competition policy made it easier for firms to profit from others' research, which may make it less rewarding to engage in innovation and, hence, ultimately hurt economic progress (Spulber, 2008).

on more and more innovative findings over time (Ahn, 2002).

However, Aghion et al. (2005) found evidence from the product market showing that the relationship between competition and innovation rather has the shape of an inverted U (when taking a proxy for innovation on the vertical axis and the Lerner index on the horizontal one). For this purpose, they use data from the US patent office and accounting data from the London Stock Exchange. Later, Bos, Kolari and Van Lamoen (2013) found further support of this inverted U-shape, by looking at individual firms in the American banking system. Further literature has found this relationship to be ambiguous, non-monotone and non-unique when looking at the willingness of firms to pay for (process) innovation in a horizontally differentiated market (Belleflamme & Vergari, 2011). Boone (2001) also found that the relationship between the intensity of the competition and the value of innovation is non-monotone. However, unlike the above-mentioned findings of Aghion et al. (2005), this relationship does not necessarily have a U-shape (inverted or otherwise), but it could rather take any form for lower intensities of competition, depending on the cost history of the firms, somewhat resembling the findings of Belleflamme and Vergari (2011).

In contrast, some theory seems to point toward the fact that competition would dampen innovation (e.g. Villas-Boas & Schmidt-Mohr, 1999). Logically, firms in industries with stronger competition have lower profit margins, causing them to afford fewer investments in innovation (e.g. Grossman and Helpman, 1991). Aghion and Howitt (1990) theorised that the market power of an innovating firm (and by proxy the degree of competition on the market) has a positive effect on the average growth rate of the economy, by approaching the problem from the point of view of the obsolesce of old technologies. Their results show how the prospect of a high level of future research can deter current research by threatening the expected gains from successful innovation (also supported by Gilbert (2006a)). This result contradicts a theoretical concept, known as creative destruction, which was first introduced by Joseph Schumpeter. He argued that, although innovation destroys the pre-existing advantage of some companies, it is necessary for economic growth and believed that it is this aspect that makes capitalism a preferred economic system.[3] Existing firms, threatened by emerging competition by new entrants, will invest (part of their) profits in R&D. In a market where firms can make profits, it is expected that there would be some entry barriers, which can only be surpassed by entering with drastically different (improved) products and services. This forces existing firms to seek such innovation first (Schumpeter, 1942).

Enhancing competition also appears to decrease investment in cost-reducing innovation, due to a dominance of the demand effect over the price-pressure effect (Vives, 2008).[4] Other theories, such

[3]In his earlier work, Schumpeter also described the process of economic development. His view was that economic activity takes the form of a 'circular flow' where, in equilibrium, all prices equal average costs and all processes are repetitive. This competitive equilibrium is a static scenario, unlike reality. The dynamic setting observed in the economy would be caused by changes in the economy - new products, new methods, opening to new markets etc.. This change, or innovation, disturbs the circular flow and pushes the economy to development. He thus believed that entrepreneurs and their innovations are necessary for growth (Schumpeter, 1934).

[4]The demand effect is a direct one, regardless of the model of competition used (in Vives' (2008) research, Cournot and Bertrand) and it refers to the decrease in quantity and price caused by more firms being present on the market. The price-pressure effect should lead firms to invest in cost-reducing technology, in order to preserve their profits, but the decrease in profits caused by the demand effect prevents them from doing so. Vives (2008) also points out how, although a Cournot competition presents more incentives to invest in cost reduction, the insights derived from a Bertrand competition will still hold.

as Stiglitz (1986), discuss how competition is more conducive to innovation than a monopoly, as it provides more incentives to become more productive. His findings also gave rise to the view that government subsidies may be necessary regardless of the market structure, as all types of markets are underinvesting in R&D, from a socially optimal point of view.

In this paper, I will develop a model tying the fierceness of competition (i.e. how many firms there are on the market) with possibilities of innovation and employee incentives. This should provide a fresh outlook on the matter, as the mechanism through which competition and innovation will be tied is optimal incentive contracts.

But first, I will take a closer look at the existing literature tying employee incentives to innovation and R&D. Property rights over the newly discovered products and production methods are a recurring issue in the discussion of incentivising innovation. Issues such as the optimal split of property rights by comparative advantage (Aghion & Tirole, 1994) or the importance of intellectual property rights for economic growth in developing countries (Chen & Puttitanun, 2005) have been widely analysed over the last years. It is more difficult to motivate workers to engage in often-times risky research, when they do not own the results of their labour (e.g. Hellmann & Thiele, 2011), making these factors instrumental to the issue of drafting incentive contracts. Due to this, the type of emerging innovation also has an effect on the optimal types of contracts. If the innovation is firm-specific, lower-powered incentives, such as stock options, are optimal, although they lead to under-provision of innovation in equilibrium, whilst higher powered-incentives work best for less firm-specific research (Hellmann & Thiele, 2011). At the same time, the unionisation of workers also appears to have an effect on the investments of a firm, with decentralisation (i.e. firms being allowed to set the wages they desire) and non-discrimination laws leading to more R&D than cases where an industry union would set the wages instead (Haucap & Wey, 2004).

Approaching the issue from a firm perspective, it is relatively often the case that managers would want to let go of less able workers as soon as possible and to exert more effort in aiding more productive workers (Bandeira et al., 2007). While workers tend to aim to maximise their private utility, this sometimes does not align with the aims of a manager. Hence, when they underperform, the manager would rather replace them with a more capable employee, especially when this lack of satisfactory results stems from an observable lack of effort or ability (rather than other exogenous shocks). This, however, may prove to not be very conducive to innovation, as R&D often involves a lot of failure prior to notable successes, while talent and effort are rarely easily detectable. Manso (2011) shows how, at times, workers may even optimally be rewarded for failure early on, in order to encourage them to perform risky, but potentially rewarding actions. Long-term incentives also seem to be positively related to the number and creativity of awarded patents, whilst short term incentive methods appear to not have any effect on the level and quality of innovation (Lerner & Wulf, 2007).

A more recent paper connecting innovation to competition and to the internal incentives of a firm was written by Chen and Schwart (2013). They argue that the monopolist's ability to coordinate prices of various goods allows him to gain more from innovation than a rival firm facing competition. However, the authors take a product rather than an employee approach. Thus, the internal incentives of motivating workers remain broadly un-analysed. Contrary to their approach, I will draw from the models laid out by Manso (2011) and Bénabou and Tirole (2016), in order to create a framework for finding the optimal incentive contracts by varying levels of competition.

Manso (2011) developed a model in which a principal tries to set an incentive payment scheme for an agent, such that the agent will choose the optimal option (of producing the good) for the principal from a choice set of shirking, sticking to a known technology, or an innovative method. This will be the starting point for this paper. Furthermore, the terminology used in the original framework will be carried forward in this paper, denoting innovation by exploration and continuing with the known technology by exploitation. Thus, the terms exploration and innovation will be used interchangeably in this model. To contribute to the findings of his research, this paper will add an efficiency analysis to Manso's base model, as well as expand his findings to differing degrees of competition. In order to link the level of competition in an economy with innovation, elements from the model of Bénabou and Tirole (2016) will be integrated with Manso's. Bénabou and Tirole (2016) analyse the impact of competition on the structure of the offered compensation, in a multitasking scenario combined with a variant of the Hotelling model.[5] Unlike their set-up, the model developed in this paper will not face the trade-off between only one well measurable task and the required effort on both available tasks. Both tasks will work toward the same goal and only one action can be engaged at a time. However, their version of the Hotelling model will prove very useful in introducing varying degrees of competition in Manso's set-up. The Hotelling model, although in a different form, was also used by Chen and Schwart (2013), indicating its suitability for this model.

The lack of literature on this particular topic is quite surprising given the interesting insights it may provide for management and organisational economics. This paper, to date, is the first to touch upon how competition may affect innovation through its effect on firms' HR practices. The market structure of a certain industry can affect the ways firms structure their resources and remunerate their workers, but these effects have been, so far, untouched upon when it comes to their link to innovation. Thus, this one worker, two-choice model with varying degrees of competition may prove to be quite insightful.

The rest of the paper will thus proceed as follows. The next section will set up and analyse the results of the model, starting with the basic structure and the range for which innovation is efficient, followed by a break-down by market size. I will thereby present the moral hazard problem and the players' incentives. These will hold throughout the remainder of the paper, irrespective of the market structure, as these are the within-firm characteristics of the model. I will commence the analysis with a monopsony setting, investigating the optimal worker contracts that will lead to the exploitation of existing methods of production or to innovation. The following sub-section will dive deeper into the efficiency considerations of the firm's choices. Due to the nature of the results, a graphical analysis will be provided, in order to better display the arising inefficiencies.

[5] The framework developed by Bénabou and Tirole (2016) combines multitasking and screening with a Hotelling model. Workers differ in their level of talent and should perform two actions, of which one cannot be measured and is only performed due to intrinsic motivation, whilst the other is measurable. The output of the measurable action depends on the level of effort used, as well as the workers' talent. The authors derive the equilibrium contracts and levels of effort and show how, in a perfect competition, competing for the highest talent, combined with asymmetric information, leads to a larger efficiency loss than that imposed by a monopsony, despite the incentives to extract rent (thus causing distortions) available to a single firm.

Subsequently, I will perform the same analysis for the case of a perfect competition and, finally, of an imperfect competition, following the same structure as that of a monopsony. Thus, both of these sections will start with a framework for the respective degree of competition, followed by the optimal contracts to incentivise certain actions and ending in an analysis of the emerging inefficiencies. A comparison between the market efficiency arising under a perfect competition or under a monopsony will be provided, implicitly, when varying the degree of competition in the analysis of the imperfect competition case. The last parts of this paper include a discussion of the assumptions and some possible extensions to this model, followed by a conclusion.

