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ARROW'S PARADOX AND MARKETS FOR NONPROPRIETARY INFORMATION

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Abstract. Arrow's information paradox asserts that demand for undisclosed information is undefined. Reassessing the paradox, I argue that the value of information for the buyer depends on its relevance, which can be known ex ante, and the uncertainty shifts to the capability of the seller to acquire the knowledge and her reliability in disclosing it. These three together form the buyer's reservation price. Consequently, differences in capability and reliability between the sellers may revoke the appropriation problem of nonproprietary information, where the original source loses her monopoly after the first purchase.

Keywords: Arrow's information paradox, markets for information, knowledge, reliability, appropriability.

JEL classification: D83, L15, O31, O34.

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1 Introduction

Conventional economic wisdom says that due to the inherent properties of knowledge, markets for information cannot exist in the absence of intellectual property rights (IPR). Yet this conclusion, while seemingly theoretically sound, appears startling in today's economy. On a daily basis and in an increasing quantity various different kinds of information are traded, for which property rights are unavailable or unenforceable. These include, naming a few, financial and market information, news, weather forecasts, databases, and encyclopedic, professional and leisure related knowledge (see, Boldrin and Levine, 2008a, for numerous other examples). In the light of this phenomenon it seems relevant to consider whether the microtheoretic analysis of information and knowledge has missed something important.

The main contribution of this study will be to show that while Arrow's information paradox diagnoses a genuine problem in trading information, the nature of the problem is misunderstood. Despite the inherent uncertainty, the demand for undisclosed information is seldom non-existing. Instead, it depends on the seller's capability (the likelihood of having the information) and reliability (the likelihood of disclosing the information) and the relevance of the information for the buyer (the utility of correct information when received). Differences in capability and reliability, i.e. whether one is more likely to have and/or to disclose the information, may also solve the appropriation problem of the supply side, which is illustrated with tentative models of producer and consumer markets.

In essence, this paper bridges gaps between three different literatures: markets for technology (e.g. Muto, 1986; d'Aspremont et al., 2000; Henry & Ponce, 2011), strategic information transmission (e.g. Crawford & Sobel, 1982; Farrell & Rabin, 1996; Dewatripont & Tirole, 2005), and signalling (Spence, 1973; Nelson, 1974; King, 2003; Gentzkow & Shapiro, 2006). Most papers studying the markets for technology have assumed IPR, in which case the valuation and appropriation problems, as identified by Arrow (1962), are considered to disappear. While some papers have studied such markets without IPR, they have usually assumed that the value of information is common knowledge and manipulation is not possible, which has permitted them to concentrate on technology resale and the problem of appropriation (e.g. Muto, 1986, 1990; Hellwig & Irmen, 2001; Boldrin & Levine, 2002, 2008b; Henry & Ponce, 2011). In this paper though, we proceed with the idea that the valuation problem persists also in potential resale, which can give an advantage to the original

source. Besides technological knowledge, another type of information that has also attracted substantial interest has been financial information (Leland & Pyle, 1977; Ramakrishnan & Thakor, 1984; Allen, 1990; Admati & Pfleiderer, 1990). A general conclusion in the finance literature has been that the problems in trading information provide a rationale for financial intermediation.

Closest to our approach are the two papers by Anton and Yao, which address Arrow's information paradox directly. In their first paper (Anton & Yao 1994), the inventor is able to overcome the problems by first disclosing the technology to one firm for free and then appropriate some of the value by threatening the new monopoly by disclosing the technology to its competitors. In their second paper (Anton & Yao, 2002), the inventor is able to make a partial disclosure, which signals the value of the remaining undisclosed information to the potential buyers. Similarly in King (2003), the form of contracting offered by the inventor is a guaranteed signal of the value of the invention to the buyers. As Anton and Yao (2005) sum up, markets for information have been typically studied as either a valuation problem or an appropriation problem.