Model

The following is a simplified version of the framework developed by Manso (2011). Due to the multitude of cases and applications present in his research, many of the variables and assumptions have proven to be redundant for the topic discussed here. As such, they have been simplified in order to allow for an easier interpretation of the results later on. Furthermore, for the remainder of this paper, it should be noted that the production technology refers to the within-firm process, whilst competition will be regarding the between-firms dynamics, and not internal competition.

The model takes place over two periods. There will be two types of players, managers (representing their respective firms) and agents (workers). Each manager hires an agent over the course of two periods. The agent can choose, in each period, from two types of actions, one representing the conventional production technology, having a known probability of success, and the second one being a new, innovative method, with an unknown chance of being successful. I will denote by A the known action, by B the exploratory action and by p_i, where $i \in \{A, B\}$, the probability of success when using one of the two methods. Furthermore, denote by S the fact that a method has been successful, and by F the fact that it failed. A successful action yields a payoff of $S > 0$ to the firm, whilst failure yields $F = 0$.

Let $E[p_i]$ denote the unconditional probability that action i will be successful. The conditional probabilities $E[p_i|S, j]$ and $E[p_i|F, j]$ denote the probability that action i will be successful, given a prior success or failure of action j, respectively.

As the known method has a known probability of success *ex-ante*, $E[p_A] = E[p_A|S, A] = E[p_A|F, A]$. Therefore, every probability concerning A will henceforth be denoted by p_A. The innovative method is risky, as it has a lower *ex-ante* probability of success, but, if successful, it drives the beliefs about the success rate above the old technology ($E[p_B] < p_A < E[p_B|S, B]$ and $E[p_B|F, B] < E[p_B]$). Furthermore, taking a certain action teaches the agent nothing about the success rate of the other technology, i.e. the probabilities are uncorrelated; $E[p_A] = E[p_A|S, B] = E[p_A|F, B]$ and $E[p_B] = E[p_B|S, A] = E[p_B|F, A]$. However, innovation comes at a cost $c_B > 0$ to the firm, which could stem from capital investments, technological changes, new materials, or trainings for the workers. This cost occurs every time the worker uses this new technology. Both actions will be used in producing the same good and are mutually exclusive. The manager cannot observe which action was taken, but only the success or failure of the project.

The agent may choose which action to take, at cost $f > 0$.[6] He can, of course, also choose to shirk, at no cost ($f_0 = 0$), which leads to a very low probability of success $p_0 << E[p_i]$ for all i. For simplicity, I will assume $p_0 = 0$, as shirking constraints are not of interest for the purpose of this model. The results including $p_0 \geq 0$ are laid out by Manso (2011). The level of effort will not affect the probability of success of either technology (p_i), so the choice of the worker will be binary for all actions (i.e. to take the action or not).

I will further denote by w_F and w_S the first period wages given failure and success, w_{FF} and w_{FS} the second period wages of failure and success, given that the action failed in the first period, and w_{SF} and w_{SS} the wages in case of failure and success in the second period given a first-period success, respectively. The manager's task will be to set up a wage scheme, or contract, $\overrightarrow{w} = \{w_F, w_S, w_{FF}, w_{FS}, w_{SF}, w_{SS}\}$ (contingent on performance) so as to induce the agent to choose her preferred action. For the purpose of this paper, I will assume limited liability ($w \geq 0$), and that the outside option of the worker is met, in order to ensure the participation of the agent. Limited liability is a realistic assumption, as most legal contracts do not allow workers to be punished for failure beyond this point. Furthermore, both the agent and the principal have a discount factor $\delta = 1$. This implies that neither player cares about the timing of the payments.

The agent observes the contract provided to him and will, in turn, engage in a plan $\left\langle i_k^j \right\rangle$, where i is his choice of action in period 1, j stands for period 2 if i succeeds, and k represents the action and effort in period 2 if i fails. The revenues created by this action plan are thus

$$\begin{aligned} R\left\langle i_k^j \right\rangle &= \{E[p_i]S + (1 - E[p_i])F\} \\ &+ E[p_i]\{E[p_j|S, i]S + (1 - E[p_j|S, i])F\} \\ &+ (1 - E[p_i])\{E[p_k|F, i]S + (1 - E[p_k|F, i])F\}, \end{aligned}$$

and the total expected payments from the principal to the agent are

$$\begin{aligned} W(\overrightarrow{w}, \left\langle i_k^j \right\rangle) &= \{E[p_i]w_S + (1 - E[p_i])w_F\} \\ &+ E[p_i]\{E[p_j|S, i]w_{SS} + (1 - E[p_j|S, i])w_{SF}\} \\ &+ (1 - E[p_i])\{E[p_k|F, i]w_{FS} + (1 - E[p_k|F, i])w_{FF}\}, \end{aligned}$$

with the total expected cost incurred by the agent is

$$C\left\langle i_k^j \right\rangle = f_i + E[p_i]f_j + (1 - E[p_i])f_k.$$

Additionally, the firm faces a cost of innovation of c_B whenever the worker will attempt to engage in this action.

Let plan $\left\langle A_A^A \right\rangle$ denote exploitation and plan $\left\langle B_A^B \right\rangle$ denote exploration. If the worker explores

[6] Thus, $f_A = f_B > 0$.

in the first period, he will gain valuable information about p_B. If he fails, he can always go back to exploitation in the second period, as $p_A > E[p_B]$. From the point of view of efficiency, innovation is socially desirable if it creates more value, so if $R\left\langle A_A^A \right\rangle \leq R\left\langle B_A^B \right\rangle - (1 + E[p_B])c_B$. Hence, innovation is efficient if and only if

$$E[p_B] \geq p_A - \frac{p_A(E[p_B|S,B] - p_A)S - (p_A + 1)c_B}{(1 + E[p_B|S,B] - p_A)S - c_B}. \tag{1}$$

The last term of this equation contains the premium in terms of expected payoffs of learning more about the new technology B, as well as a constraint on $E[p_B]$ based on how costly the new method is relative to the expected gain in output. Moreover, as the cost of innovation increases, the expected success rate $E[p_B]$ needs to be higher in order for exploration to be efficient, *ceteris paribus.*

Monopsony

In a monopsony setting, the manager will set the wage so as to maximise the expected profit Π subject to the participation constraint of the worker, which is based on his outside option $\overline{W} = 0$. This corresponds to paying the worker only the amount needed to induce the desired outcome and nothing more, so just meeting his incentive compatibility constraints.

Exploitation

In order to incentivise the worker to keep using the known production method, a few insights are useful in order to simplify the problem.

First of all, in the second period, there is no reason to reward failure in any way, as it is the last period and the wage will not affect the workers' actions thereafter; thus, $w_{SF} = w_{FF} = 0$. Similarly, $w_F = 0$, since $p_0 = 0$ and negative wages are forbidden due to the limited liability constraint, thus making further punishments for failure impossible. Moreover, providing high wages for a second-period success would only cause the workers to explore, since $E[p_B|S,B] > p_A$. Therefore, in the second period, the manager should offer a wage as low as possible, but just high enough to prevent the worker from shirking. This is also supported by the fact that $p_A > E[p_B]$, so, if there was no exploration in the first period, there will also be none in the second. Thus she will choose a wage such that $p_A w_{SS} - f \geq 0$ and $p_A w_{FS} - f \geq 0$, yielding a wage

$$w_{SS} = w_{FS} = \frac{f}{p_A} \equiv \alpha_1.$$

Note that, if the worker implements the traditional method of production in the first period, whether he succeeds or fails, he will have no incentive to explore in the second period, due to the fact that $E[p_B] < p_A$. Hence, the shirking constraint will always bind.

In the first period, the manager needs to prevent the worker from shirking *and* exploring. To prevent shirking, the same condition holds as for w_{SS} and w_{FS}, namely, $p_A w_S - f \geq 0 \iff w_S \geq \frac{f}{p_A}$. However, the worker may still have incentives to innovate in this period. To prevent this, the manager needs to ensure that $W(\overrightarrow{w}, \left\langle A_A^A \right\rangle) \geq W(\overrightarrow{w}, \left\langle B_A^B \right\rangle)$. Keeping in mind the wages derived above, the lowest w_S to satisfy this condition is $w_S = \frac{E[p_B](E[p_B|S,B]-p_A)}{p_A - E[p_B]} \frac{f}{p_A}$. Thus, the shirking constraint is binding if and only if

$$1 \geq \frac{E[p_B](E[p_B|S,B] - p_A)}{p_A - E[p_B]} \equiv \beta_1.$$

Due to the incentive compatibility constraints of the worker, if the exploration constraint is binding, w_S will be higher. The reason is that, no matter the parameters, if the worker is to be incentivised to perform, his shirking constraint will be met. However, in some cases, the worker will also need to be prevented from working. Specifically, this is the case when $E[p_B|S,B]$ is relatively very large compared to p_A. The first-period success wage will need to increase, in order to shift the workers' incentives away from the second period and toward the first. As $p_A > E[p_B]$, increasing w_S will achieve this goal.

Proposition 1: The wage scheme that will induce a worker to engage in exploitation has

$$w_{SS} = w_{FS} = \alpha_1,$$

$$w_{SF} = w_{FF} = w_F = 0,$$

$$w_S = \alpha_1 max[1, \beta_1].$$

Exploration

Similar insights as for the exploitation case can be derived here.

Firstly, if w_{FF} and w_{SF} were to be higher than zero, it would only offer incentives for the worker to shirk. In this case, however, the first wage success wage should be $w_S = 0$, as rewarding early success would create incentives for exploitation, since $E[p_B] < p_A$. Additionally, exploring in the first period provides crucial information in the second period. If the worker explores early on and is successful, that improves his chances of success in the second period, as $E[p_B|S,B] > p_A$, and so exploration could easily be incentivised via w_{SS}. Here, delaying compensation is optimal, whereas exploitation required earlier compensation.

In case of failure in the first period, the worker cannot expect the innovative method to be more productive and will always choose exploitation. In this case, the same above-mentioned shirking constraints hold and $w_{FS} = \alpha_1$.

A similar constraint as above can also be derived for this case, namely

$$1 \geq \frac{E[p_B]p_A(E[p_B|S,B] - p_A)}{p_A^2 - E[p_B]E[p_B|S,B]} \equiv \beta_2,$$

whereby shirking is the binding constraint rather than exploiting. The starting point for this constraint was once again the first-period success wage, derived as for β_1. However, as mentioned above, w_S should optimally be zero. This new constraint thus needs to be met in the second period, more specifically as part of w_{SS}. Therefore, we now take into account the probabilities of two consecutive successes using either technology, generating β_2.

Definition: If the relative probability of failure using the innovative method is higher than the relative probability of two consecutive successes, or formally if

$$\frac{1-E[p_B]}{1-p_A} \geq \frac{E[p_B]E[p_B|S,B]}{p_A^2},$$

then innovation is radical, otherwise it is moderate.[7]

Proposition 2: The wage scheme that will induce a worker to engage in exploration has

$$w_{FS} = \alpha_1 \ \ and \ \ w_{SF} = w_{FF} = w_S = 0.$$

If exploration is moderate

$$w_F = 0$$

and

$$\begin{cases} w_{SS} = \alpha_2 & if\ \beta_2 > 1 \\ w_{SS} = \frac{(p_A - E[p_B])p_A\alpha_1}{E[p_B]E[p_B|S,B]-p_A^2} & if\ \beta_2 \leq 1 \end{cases}.$$

If exploration is radical

$$\begin{cases} w_F = 0 & w_{SS} = \alpha_2 & if\ \beta_2 > 1 \\ w_F = \frac{p_A^2(1-E[p_B]) - E[p_B]E[p_B|S,B](1-p_A)}{p_A E[p_B](E[p_B|S,B]-p_A)} & w_{SS} = \frac{(p_A - E[p_B])p_A\alpha_1}{p_A E[p_B](E[p_B|S,B]-p_A)} & if\ \beta_2 \leq 1 \end{cases}.$$

The variable α_2 has been introduced in order to simplify the equations above and it represents $\alpha_2 \equiv \frac{(1+E[p_B])p_A\alpha_1}{E[p_B]E[p_B|S,B]}$.

The formal derivation of Proposition 2 is also shown in Appendix A.

Proposition 2 above shows that, if $\beta_2 > 1$, the worker should not be rewarded for failure. That is, if in the first period the worker would already be more likely to exploit rather than shirk, rewarding him for failure would only make it more costly for the manager to incentivise exploration in the second period, due to the fact that the worker would have an assured income in period 1 if he were to exploit. However, if shirking is binding, the worker needs to be incentivised to exert effort. However, if the chance of failure is very high (so in the case of radical exploration), the worker would require a 'safety net' in the first period, otherwise he will find the action too costly.

Rewarding failure in the first period can also be supported by other theoretical findings. Jovanovic and Nyarko (1994) developed a Bayesian model whereby workers learn about unknown para-

[7] As in the model laid out by Manso (2011), the word 'radical' is used merely to express a relatively high *ex-ante* likelihood of failure, and it does not reflect the meaning usually assigned to it in management literature. There, radical innovation refers to a purely technological improvement, rather than a new business model, which would be referred to as disruptive innovation.

meters of new technologies by repeatedly performing tasks with them. However, continuously switching to better technologies is beneficial to long term growth. They find that, as agents become more familiar with their chosen technology, or, in their words, become human-capital-rich agents, they will optimally not seek new methods of production, due to the high expected loss when taking a 'technological leap'. Providing leniency upon early failure when switching may offer workers a sort of safety net, even if everything about the known technology (here A) is familiar and safe to them.

Efficiency

From the two propositions laid out above, we can compute the firm's choice of exploration or exploitation in three separate cases: (1) $\beta_1 < \beta_2 \leq 1$, (2) $\beta_1 \leq 1 < \beta_2$ and (3) $1 < \beta_1 < \beta_2$. This is based on the observation that $\beta_1 < \beta_2$ for all values of p_A and $E[p_B]$. In the following, I have derived the monopsonist's choice based on these constraints and the optimal wages derived above. However, the conditions under which the firm would like to innovate are very lengthy and difficult to trace. A qualitative graphical analysis of the results has therefore been included, such that the arising inefficiencies can be easily detected and analysed. This will become particularly useful later, when evaluating firms operating under an imperfect competition.

The values chosen for the graphical depictions to follow were selected on the simple basis of being as clear as possible when showing the relevant ranges. Similar results can be observed when taking other values, but they cannot be well observed graphically. Whenever relevant, more explanations and graphs with alternative values of the exogenous variables will be provided in Appendix B. Therefore, the graphs presented below serve mostly as a generalised representation of the outcomes, so that the insights provided by the computed constraints can be seen in a clearer manner. The values chosen for the graphs below are therefore $E[p_B|S,B] = 1$, $S = 100$, $f = 20$, $c_B = 1$. The value for c_B was chosen mainly to show a starker contrast between the costs and the benefits of innovating, thus creating more space for the efficiency constraints in the graphs.

Increasing S, whilst keeping c_B constant, only minimally affects the graph, thus the value of 100 (so as to make $\frac{c_B}{S} = 0.01$) is most optimal from a graphical point of view. The effort costs f for the worker were selected for a similar reason, as well as to keep a reasonable scale relative to the firm's payoff from success S. Changing f only marginally affects the shape and location of the firm's choice for innovation and exploitation, but changing this value does not affect the outcome otherwise.

Figure 1 contains all relevant conditions of this model. The purple shaded region in the top left corner represents the area in which exploration is efficient. The light blue curve titled 'Radical' represents all values of p_A and $E[p_B]$ for which $\frac{1-E[p_B]}{1-p_A} = \frac{E[p_B]E[p_B|S,B]}{p_A^2}$. Innovation is radical in the area below and to the right of this curve, and moderate otherwise. This also implies that, below this curve, if $\beta_2 \leq 1$, it must be that $w_F > 0$, otherwise innovation cannot take place. The last two curves, $b1$ and $b2$, represent the combinations of p_A and $E[p_B]$ for which $\beta_1 = 1$ and $\beta_2 = 1$ respectively. Both β values drop below 1 as we move to the bottom right of the grid. The initial

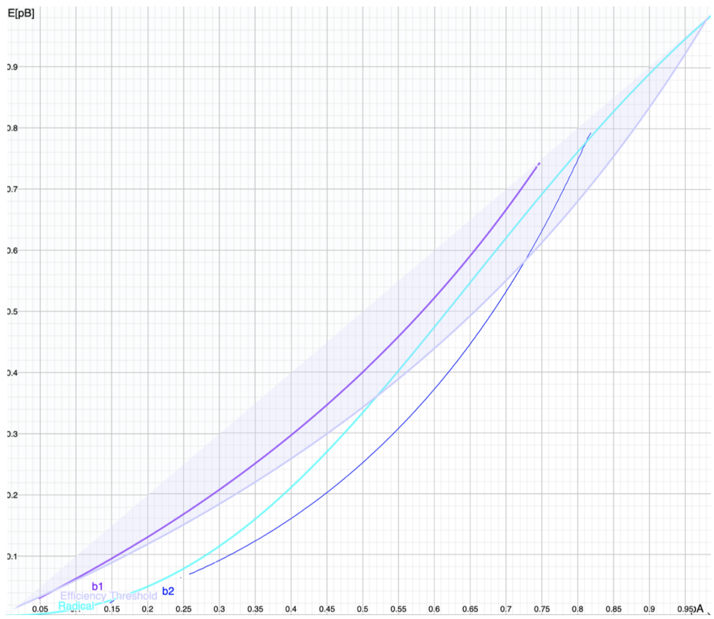

Figure 1: Equilibrium conditions and constraints

observation that $\beta_1 < \beta_2$ can also be seen when looking at these graphs.[8] The two curves, $b1$ and $b2$, are only relevant for the analysis of optimal contracting, but they have, nonetheless, been added to the figure in order to clearly show their position before showing their effects. Their position gives rise to the necessity to split the provided grid into three areas, as presented below.

(1) $\beta_1 < \beta_2 \leq 1$ In this case, the shirking constraint is binding for both action plans. The firm will choose to innovate if and only if $\Pi\left\langle A_A^A \right\rangle \leq \Pi\left\langle B_A^B \right\rangle$, thus if

$$\begin{aligned} 2p_A S - 3\frac{f}{p_A} & \\ &\leq (E[p_B] + E[p_B]E[p_B|S,B] + (1 - E[p_B])p_A)S - (1 + E[p_B])c_B \\ &- \frac{f}{p_A} - \frac{(p_A - E[p_B])p_A\alpha_1}{p_A E[p_B](E[p_B|S,B] - p_A)} \\ &- max\left[0, \frac{p_A^2(1 - E[p_B]) - E[p_B]E[p_B|S,B](1 - p_A)}{p_A E[p_B](E[p_B|S,B] - p_A)}\right]. \end{aligned} \tag{2}$$

The green curves in Figure 2 depict the combinations of p_A and $E[p_B]$ under which the firm is indifferent between exploring and exploiting, based on equation (2). When innovation is radical, the light green curve holds, whilst the dark green curve takes over when innovation is moderate.