Conditions under which markets for information will emerge and operate efficiently can be very challenging (Gans & Stern, 2010). In an attempt to address these challenges, we develop a model in which the demand for information is determined, under favorable conditions, without revealing anything *ex ante*. This also implies that there are no spillovers (cf. Baccara & Razin, 2007), which allows us to concentrate on the potential appropriation problem caused by the resale of information. As such, our model starts with the valuation problem, which is then applied to solve the subsequent appropriation problem in the presence of unrestricted resale. While price-taking inventors may be able to profit as well (Hellwig & Irmen, 2001; Boldrin & Levine, 2008b), here we demonstrate that the original source of new information might have some natural market power even without IPR.

We model the demand for information to depend on relevance, capability, and reliability. Relevance is the value of knowledge for the buyer, which can be known beforehand when description is possible without disclosure. Whether the buyer receives knowledge after having paid for it, however, depends on the seller's capability, i.e. how likely the seller's belief is true, and reliability, how likely the seller is to disclose her belief. Our idea of capability borrows from the signaling literature in the sense that the seller is able to signal his capability by, for example, an observable R&D investment. The notion of reliability is connected to the strategic information transmission literature, in which the central idea is that the informativeness of a message, which is not costly to send, depends on the incentives of the

sender. Similarly as in this literature, our paper attempts to address different kinds of information exchanges rather than merely that of technology. Information-embedded goods that are stored in a digital form, such as music, movies or software, are beyond our scope, since these are not bought to gain any knowledge per se (see, however, Schmidt, 2006), although knowledge required to produce such goods is within it. Deviating from the information transmission literature, however, we assume that acquiring knowledge requires a costly investment, which is worthwhile only if the investor receives a sufficient monetary compensation. What we attempt to offer in the end is not only a reconsideration of Arrow's information paradox but also a new perspective on markets for information and on the role of capability and reliability in them.

The rest of the paper is structured as follows. In the next section, we will address Arrow's paradox by claiming that the demand for information can exist but it depends on capability, reliability and relevance. The following section continues with this proposition, operationalizes these three factors and attempts to illustrate that due to them the market price for nonproprietary information is not necessarily driven to zero after the first purchase. First we study the phenomenon in a producer market and after that in a consumer market. The final section concludes the paper.

2 Arrow's paradox and demand for information

“[T]here is a fundamental paradox in the determination of demand for information; its value for the purchaser is not known until he knows the information, but then he has in effect acquired it without cost.” Kenneth Arrow (1962, p. 615)

Arrow's information paradox, quoted above, states that *ex ante* the buyer cannot assess the value of some particular information; it can be known only after it has been disclosed. But then again, the buyer has no reason to compensate the seller *ex post*. Hence, there is no demand for information as such. The paradox can be solved through IPR, such as patents, not by making the pre-disclosure valuation easier but by removing the disincentive to disclose the information (Gans & Stern, 2003). That is, protection cannot be given to an undisclosed invention, but it is assumed that a patent officer will not use or distribute it (unlike a potential buyer would do) before granting the patent, which then allows the inventor to appropriate the social value of her invention.

The impossibility of valuation in Arrow's paradox arises when a statement is self-referential or self-descriptive. Pure examples of this in natural language seem hard to find, since we can usually describe what particular information is about without giving it away. As such, it seems that in its strongest form Arrow's paradox assumes a certain kind of one-dimensional information. For example, think of a sequence of binary digits (e.g. "01100010") and that the only way to describe it is to articulate the complete sequence itself.

Admittedly, the expected value of undefined information cannot be determined, because as long as we are unaware of some types of information we cannot form any probability distribution over all the different types of information. As such, it has been acknowledged for some time that the standard state-space model is incompatible with analyzing unawareness (Dekel et al., 1998). A key issue in this respect is the so-called axiom of wisdom (also known as negative introspection), i.e. "one knows what one does not know". While one might not always know what one does not, Arrow's paradox, however, is incompatible with awareness altogether; according to it one can never know what one doesn't know. Equivalently, one could not ask a question without already knowing the answer.

If however, we grant that we can in some cases be aware of something that we do not know, the paradox disappears. Relevance, or the value, of knowledge cannot be known before the buyer is told what the information is about, i.e. if the buyer does not know what he might not know. Specifying the type of information offered, however, need not always disclose the information itself or any part of it (cf. Anton & Yao, 2002; see also, Klein, 2002, p. 182). What the buyer needs to ponder in this situation is whether the seller is in a position of being capable of acquiring and reliable in disclosing the knowledge. The uncertainty concerns no longer the type of knowledge, but whether it will be gained after the purchase, which depends on the seller's characteristics. Some cases, most importantly certain business ideas, might not permit any significant description without disclosing the information altogether, but this seems a special rather than the general case.

At this point we are ready to fix some central concepts within the context of Arrow's paradox. The starting point is that individuals wish to gain knowledge of facts that are relevant to them. Since there is no direct access to anyone's mental states, gaining knowledge from others requires an exchange of information, which can be in verbal, written or in some other such form. If the belief held by the sender/seller is true in the sense that it corresponds to a fact, we say that she knows the fact. The following is where the distinction between information and knowledge becomes apparent. The belief of the seller either corresponds to a fact or not, which is a matter of her capability and determines whether she knows the fact. In

addition, the sent message, i.e. information, either corresponds to her belief or not, which is a matter of reliability. With perfect capability and reliability the information corresponds to a fact and the receiver/buyer has gained new knowledge.

2.1 *Relevance*

The relevance of information is the value of knowing the fact to the buyer. As knowledge is a discrete and durable good (assuming perfect memory or other form of storage), this value can be gained only once and further purchases do not yield anything. Relevance can be exogenous or endogenous and either symmetrical or asymmetrical between the buyers. In the case of knowledge as a consumer good, relevance is exogenous as the number of others possessors or other market factors do not affect it. In this case relevance may be different between the consumers (C) as some value particular knowledge higher than others. Here we use a notation that the relevance for an individual i is $\theta_i \geq 0$, with equality when the information is utterly irrelevant for the individual or she already has it. In our later analysis, however, we make a simplifying assumption by supposing that the value is the same for all N potential buyers. This assumption is made because even in the case of permanent monopolist in a durable goods market, it has been found that the model specification in the case of heterogeneous buyers affects greatly the outcome (see, Bagnoli et al. 1989; von der Ferh & Kühn, 1995). Our attempt is merely to demonstrate that the original seller may retain some market power even when resale is unrestricted.

When knowledge is an intermediate good, the potential buyer is typically a firm (F) that can use the knowledge to develop new goods or produce existing goods more efficiently. When the customer firms, again indexed by i , are homogenous they value the knowledge similarly, i.e. $\theta_i = \theta$ for all firms N . Among rival firms, however, knowledge has a strategic component and the relevance is therefore endogenous and depends on the number of all the firms, n , that have acquired the knowledge. That is, $\theta(n) \geq 0$ where $n \in [1, N]$ and, typically, $\frac{\partial \theta}{\partial n} < 0$. Relevance includes, but is not restricted to, a process innovation, which decreases the marginal production cost from level \bar{c} to \underline{c} . Usually in the literature this situation is modeled as a Cournot oligopoly between similar firms, to which an inventor offers a license of the process innovation. In the case of (non-drastic) process innovation, it can be shown that $\theta'(n) < 0$ and $\theta''(n) = 0$. (See, Proposition 1 in the appendix.)

While the value of knowledge is given by relevance, this is not the same as the value of information as the latter is the expectation of whether the knowledge will be gained after the payment, that is $v = E[\theta]$. This expected value depends on capability and reliability and, unlike relevance, these depend on the seller's characteristics. As per the R&D firm (RD), the original source and seller, we assume that in both cases the knowledge has no relevance to her, i.e. $\theta_{RD} = 0$.