[8]Note that the curves b1 and b2 contain gaps. The gaps occur when certain combinations of p_A and $E[p_B]$ do not yield exactly $\beta = 1$. For values of $\beta \to 1$, these gaps no longer exist. However, due to technological knowledge constraints, $\beta \to 1$ could not be graphically modelled for the purpose of this paper.

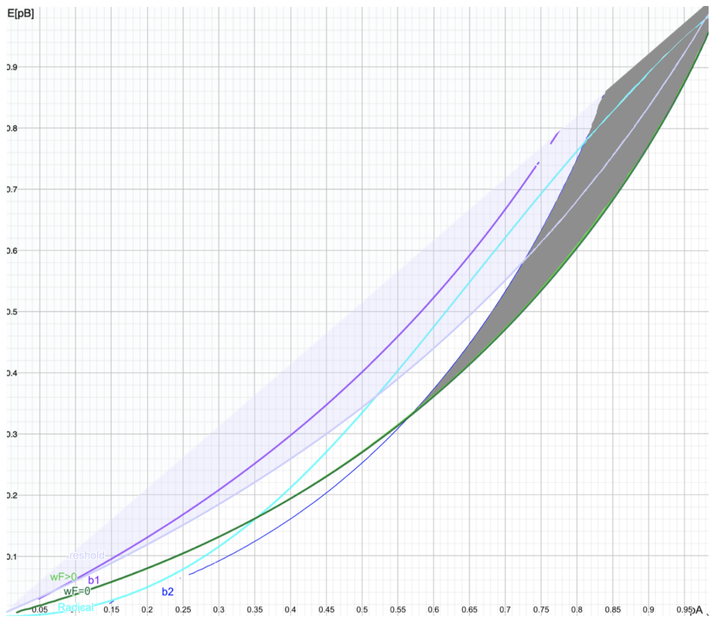

Figure 2: Monopsony choice if $\beta_1 < \beta_2 \leq 1$

The curves overlap almost perfectly[9], implying that both contracts derived in Proposition 2 yield similar profits. Moreover, the firm will choose to innovate in the range above (and left) of the green curve, implying there is a range, between the green curves and the Efficiency Threshold, for which the monopsonist innovates inefficiently. This occurs because the manager would have to pay the worker a higher wage, in expected terms, when inducing exploitation rather than exploitation, if p_A is high or if $E[p_B]$ is low, due to the incentive compatibility constraints of the worker.

The grey shaded region shows the area in which $\beta_1 < 1$, $\beta_2 < 1$ and the firm wants to innovate.

(2) $\beta_1 \leq 1 < \beta_2$ Here, the shirking constraint only holds for the exploitation inducing contract, whereas the exploitation constraint is binding for exploration.

Thus, innovation will take place if and only if

$$\begin{aligned} 2p_A S - 3\frac{f}{p_A} & \\ & \leq (E[p_B] + E[p_B]E[p_B|S, B] + (1 - E[p_B])p_A)S - (1 + E[p_B])c_B \\ & - \frac{f}{p_A} - \frac{(1 + E[p_B])p_A \alpha_1}{E[p_B]E[p_B|S, B]}. \end{aligned} \tag{3}$$

The relevant area showing the range in which exploration will be chosen is shaded grey in Figure 3. Here, once again, there is a small range of values for which the firm would like to innovate even

[9] This overlap holds also for other values of the exogenous variables.

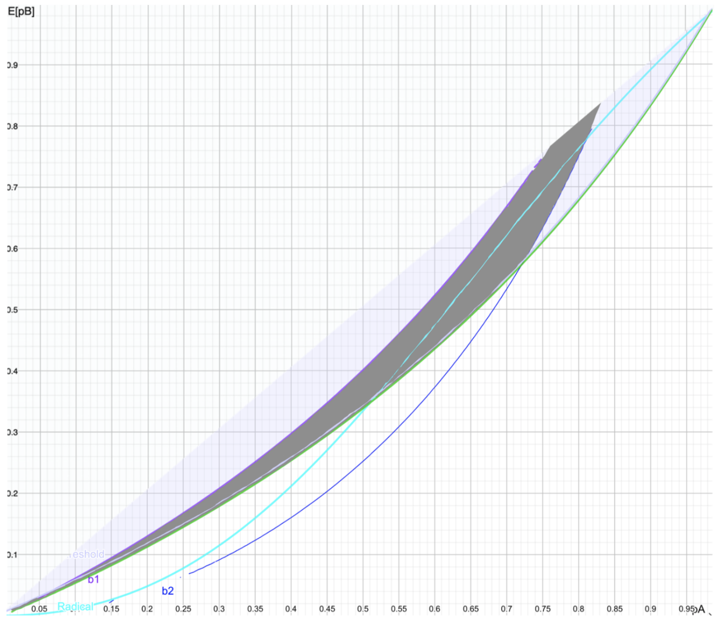

Figure 3: Monopsony choice if $\beta_1 \leq 1 < \beta_2$

if it is inefficient. This can, however, only be seen by inspecting the figure very closely.

(3) $1 < \beta_1 < \beta_2$ If both betas go beyond 1, then the binding constraint for both will be ensuring that the worker does not have any incentives to choose the undesirable option. Innovation will then take place as long as

$$2p_A S - 2\frac{f}{p_A} - \frac{E[p_B](E[p_B|S,B] - p_A)}{p_A - E[p_B]}\frac{f}{p_A} \leq (E[p_B] + E[p_B]E[p_B|S,B] + (1 - E[p_B])p_A)S - (1 + E[p_B])c_B - \frac{f}{p_A} - \frac{(1 + E[p_B])p_A\alpha_1}{E[p_B]E[p_B|S,B]}. \quad (4)$$

Figure 4 once again shows, in grey, when the manager would like to innovate. The same analysis as before applies. However, there are now values for which innovation would be efficient, but the monopsonist chooses not to do so. This range is delimited by the grey line. The cause of this finding is that a monopsonist will always try to extract as many rents as possible, but, in cases where p_A and $E[p_B]$ are relatively close in value, the workers would require a relatively too high wage, which the firm is not willing to pay.

Overall, a monopsonist will choose an exploration contract in the grey areas of Figure 5. Thus, there exist values for which innovation would be efficient, but the manager will choose not to innovate, as this would create too high payments toward the worker and decrease her profits too

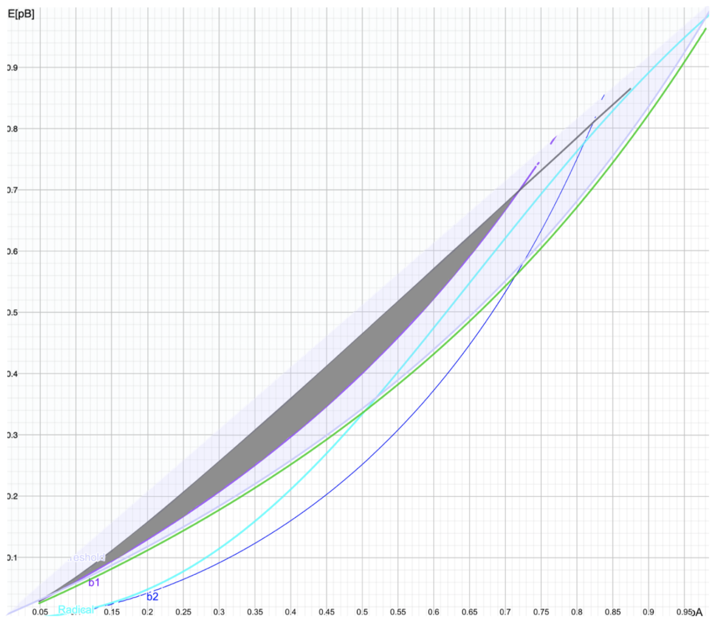

Figure 4: Monopsony choice if $1 < \beta_1 < \beta_2$

much. For the remaining purple shaded region in Figure 5, the monopsonist would prefer to exploit, since this would be relatively easy to motivate. Similarly, there are values of p_A and $E[p_B]$ for which the monopolist would derive higher profits from innovation, even if it is inefficient, especially in the case in which both β's are below 1.

Perfect Competition

In a perfect competition setting, the manager will set the wage in order to maximise the utility $U \equiv W(\overrightarrow{w}, \left\langle i_k^j \right\rangle) - C\left\langle i_k^j \right\rangle$ of the worker, subject to the fact that the expected profits $E(\Pi) = 0$. Thus, if possible, a perfect competition would strive to reach the efficient market outcome. In the previous section, the firm was trying to not leave any rents to the worker, thus leading to distortions, but now, the firms wish to maximise the total output, such that they can attract more workers. Put differently, a monopsony manager aims to maximise her share of the pie, while a manager working for a firm under perfect competition tries to maximise the size of the pie, so she can offer the most to the employee, and hence attract him to work for her firm.