2.2 Capability

Capability is important in this framework because the seller cannot prove *ex ante* that she knows the fact, only claim that she does. Capability is therefore the probability that the claim is true. In some cases, capability could simply be exogenous and depend on the observed type of the seller. For example, because of their background, education, local circumstances etc. some individuals are more likely to know particular things than others. Many times, however, gaining knowledge requires a costly investment, in which case the social dissemination of knowledge is crucial for capturing its non-rival benefits. If the knowledge investment is observable it can then be taken as a signal of capability. Here the meaning of signal is slightly different than usually in the literature, as the investment is considered to reveal *and* to affect the capability directly rather than merely reveal one's innate capability. The output of knowledge investment is uncertain, particularly in the case of technological research and development investments, but more likely higher the effort. In this paper, therefore, we model capability of the seller, κ , as a function of an observable investment cost, c , such that after some minimum level of necessary investment, \underline{c} , $\kappa(c > \underline{c}) \in (0,1]$, and $\kappa(c \leq \underline{c}) = 0$ otherwise, and that $\kappa' > 0 > \kappa''$. We assume \underline{c} to be high enough so that it prevents all the potential customers to invest themselves for their own use. Likewise, it requires that RD receives sufficient revenue as she does not benefit from the investment directly. This is, after all, the context where the profitability of specializing in knowledge production and invention becomes critical for efficient division of labor and reduction in the duplication of effort (Baumol, 2004). Capability is assumed to be common knowledge among all the market participants.

Besides an R&D investment, the capability could also be signalled by reputation (Gentzkow & Shapiro, 2006), contracting behavior (King, 2003), professional credentials or education (Spence, 1973), advertising (Nelson, 1974), or by a combination of several factors.

Some cases may also permit signalling by partial disclosure (Anton & Yao, 2002). Situations where Arrow's paradox comes true can also be fit to our framework. These could include business ideas or screenplays, which can be hard to describe without giving the central idea away. In this context, it would simply mean that the seller cannot convince the buyer that she truly has a valuable idea through any other means than by revealing it completely and is hence unable to signal her capability. Again, we take it as a special rather than the general case.

2.3 *Reliability*

In addition to capability, reliability is the other factor that affects the expected value of information. Critically, this becomes an issue when the seller can, not only withhold information, but also manipulate it (Hirshleifer, 1973; Milgrom & Roberts, 1986; Henry, 2009). Even if the seller knows the fact (i.e. has perfect capability), no knowledge is gained by the buyer unless the seller sincerely discloses it after being paid. In this regard, the seller has two options: either disclose her belief (D) or misreport it (\tilde{D}). In this paper we assume that even if the buyer is able to later verify the received information, he cannot attest in the court that the received misinformation was due to dishonesty rather than a lack of capability.

Reliability is then clearly an endogenous factor as the decision to disclose depends on the seller's incentives. The informativeness of a disclosure hence depends on how closely related agents' goals are. This issue has been studied in the context of strategic communication (e.g. Crawford & Sobel, 1982; Farrell & Rabin, 1996; Dewatripont & Tirole, 2005), but it is equally relevant when information is exchanged for money. Similar agency problems have earlier been shown to arise in political advisory (Dur & Swank, 2005; Che & Kartik, 2009), persuasion (Mullainathan et al., 2008), and group decision-making (Visser & Swank, 2007). When the inventor's wealth serves as a bond (King, 2003) this can also be considered as increasing the reliability by aligning the incentives of the seller and the buyer.

A critical assumption we make in this regard is based on what epistemologists call "testimonial foundationalism". According to it, a person is entitled to accept, as a default, something that is presented as true; unless there are reasons not to do so (see Goldman, 1999). We take this to mean also that the seller will disclose the information if she is indifferent regarding that choice, which is also known as the assumption of intrinsic preference for honesty in implementation theory literature (Matsushima, 2008). In the concluding section we will return to discuss this assumption.