In the case of perfect (and later on imperfect) competition, I will introduce one further assumption, namely that firms have a liquidity constraint. Failure in the first period can imply that firms are unable to pay out dividends to the shareholders, or that their chances of bankruptcy increase and they can consequently not afford to pay out wages. This is consistent with real-life observations that firms operating under competition tend to focus on performing better in the short run, due to their attempts to attract investors and shareholders. A monopsony does not need to worry about this, as it will, in expected terms, always make (at the very least accounting) profits in equilibrium. Further support for this assumption, which will also be implemented to the case

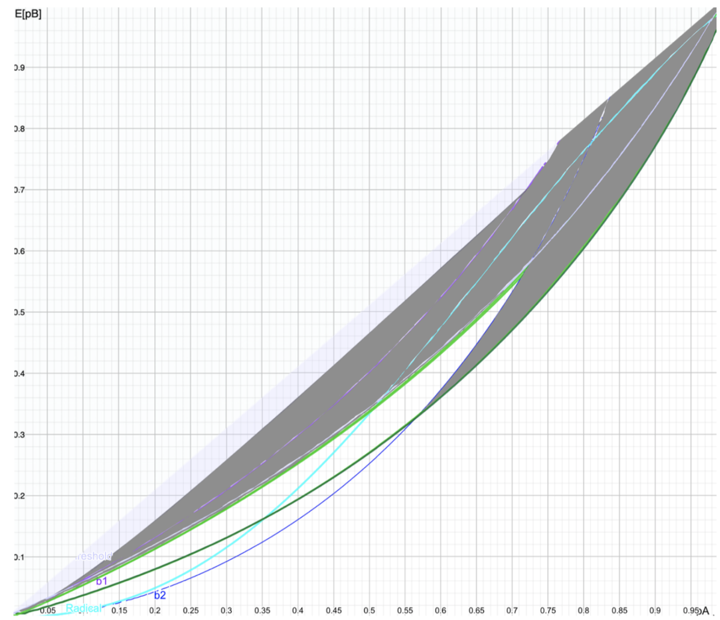

Figure 5: Monopsony innovation range for all values of p_A and $E[p_B]$

of an imperfect competition, was found by Dick and Lehnert (2010), whose research resulted in compelling evidence, from the US market, that increased competition leads to higher bankruptcy rates.[10]

As before, there is also no purpose in compensating the worker in case of failure in the second period, hence $w_{FF} = w_{SF} = 0$. However, this new constraint implies that w_F must be zero as well, otherwise the firms would not only make a loss in the first period, but also remain at a lower expectation of success in the second period, which would lead to likely bankruptcy.

Exploitation

In order to induce exploitation, the firm must simply create as many incentives as possible for the workers to not explore.

Proposition 3: As in the case of a monopsony wanting to exploit a known method,

$$w_{FS} = w_{SS} = \alpha_1,$$

$$w_{SF} = w_{FF} = w_F = 0,$$

[10] Dick and Lehnert (2010) use data over 15 years from state-level banking deregulation in the US and find that 10-16% of the increase in bankruptcies over their observation period was caused by the removal of entry barriers. To this aim, they use a time series model which controls for fixed effects for the state and year.

but, unlike a monopsony, a firm in a perfect competition will offer a wage

$$w_S = 2p_A S - 2\frac{f}{p_A}.$$

The shirking constraints derived under a monopsony situation for the second period still hold and thus $w_{FS} = w_{SS} = \frac{f}{p_A}$. Rewarding second-period success any more than this would only create more incentives to explore. The profits of a firm operating under perfect competition are zero in equilibrium, implying that $w_S = R\left\langle A_A^A \right\rangle - 2\frac{f}{p_A}$.

Strictly speaking, due to the liquidity constraint, w_S should not be higher than S. However, minding this would make it more difficult for the firm to incentivise exploitation. I will therefore relax this assumption by stating that, if a worker has been successful in the first period, the firm can use this success itself as leverage to attract stakeholders. Thus, rewarding a worker for success in the first period, even is slightly more than the revenues he created, should not be an issue, considering the fact that the expected revenues in the second period are strictly larger than the expected wage to be paid out to the worker.

Exploration

In order to induce exploration, the firm must create as many incentives as possible for the workers to not exploit.

Proposition 4: As in the case of a monopsony wanting to explore,

$$w_{FS} = \alpha_1,$$

$$w_{SF} = w_{FF} = w_F = w_S = 0,$$

but, unlike a monopsony, a firm in a perfect competition will offer a wage

$$w_{SS} = (E[p_B] + E[p_B]E[p_B|S,B] + (1 - E[p_B])p_A)S - (1 + E[p_B])c_B - \frac{f}{p_A}.$$

Similar to the monopsony setting, a firm trying to create innovation will offer $w_S = 0$, so as to discourage exploitation, and $w_{FS} = \frac{f}{p_A}$ in order to discourage shirking in the second period. Here, most of the incentives should be once again placed on w_{SS}, implying that $w_{SS} = R\left\langle B_A^B \right\rangle - \frac{f}{p_A}$.

The issue arises, however, when the workers do not wish to innovate. The incentive compatibility constraints derived for a monopsony revealed that, if innovation is radical and $\beta_2 \leq 1$, workers would require $w_F > 0$ in order to innovate. This is impossible for a competing firm, as they cannot afford to pay out more than they earn in the first period.

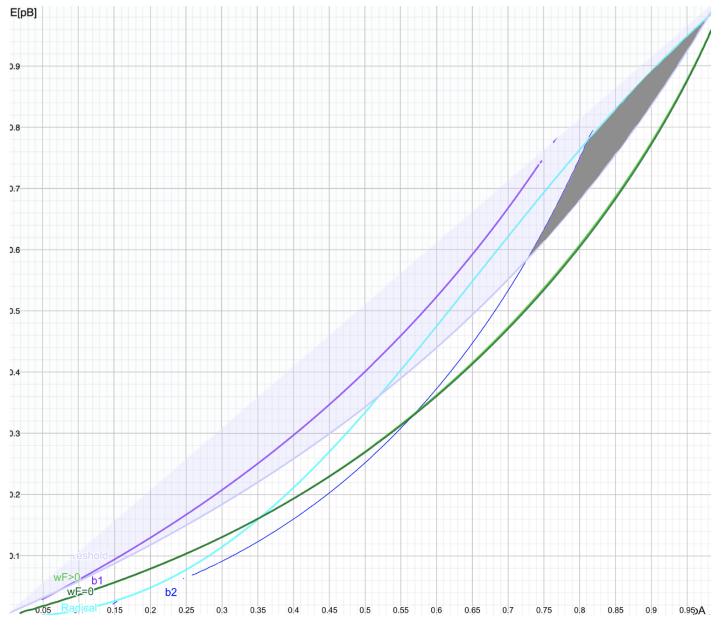

Figure 6: Inefficiencies under Perfect Competition

Efficiency

A perfect competition will always strive to achieve an efficient outcome. This occurs due to the fact that the workers, in a sense, now own the firm, as all profits will be assigned to them eventually. However, if the firm cannot create a contract that will incentivise workers to perform the right task, this leads to inefficiencies.

Figure 6 shows the same graph as Figure 2, but with one added insight. As mentioned above, if we find ourselves below the Radical threshold, if $\beta_2 \leq 1$, it must be that $w_F > 0$. As previously mentioned, radical innovation implies a relatively very low chance of success. Specifically, the relative chance of failure is lower than the relative probability of two consecutive successes. Due to this high likelihood of failure, the worker would want to avoid taking this risk, unless he is 'insured' against failure, my means of a positive wage in case of failure. However, firms under a perfect competition may find themselves unable to pay $w_F > 0$ due to their liquidity constraints. Therefore, for all values of $\beta_2 \leq 1$ where innovation is radical, a perfect-competition firm will be unable to incentivise innovation, whilst a monopsony would (and also does, as this range is above the green curves). Hence, for this region (and its combinations of p_A and $E[p_B]$), shaded grey in Figure 6, a monopsony will to lead to an efficiency-enhancing innovation whilst a perfect competition would fail to do so. However, looking back at Figure 5, we can also identify areas where a monopsony is inefficient, whilst a perfect competition is the optimal market structure. In this case, not only do we have values for which the firm will exploit the old technology whereby innovation would be optimal, but we also have cases in which there would be too much innovation.

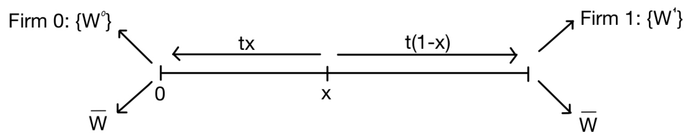

Figure 7: Hotelling variation with co-located firms and outside options

Imperfect Competition

The liquidity condition mentioned above will also hold for an imperfect competition. When there is more than one firm, they will need to compete for shareholders who, in turn, will want to contribute to the firms with the highest expected profits and will avoid firms making any losses in the first period, particularly in case of failure. Hence, the insights provided by Figure 6 will also hold here.

In order to model imperfect competition, a variation of the Hotelling model inspired by Bénabou and Tirole (2016) will prove very useful.

Take a unit continuum of workers distributed according to $x \sim U(0,1)$. Two firms denoted by $y \in \{0,1\}$ are located respectively at either end of the distribution and offer all workers a contract W^y. As the market conditions faced by companies are identical, all employers will desire the same action, either exploitation or exploration. Thus we can let $W^y \equiv W^y(\overrightarrow{w}, \left\langle i_k^j \right\rangle)$[11] for all symmetric choices of contract. The workers also have the option of an outside wage $\overline{W}$. As in Bénabou and Tirole (2016), the outside option can be found at either extremity of the distribution, implying that workers will need to travel, no matter which income source they choose. Similarly, $\overline{W}$ can be seen as some sort of 'home' production, but households must still travel to a local market-place to sell what they produced.

When a worker travels, he faces a cost proportional to the distance he traverses, namely tx when moving toward the left, where firm 0 is located, at $t(1-x)$ when traveling toward firm 1. [12]The situation above is also depicted in Figure 7.

The position of each worker x is unknown to the firms, but t is common knowledge. Any change in t will not only affect competitiveness, but also the outside option. The participation constraints of each worker may no longer be met if t becomes too high. Note that, up until this point, I have assumed the outside option $\overline{W}$ to be zero. Taking any higher value for this variable will not affect the insights provided by this model. For the case of an imperfect competition, the outside option becomes redundant, as shown below.

Without loss of generality, being offered W^y by each firm, worker x will choose firm 0 if and only if

$$W^0 - tx \geq max\{\overline{W} - tx, \overline{W} - t(1-x), W^1 - t(1-x)\}.$$

[11]Recall that $\overrightarrow{w} = \{w_F, w_S, w_{FF}, w_{FS}, w_{SF}, w_{SS}\}$ and thus the value of W^y will be equal to $w_F + w_S + w_{FF} + w_{FS} + w_{SF} + w_{SS}$.

[12]Strictly speaking, cost t is incurred every time the worker leaves to visit a firm or the outside option. For simplicity, I will assume t to be the total cost of traveling during both periods, since the worker will always choose the same destination, based on which establishment is closer to him.

Taking apart this inequality, the first part indicates that $W^0 \geq \overline{W}$, implying that each firm needs to match the outside option, which was always the case. Naturally, firm 1 must do the same, implying that $W^1 \geq \overline{W}$, deeming the second part of the right-hand side of the inequality redundant. Since both firms will meet the outside option, the binding condition will remain $W^0 - tx \geq W^1 - t(1-x)$. Letting $\overline{W} > 0$ simply implies that both firms may need to provide (or increase) a fixed part of the wage they offer, but the symmetry provided by the model makes this insight unnecessary.

Thus, the share of workers firm 0 attracts will be

$$x^0(W^0, W^1) = \frac{W^0 - W^1 + t}{2t}.$$

This problem has a unique symmetric equilibrium, in which each firm attracts half of the workforce. Each firm will set W^y subject to $max\left\{x^y \Pi\left\langle i_k^j \right\rangle\right\} \iff max\left\{\frac{W^0 - W^1 + t}{2t}\left(R\left\langle i_k^j \right\rangle - W^y\right)\right\}$. Solving this yields an equilibrium contract value

$$W^y = R\left\langle i_k^j \right\rangle - t.$$

Thus, an increase in the travel cost t indicates a lower contract value and less competition, while a lower t brings the two-period wages closer to the firms' revenues, similar to a perfect competition. To better demonstrate this effect, suppose one randomly selected worker happens to be located closer to firm 0. At low values of t, any increase in the contract value presented to him by firm 1 could easily attract the worker to switch, as the cost of doing so is low. At the limit, as the cost approaches $t = 0$, the competition between the firms will be maximised: they both must offer the total value of their expected profits to the worker, if they wish to attract him. As t increases, however, the cost to the worker of switching to a different firm increases. As it becomes more costly for the worker to visit firm 1, firm 0 can afford to not offer the total value of their profits to the worker, but rather keep some rent to itself. For very high travel costs, firm 1 will not find it worthwhile to attempt to attract this worker, and so, the only 'competition' left for firm 0 will be the outside wage. Thus, at the upper limit of t, as long as the firms meet the participation constraint of the worker, he will work for them, much like in the case of a monopsony.

Exploitation

In order to prevent a worker from exploring, the firm will follow the same wage structure as that of a perfect competition. However, as the competition becomes less fierce, due to the higher value of t, the firm can afford to extract some rent from the worker. The previously derived shirking constraints still hold.

Proposition 5: A firm competing in an imperfect competition which wishes to exploit known methods will set a contract similar to the one under a perfect competition, where

$$w_{FS} = w_{SS} = \alpha_1$$

and

$$w_F = w_{SF} = w_{FF} = 0,$$

but now, due to the travel costs,

$$w_S = 2p_A S - 2\frac{f}{p_A} - t.$$

Exploration

Once again, the incentives to explore are largest when the second-period success wage is maximised, taking into account the shirking constraints.

Proposition 6: A firm competing in an imperfect competition which wishes to explore will set a contract similar to the one under a perfect competition, where

$$w_{FS} = \alpha_1$$

and

$$w_F = w_{SF} = w_{FF} = w_S = 0,$$

but now, due to the travel costs,

$$w_{SS} = (E[p_B] + E[p_B]E[p_B|S,B] + (1 - E[p_B])p_A)S - (1 + E[p_B])c_B - \frac{f}{p_A} - t.$$

We might, however, once again, stumble upon the issue that innovation may prove to be impossible, if $w_F > 0$ is required.

Efficiency

In order to derive the efficiency considerations in the case of an imperfect competition, we could return to the three cases derived based on the β constraints under a monopsony, comparing them to the perfect competition situation, and finding a threshold for t. Solving this mathematically, however, would not provide much insight in the mechanism at hand. A theoretical analysis proves to be more worthwhile in this case.

Starting with a low value of the travel cost, the economy can be considered to have fierce competition. The liquidity constraint developed above is relatively more important than the constraints derived under a monopsony, due to the lack of incentives for the firms to capture rents. In case w_F can optimally be set no higher than zero, this situation will be, at the limit $t \to 0$, fully efficient. More generally though, the situation can be depicted as in Figure 6 above. However, as the competition disperses, so when traveling becomes more costly, the optimal contract will be distorted, as firms will attempt to capture more of the available profits. Thus the constraints and inefficiencies shown in Figure 5 will become more prominent, whilst the efficiency concerns of Figure 6 become less relevant. As t increases, the firms operating on the market will start earning expected profits, thus being able to afford to pay out low amounts of w_F, until, for a high enough level of costs, the constraint will no longer be an issue. However, as the competition lessens, the firms' incentives to distort the market outcome according to their private needs increase, with firms aiming to capture more and more of the available profits. With a high enough t, we will reach the situation depicted in Figure 5.

Discussion and extensions

The section above has described the market outcomes and inefficiencies arising in various degrees of competition. Starting from a monopsony situation, inefficiencies arise due to the distortions created by a firm trying to maximise the rents it extracts from its employees. However, as more competition emerges, these distortions dissipate, as the competition for workers heightens. After a while, the competition becomes so fierce that the distortions become negligible, but, as more firms compete for stakeholders, their limitations may, in some cases, lead to new inefficiencies. Thus, both extremes can lead to inefficiencies through different mechanisms, but there is a middle-ground level of competition where inefficiencies can be minimised. These results, at least for some range of the values of p_A and $E[p_B]$, thus seem to point toward an inverse-U shape for the relationship between competition and efficiency, when it comes to the mechanism if internal innovation of a firm's workers.

In order to better depict these results, I will speculate on possible outcomes in certain markets. In order to properly assess whether the findings of this model (and the assumptions I will estimate based on anecdotal evidence) are accurate, empirical research would be required.

Analysing the Figures from previous sections, it appears that, for high values of p_A, more competition would yield too little R&D, whereas a lack of competition may lead to too much innovation. On the other hand, for smaller levels of p_A, a perfect competition yields an efficient level of innovation, whilst an imperfect competition may possibly lead to under-provision, if the *ex-ante* expected probabilities are close in value. It could then be argued that, in cases where the technology is truly new (such as switching from a CD to a USB-stick), imperfect competition is likely to be detrimental. However, in the case of an industry where the technology is well-established and successful (e.g. gasoline car engines), competition is likely to cause an under-provision of innovation, whilst a lack of competition may cause over-provision.

Another example could be the healthcare system, or, more specifically, the drugs industry. Relatively well established, wide-spread medicine (for instance paracetamol), yields a consistent return for the firms producing it. However, many small brands, such as supermarket 'house brands', always try to find cheaper methods to provide these. Innovation in this industry is quite probable, but, as there is a lot of competition, small firms will have to compete for investors. This implies that they cannot afford to make losses in their early days, as stakeholders may switch to more successful firms when that happens. This may lead to underinvestment in innovation, whilst reducing the fierceness of competition in this industry may improve exploration. On the other hand, research for new types of medicine, say, a cure for previously untreatable diseases, may better be achieved in a more competitive market. The existing technology does not allow us to successfully heal certain conditions, and new methods, *ex-ante*, are also unlikely to succeed. Companies may be inclined to simply maximise their profits, rather than invest in R&D. However, with more competition, rents would become more difficult to extract, hence pushing firms to compensate their workers more, which would allow for more exploration.

On the other hand, there are cases where a lack of competition may lead to under-provision of innovation. Education, for instance, would be one of those industries. One could argue that, due to the abundance of schools, this sector would be quite competitive, but there are reasons to believe otherwise. First of all, most schools are public schools, which are highly standardised and usually fairly similar. Most children would then attend a school closest to their home, or, in some countries, may be legally required to attend a school in their neighbourhood.[13] Thus, in that regard, schools do not have to compete with each other. Moreover, the education system is one that does not see much innovation over time. This is likely due to the fact that old and new methods of educating children are likely to have the same *ex-ante* probabilities of success and, with a lack of competition, schools have no incentives to explore. Here, more competition in the industry could diminish the inefficiencies caused by the under-provision of research in new education methods in schools.

Similar speculations could be made regarding the manufacturing sector. In recent years, this industry has not noticeably changed. This is likely due to the existence of natural monopolies, as such a capital intensive sector presents large economies of scale. The difficulty with which competition can arise in this market removes firms' incentives to innovate in researching more productive methods. In this case, an imperfect competition may prove to be the optimal market structure. The high entry costs place a burden on the market, which could, at some point, offset the efficiency gain from reaching an optimal amount of innovation.

An example of too little competition leading to too much investment in innovation can be found in the technological industry. A very common example of this would be Apple Inc.. The company has few direct competitors and a very loyal customer base strengthening its position in the market. When the company was first founded in 1976, it did so by showing incredible speed and quality of innovation and it has continued spending very large amounts on R&D in years to come. However, over time, this spending has begun yielding less and less returns, as most improvements to their products are often-times only incremental from one year to another. Currently, the firm still spends a vast amount of its resources on R&D, potentially at the expense of growth (Fast Company, 2004). Strengthening competition could reduce the potential for profits in the industry, while also providing more profits to other firms to invest in innovation.[14] Both effects would contribute to reducing the amount of exploration of this (almost) monopsony, thus improving the market efficiency.

Nevertheless, various assumptions were made in this paper, which somewhat framed the context in which the results were presented.