As the disclosure can take place only after the buyer has decided whether to pay (P) or not (\tilde{P}), reliability of the seller, ρ , is either $\rho = 1$ if $\pi(D) \geq \pi(\tilde{D})$ or $\rho = 0$ if $\pi(D) < \pi(\tilde{D})$. While in this paper the decisions are made sequentially, due to Arrow's information paradox, in some situations it could be possible to use the mixed strategy for reliability if the choices are made simultaneously. In such a case, reliability of the seller (S) is the probability of disclosing her belief, ρ , in the mixed strategy Nash equilibrium: $\sigma_S \in \mathcal{P}(D, \tilde{D})$, $\sigma_S \neq \sigma_S^*$: $u_S(\sigma_S^*, \sigma_B^*) \geq u(\sigma_S, \sigma_B^*)$ and $\sigma_B \in \mathcal{P}(P, \tilde{P})$, $\sigma_B \neq \sigma_B^*$: $u_B(\sigma_B^*, \sigma_S^*) \geq u(\sigma_B, \sigma_S^*)$, where \mathcal{P} is the set of probability distributions on the available strategies. In some other context, where it would be natural to assume the seller's type to be private knowledge, reliability can be considered as the probability that a particular seller is of sincere type.

2.4 Demand for information

Having determined the components of the expected value of information, we can show that the reservation price for (one unit of) information, r_1 , is the price where the buyer is indifferent between buying the information or not, i.e.

$$u(0, m) = u(1, m - r_1), \quad (1)$$

where m is the consumer's income. Suppose further a quasilinear utility function, $u(x_1, x_2) = v(x_1) + x_2$, such that $v(x_1 \geq 1) = \rho\kappa\theta$ and $v(0) = 0$. Then (1) gives us $m = \rho\kappa\theta + m - r_1$ and the reservation price is then given by

$$r_1 = \rho\kappa\theta. \quad (2)$$

If in the equilibrium all of the three factors on the RHS of (2) are positive, then there exists demand for information. Consequently, our interpretation of Arrow's information paradox is therefore, that it describes an equilibrium where the reservation price is zero, particularly when it is impossible to signal capability except by disclosing the information altogether. The lack of capability or reliability may also explain why some knowledge appears to be tacit and resists dissemination (Leppälä, 2012). Assuming that the knowledge is equally relevant to all the potential buyers N , the market demand for information is $D(p) = N$ when $p \leq \rho\kappa\theta$ and zero otherwise.

Note that due to the sequence of events as dictated by Arrow's information paradox, the possible verifiability of information has no effect in a one stage game: the buyer can verify the truthfulness of information only afterwards and the seller cannot do anything else but to signal it through his capability. However, if the market for information extends to several

periods, then verifiability might result to belief updating. For simplicity, we therefore assume that the received information is unverifiable, at least during the game. One should also note that positive relevance, capability and reliability are not always sufficient for a positive reservation price. If information is unverifiable and false information would lead to a costly action, C , i.e. a bad investment decision or missing the train, then this should be incorporated to the reservation price such that $r_1 = \max\{\rho\kappa\theta - (1 - \rho\kappa)C, 0\}$. In our examples we do not, however, consider this possibility.

The difference between the reservation price and the actual market price will depend on the buyer's possible profits from resale as well as on the outside options, namely purchasing the information in a later period or making the investment yourself. Everything else except the information possessed by the seller(s) is here assumed to be common knowledge.

3 Appropriability and markets for information

In the previous section it was proposed that Arrow's information paradox is not a fundamental obstacle to markets for information. The nature of information sets some specific requirements, but when they are met the demand for information exists. There is, however, another problem, also noticed by Arrow (1962), which still remains. If there is only a fixed cost of producing information and the marginal cost of selling it is zero, then due to competition the market price of information will go to zero after the first purchase. In general, the situation is at first much like any durable goods monopoly (e.g. Coase, 1972; von der Ferh & Kühn, 1995), but with a difference that after the first period the former buyers are permitted to resell the information they have bought. As such, the fulfilment of the Coase conjecture would imply the breakdown of the market.

However, the difficulty in valuating information before disclosure prevails also in resale. As such, there may be differences in capability and reliability between the sellers that permit a positive price for information and prevent the collapse of the market. The valuation problem may then be a solution to the appropriation problem. Conversely, if the valuation problem does not exist then market power will also vanish.

When there are two or more sellers and no binding capacity constraints in disclosing the information, the market price is determined by Bertrand competition between the two most competent sellers. Suppose that sellers 1 and 2 are the most competent, i.e. the product of their reliability and capability is higher than that of any other seller, if there exist any, and that

there is at least one buyer, whose relevance is θ_B . The buyer, whether a firm or a final consumer, will choose the seller 1 over 2 if

$$\kappa_1\rho_1\theta_B - p_1 \geq \kappa_2\rho_2\theta_B - p_2, \quad (3)$$

where p_1 and p_2 are the sellers' respective asking prices. Suppose that 1 is the more competent of the two and therefore, $\kappa_1\rho_1 > \kappa_2\rho_2$. Since the marginal price is zero, the less competent 2 will tighten the competition until $p_2 = 0$. Hence, in order to keep its customers, 1 cannot set any price higher than $p_1 \leq (\kappa_1\rho_1 - \kappa_2\rho_2)\theta_B$, which is set to equality to maximize profits. For simplicity, we assume that every buyer will choose the more competent seller in this case, as seller 1 could decrease its asking price by an infinitesimal amount, ε , to make its offer strictly better. In general therefore, the market price is given by

$$p = |(\kappa_1\rho_1 - \kappa_2\rho_2)\theta_B|, \quad (4)$$

and it is above zero if there are differences in competence between the two most competent sellers (1 and 2). The implication of Bertrand competition is that only the most competent seller is able to make profit, given that the difference in competency, i.e. a competence premium, covers the initial investment cost. Note that other, less competent sellers would have no effect on the equilibrium price.

Next, we will endogenize these two important factors for markets for information. To analyze the importance of reliability, we first study a producer market where the relevance of information depends on its commonness among rival producers. After that we move on to a consumer market where this strategic component in the value of information is absent. There, when the reliability is the same among potential sellers, differences in capability become relevant.

3.1 Reliability and markets for intermediate information

The first situation concerns a producer market where there are N similar, rival firms (F). In addition, there is one R&D firm (RD), not competing at the same market, but which offers to sell the firms some particular information. (While having named it as such, RD could equally well be a consulting firm selling market information or a bank selling financial information.)

The rival producers value the information similarly, but the relevance depends on its commonness as noted earlier. Critically, we assume that RD is fully able to commit not to enter the market where the other firms compete and as such the information it produces has no direct value to it. To cover the investment cost, which also signals its capability, it needs, however, receive large enough revenues from the other firms.

The timeline is the following:

1. RD chooses the investment c , which is observed by Fs and reveals RD's capability κ to them.
2. RD chooses its price p for the first period and customer firms decide whether to purchase the information or postpone.
3. If there is unsatisfied demand left, the market price is set by Bertrand competition as in (4) between RD and its former customers. This process continues as long as the market for information has cleared.
4. When the information market has cleared, the customer firms engage in (Cournot) competition and the relevance in the second stage market is realized with probability $\rho\kappa$ to all who had bought the information.

We assume that there is no discounting between the stages 2, 3 and 4 due to unlimited possibilities to buy and resell before stage 4. However, we assume that while a seller is able to supply multiple buyers simultaneously, buyers only make one purchase in any moment. The critical issue in this market is that if resale at stage 3 decreases the price level to zero then this will also decrease Fs' willingness to pay at stage 2. If the total revenue is low, a high investment c is not worthwhile. We proceed to study the equilibrium outcome through backward induction.

At stage 4, the benefit that a firm receives from having bought the information is $\rho\kappa\theta(n)$, which is also his reservation price. To concentrate on the issue of reliability, we assume that the events on stage 2 are common knowledge because the market is small and everyone observes who has purchased the information. This implies that the capability is only determined by the initial investment c and is hence the same for all sellers, whether RD or any of its former customers. Reliability, on the other hand, depends from whom the information is purchased. Let's then proceed to stage 3 assuming that there are several sellers.

Since any remaining customer has always the opportunity to buy the information from RD, also its competitors would be willing to sell the information, even if some competitive advantage is lost. Due to Arrow's paradox, however, the decision regarding information disclosure is always made after the payment.