Firstly, the model above operates under the implicit assumption that innovation is person-

[13]This is also very closely tied to the Hotelling model presented in the Imperfect Competition section.

[14]If more firms can invest more in research, current technology can become obsolete sooner. Following the theory of Aghion and Howitt (1990), this should reduce the amount spent on exploration by each firm.

specific rather than company-specific. If the opposite were true, all workers would wish to move to a firm that has been successful after the first period, since they know they would have a probability $E[p_B|S, B]$ of success. This possibility of workers leaving after a failure in period 1 would affect the firms set up the exploration contracts and affect the constraints under which a firm may want to explore or exploit. Note that, in equilibrium, all firms will provide the same contracts to their workers, for the same action plan $\left\langle i_k^j \right\rangle$. The risk of losing workers will decrease the firms' payoffs in case of exploration and push them toward less innovation. At the same time, returning to the assumption that the worker owns the intellectual rights to his finding, if the worker is not contractually bound to one firm, this discovery makes him more attractive to other firms. They would therefore attempt to offer him a premium in order to 'steal' him, which would, in turn, in equilibrium, increase all innovation contract values in the economy.[15] The exact mathematical derivations of these cases are beyond the scope of this paper, but would be interesting topics for further research. These additions to the model could also provide interesting applications concerning the topic of intellectual property rights, which presents an ongoing debate.

Moreover, if the workers live for a longer time, the benefits from exploring increase. This has further implications on the resulting contracts. Similarly, when workers perform their tasks in teams, the whole team may benefit from a more productive method, or hurt by the more probable failure of exploring, while employees' attitudes toward their peers may also affect their action plan. Termination could also be a concern to workers, as shown by Manso (2011). The threat of termination in case of failure can and would affect the optimal contracts presented by the manager. However, within the framework of this paper, this is of no concern. Analysing Manso's model (2011) within a competition setting also allows for the introduction of more institutional aspects. Labour unions could be an example of this, together with laws concerning wrongful termination. These help protect workers against threats of termination from the employer. For instance, in the Netherlands, as well as in most European countries, unless the termination is mutually agreed upon and unless the worker has misbehaved (e.g. theft, illegal activity), the firm cannot unilaterally decide to end the contract. If it does, it must pay the worker a mandatory transition fee, which, in most cases, acts as a strong deterrent from performing such action.

Commitment is also assumed not to be an issue in this paper. Within the context of this model, there would be no reason to expect that the firm could commit to paying the worker (in the second period). Realistically, firms operating in an economy are typically either legally forced to pay out the contractually agreed upon wages, or concerned with their reputation as an employer. This holds especially well if we imagine this model to extend over longer periods of time and that workers could switch to a different employer if their payment is being held back. Within this two-period framework, however, lack of commitment would merely make it more difficult to incentivise innovation. Since refusing to pay wages is more likely in the second period, the wages in the first period would need to increase to account for the higher risk of default in the second period. However, exploration requires high second period wages and low first period wages, which not only increase the incentives for a manager to default, but also makes it more difficult to ensure exploration rather

[15] This holds only for imperfect competitions, as a monopsonist has no competitors and the wages are already maximised in a perfect competition.

than exploitation. This effect also makes it an interesting topic for further (empirical) research. From a theoretical point of view, Manso (2011) has extended his model to account for the possibility of defection, finding the necessary changes to the workers' participation and incentive constraints. He finds that the contract derived initially in case of exploitation, which is qualitatively similar to the one derived in this paper, can be achieved through a series of short-term contracts. However, if innovation is desired, the initial wage scheme cannot be replicated using short-term contacts. Moreover, in some cases, exploration may prove to be impossible to incentivise altogether.

Throughout the paper, I have also assumed that the timing of the payments does not matter to either player and that both players are risk-neutral. This was done in order to remove unnecessary forces so as to not cloud the main results of the model. Naturally, the agent will most likely be the one to have a lower discount factor $\delta < 1$ or to be more risk-averse. The firms typically expect a steady flow of payments and are less likely to be affected by such factors. If the worker discounts future income, this will imply higher transfers in the second period, and lower profits to a monopsony or oligopoly. A perfect competition already makes no profits, thus there will be no major impacts in that case. The presence of risk aversion for the worker would have implications on the risk-sharing aspect of the scenario, which was previously not touched upon. The firm may need to pay out higher wages, or perhaps a low basic wage to the employee, as they would like a more certain income flow. Holmstrom and Milgrom (1991) develop such a model using a multitasking setting, showing that, even when objective output measures exist and are accurate and workers respond to incentives appropriately, fixed wages must be adjusted to account for the risk aversion of the worker. Once again, in a perfect competition, the worker essentially owns the firm, thus there will be no changes for this case either.

Conclusion

This paper proposes a first framework to study the effects of competition on firms' internal incentives. It has been previously shown that traditional pay-for-performance schemes are inefficient in such a set-up, as innovation involves very high risk. Rewarding workers only for successes has been proven to be inefficient in an innovation setting, as workers need to be protected in case of early failure.

To a certain measure, this model also reflects on the issue of whether entry-level workers should be punished for their early failures, or rather be treated leniently or even rewarded for their attempts. As Pisano (2019) suggested, the most innovative firms show 'tolerance for failure but no tolerance for incompetence'. Within an extended framework of this model, allowing for heterogeneity within the workers, ability could be measured and workers who do not meet the expectations or requirements of the job can be punished. However, in the basic framework analysed here, early failure should not be punished in an environment conducive to exploration. In some markets, in fact, failure is considered as a sort of rite of passage. Failure is seen as a learning opportunity as well as a willingness to learn and innovate and, for instance, Silicon Valley, takes failures in a worker's early career as a positive, rather than something to punish (Farson & Keyes, 2003).

Further evidence that tolerance for early failure and rewards for long-term success are an effective means to incentivise innovation can be found by running laboratory experiments (Ederer & Manso, 2013).

These results are supported by the findings of this model. It has shown how, in some cases, workers may need to be rewarded even if they fail. More generally, this model has shown the optimal incentive contracts for employees of firms operating under different market structures. Notably, perfect competitions may prove to be inefficient in some cases, as they cannot create the optimal contracts, whilst monopsonies may have preferences that do not fit the societal ones in other cases. For an imperfect competition, the results are somewhat of a mix between the two extremes. Under certain conditions, the existence of competition itself may create inefficiencies, but for other ranges of the model parameters, more competition leads firms to a first-best equilibrium. Furthermore, in line with some recent empirical findings, the results show how the relationship between competition and innovation is non-monotone and ambiguous. Efficiency, on the other hand, may increase or decrease with changes in the level of competition, depending on the parameters of the model.

This paper has provided a first analysis of an employee-focused approach to the discussion on the efficiency of market size with regard to process innovation. Given the policy implications of these results on market regulations and competition law, this paper should serve as a starting point for a range of literature on the topic, which may, in the future, shed more light on previously unknown effects of the industrial organisation of a market.

Appendix A

This Appendix elaborates on the derivations of the monopsony results under exploration. A more elaborate explanation regarding why the constraints mentioned below are the binding ones can be found in Manso's paper (2011). I will then focus only on the relevant constraints going forward.

Firstly, an important definition, as laid out in the original model, is that for the optimal contract to implement action plan $\left\langle B_A^B \right\rangle$, which should satisfy

$IC\left\langle i_k^j \right\rangle$**:**

$$\begin{aligned}&(E[p_B]-E[p_i])(V_S\left\langle B_A^B\right\rangle)-V_F\left\langle B_A^B\right\rangle)\\&+E[p_i](E[p_B|S,B]-E[p_j|S,i])(w_{SS}-w_{SF})\\&+(1-E[p_i])(p_A-E[p_k|F,i])(w_{FS}-w_{FF})\\&\qquad\qquad\qquad\qquad\geq 2f-(c_i+E[p_i]c_j+(1-p_i)c_k),\end{aligned}$$

where

$$V_S\left\langle B_A^B\right\rangle = w_S + E[p_B|S,B]w_{SS} + (1-E[p_B|S,B])w_{SF}$$

and

$$V_F\left\langle B_A^B\right\rangle = w_F + p_A w_{FS} + (1-p_A)w_{FF}.$$

As mentioned in the main text, it should be the case that $w_S = w_{FF} = w_{SF} = 0$ and $w_{FS} = \frac{f}{p_A}$. Rewriting and simplifying the incentive compatibility constraints that are not redundant:

$$IC\left\langle 1_1^1\right\rangle:\ (E[p_B]E[p_B|S,B]-p_A^2)w_{SS}+(p_A-E[p_B])w_F-(p_A-E[p_B])p_A w_{FS}\geq 0$$

$$IC\left\langle 0_1^1\right\rangle:\ (E[p_B]E[p_B|S,B])w_{SS}-(E[p_B])w_F-(E[p_B])p_A w_{FS}\geq f$$

$$IC\left\langle 0_1^j\right\rangle:\ (E[p_B]E[p_B|S,B])w_{SS}-(E[p_B])w_F+(1-E[p_B])p_A w_{FS}\geq 2f$$

The value of β_2 can easily be computed using the same process as for β_1.

- If $1 \geq \beta_2$, we can either have that $w_F = 0$ and $IC\left\langle 1_1^1\right\rangle$ is binding, or that $w_F > 0$ and both $IC\left\langle 1_1^1\right\rangle$ and $IC\left\langle 0_1^1\right\rangle$ are binding.

In the first scenario, taking $w_F = 0$ and $w_{FS} = \frac{f}{p_A}$, we find

$$w_{SS} = \frac{(p_A - E[p_B])p_A\alpha_1}{E[p_B]E[p_B|S,B]-p_A^2}.$$

If $w_F > 0$ and $w_{FS} = \frac{f}{p_A}$, solving $IC\left\langle 1_1^1 \right\rangle$ and $IC\left\langle 0_1^1 \right\rangle$ for w_F and w_{SS} yields

$$w_F = \frac{p_A^2(1 - E[p_B]) - E[p_B]E[p_B|S,B](1 - p_A)}{p_A E[p_B](E[p_B|S,B] - p_A)},$$

$$w_{SS} = \frac{(p_A - E[p_B])p_A\alpha_1}{p_A E[p_B](E[p_B|S,B] - p_A)}.$$

It is then quite straightforward to see why, if $\frac{1-E[p_B]}{1-p_A} \geq \frac{E[p_B]E[p_B|S,B]}{p_A^2}$, the latter contract is less costly for the principal, whilst the former is more costly otherwise.

- If $1 < \beta_2$, the first period wage $w_F = 0$ and the optimal contract will be bound by $IC\left\langle 0_1^j \right\rangle$, resulting in
$$w_{SS} = \frac{(1 + E[p_B])p_A\alpha_1}{E[p_B]E[p_B|S,B]} \equiv \alpha_2.$$

Appendix B

This appendix includes more information on how some of the main conditions of the model change with changes in the exogenous variables: $E[p_B|S, B]$, c_B, S and f. Note that, in this appendix, the upper left corner of the graphs was not removed. This was done on purpose, as the effects of the variables remain much clearer when the entire figure can be seen. However, only the range of values for which $p_A > E[p_B]$ remains relevant.

Figure 8 shows how the range in which innovation is efficient changes with varying exogenous parameters. Logically, as the success probability of the innovative method rises, it will also become efficient to innovate for lower values of $E[p_B]$ or higher values of p_A. Similarly, as the ratio $\frac{c_B}{S}$ decreases, more values of the two *ex-ante* probabilities can create an efficient ground for innovation, since the cost of innovating becomes lower relative to the rewards. The absolute value of the parameters (and thus the scale of the chosen numbers) is irrelevant for this condition.

Similarly, Figure 9 shows how β_1 and β_2 shift when $E[p_B|S, B]$ changes. Evidently, as $E[p_B|S, B]$ decreases, both graphs shift upwards and left and rotate toward the left as well. This shows that, as the conditional second-period expectation of B decreases, the shirking constraint becomes binding for a wider range, which is in line with the theory. A lower $E[p_B|S, B]$ implies that innovation is, *ceteris paribus*, less valuable for the worker, hence he is more likely to simply need to be prevented from shirking, rather than exploring.

Figure 10 shows how the threshold for radical versus moderate innovation shifts as $E[p_B|S, B]$ changes. Once again, as as the expected probability decreases, the threshold slightly shifts to the left, which is also in line with all conditions so far.

While f does not affect any of the constraints discussed above, it affects the firms' choices of exploration and exploitation, due to the wage required by the workers. More specifically, increasing the value of f shifts the green conditions from the main text downwards and to the right. This would make it easier to reach the innovation constraints from the perspective of the firm, but it would also increase inefficiencies, as firm would be tempted to explore more, even though exploitation may be efficient. While f is a cost incurred by the worker no matter which action he chooses, the differences between the two actions will be caused by the incentive compatibility constraints of the worker. For higher values of f, the shirking constraint appears to be more difficult to meet when exploiting rather than simply trying to avoid exploration. On the contrary, exploitation becomes easier to incentivise for these higher values of the effort cost.

Looking at the effect of c_B and S on the same constraints, we find that a higher value for the revenue generated by success increases the managers' incentives to explore, similar to f, whilst a change in c_B does not cause any great changes. This finding, while surprising at first glance, is consistent with what one might expect at a certain size of the firm and market. Innovation tends to bring significantly higher revenues in the future to a company compared to their previous practices, while the investment required rarely compares. Thus, in many cases, a slight change in the cost of innovation will not deter firms from wanting to innovate.

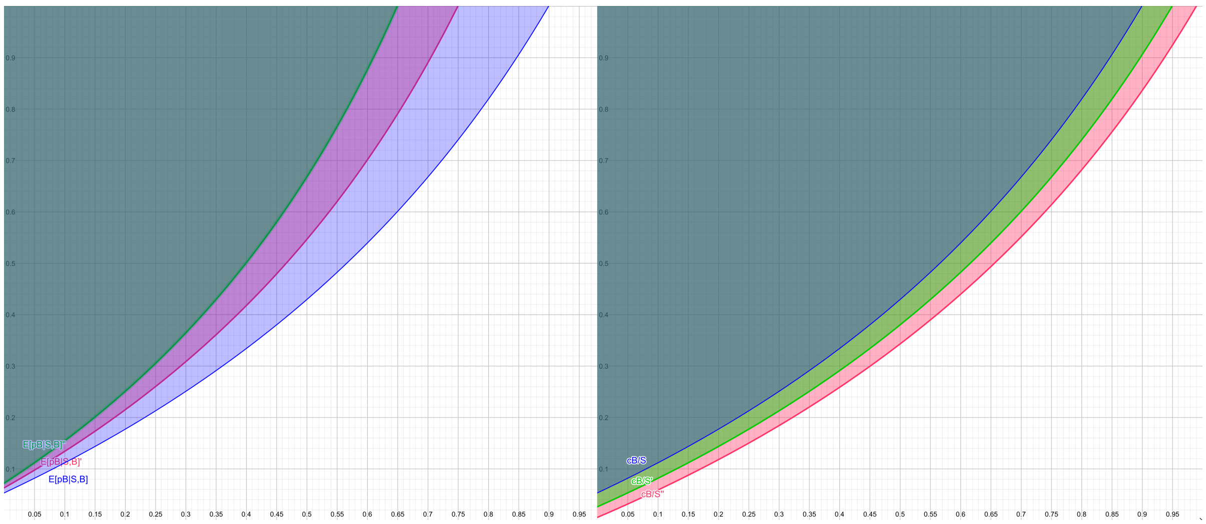

Figure 8: Efficiency range with varying $E[p_B|S,B]$ and $\frac{c_B}{S}$ - the shaded region shows all combinations of p_A and $E[p_B]$ where innovation is efficient. $E[p_B|S,B] > E[p_B|S,B]' > E[p_B|S,B]''$; $\frac{c_B}{S} > \frac{c_B}{S}' > \frac{c_B}{S}''$.

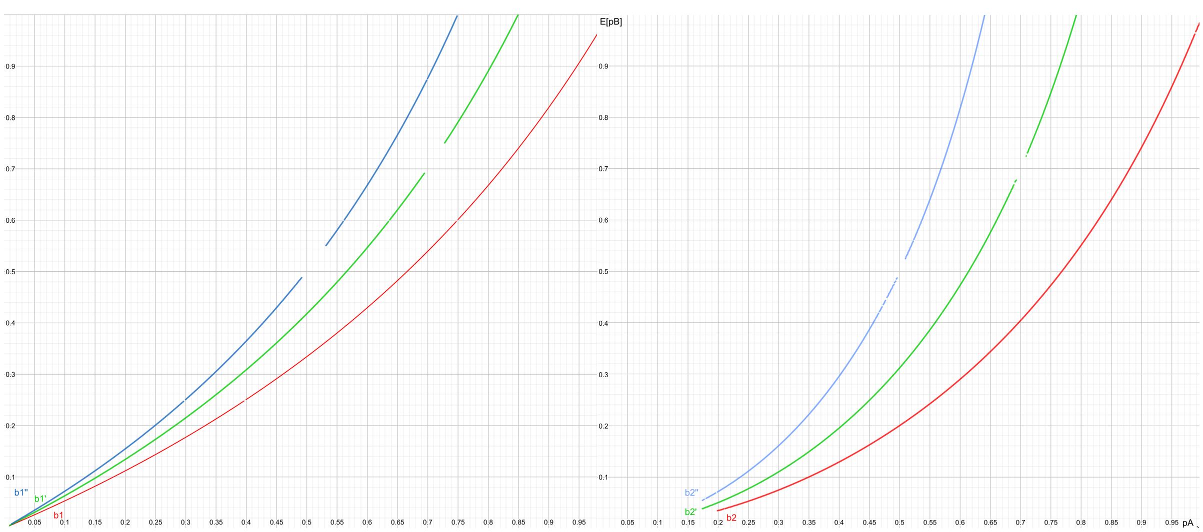

Figure 9: The changes in β_1 and β_2 with varying $E[p_B|S,B]$. $E[p_B|S,B] > E[p_B|S,B]' > E[p_B|S,B]''$.

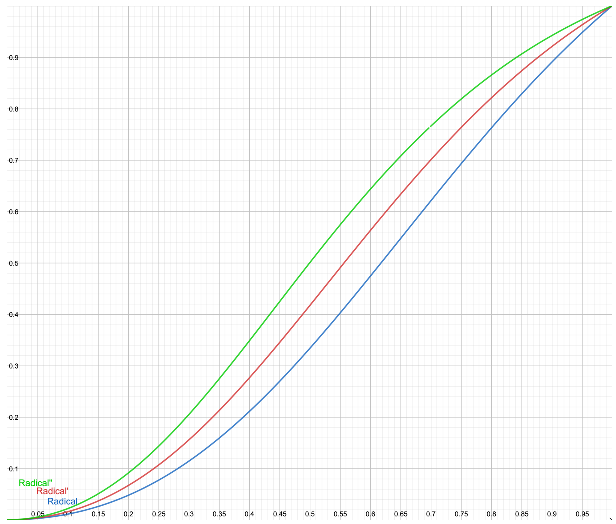

Figure 10: The changes the threshold of radical versus moderate innovation with varying $E[p_B|S,B]$. $E[p_B|S,B] > E[p_B|S,B]' > E[p_B|S,B]''$.

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