The decision to disclose the information does not affect RD's payoff, i.e. it will receive the asking price in any case. The situation is different for any F attempting to resale, however. By disclosing the information, F loses some of the informational value of its earlier purchase, $\Delta\theta = \theta(n+1) - \theta(n) < 0$, since one of its rivals receives the same information. Hence, irrespective of the price it will never disclose the knowledge truthfully, because $\pi(\tilde{D}) = p > p + \Delta\theta = \pi(D)$ and hence $\rho_F = 0$. RD, on the other hand, is indifferent regarding the disclosure, since $\pi(D) = p = \pi(\tilde{D})$. Therefore, $\rho_{RD} = 1$ as assumed earlier. To use the terminology of Muto (1990), the market is "resale-proof" as no rival firm can be expected to disclose the information truthfully.

During any period, no F will buy the information from its rival and RD retains its monopoly even if it does not have exclusive rights to sell the information. RD will thus set the market price equal to the F s' reservation price. Since $\rho_{RD} = 1$, however, buyers know that the information is leaked to their rivals as well and the relevance is thus $\theta(N)$. If $\theta(1) > N\theta(N)$, some F could in principle bribe RD to not to disclose the information to others. Without any contract enforcement mechanism such as transferable rights or equity stakes (Bhattacharya & Guriev, 2006; King, 2003), however, this is not possible: if paid up front, RD has no incentive to keep its promise, and neither will RD receive any payment afterwards whether it has complied or not.

Therefore, RD sets $P_1 = \kappa(c)\theta(N)$ and all F make the purchase at stage 2. Recursively, the optimal investment c^* in stage 1 is such that it maximizes profits, $\pi = \delta_{RD}N\theta(N)\kappa(c) - c$, where $0 \leq \delta_{RD} \leq 1$ is RD's discount factor, hence given by $\kappa'(c) = 1/\delta_{RD}N\theta(N)$. To restate, an important feature of this model is that rival F s cannot commit to disclose the information, whereas RD cannot commit not to disclose it. This outcome is largely due to the sequential form of the game as given by Arrow's information paradox.

In a similar sense as in Anton and Yao (1994), the rivalry between the buyer firms helps to overcome the appropriation problem and trade of information emerges without IPR. Here however, the trade does not stop after the first purchase, hence permitting a wider utilization of knowledge from the social point of view. With a patent, RD might benefit from exclusive licensing, but given the incentive for issuing multiple licenses the only alternative would be to sell the patent itself to a single firm. Depending on the characteristics of the product market, the optimal number of sales can be either 1 or N or anything in between. Therefore as in Muto (1987), patents, if they have an effect, would be expected to benefit the innovator but decrease the consumers' welfare.

3.2 *Capability and markets for consumer information*

In comparison to producer markets, trading information in consumer markets is very similar with respect to the fact that the first purchase will break the monopoly. The process follows the same timeline as earlier and the number of purchases per period is limited to one but sales are unlimited. However, when information is a consumer good its value is independent of its commonness and hence has no strategic value. In other words, $\theta_i = \theta$ for all i , making the simplifying assumption that the information is equally relevant for all consumers. For simplicity we further assume that $\theta = 1$. Furthermore, as the relevance is not captured during any particular period as such, we introduce discounting between the periods to capture the time value of information.

Regarding information disclosure, every consumer (C) will behave like RD in the previous part. As one does not need to part with her knowledge when disclosing it, we do not need similar legal rights to enforce the seller to keep her side of the bargain. For this reason, contrary to normal goods, property rights are not similarly fundamental for information. Furthermore, when information is a consumer good, it is unlikely even in the first place that IPR would solve Arrow's paradox. Since it is next to impossible to know if a consumer has benefitted from disclosed information, IPR do not encourage disclosure before payment. As such, their main effect is to prevent resale by former customers. Nevertheless, $\rho_C = \rho_{RD} = 1$ for consumer markets and RD cannot anymore rely on the lack of reliability among buyers. Capability is hence the factor which becomes critical.

Let us assume that $\kappa(0) = 0$. Hence, for period one, it is only RD who has the knowledge with probability $\kappa_{RD} \geq 0$. For the forthcoming periods, the capability of Cs, and hence the market price, will depend on previous purchases. This issue makes the strategic interaction between consumers and RD highly important.

In general, a C prefer to postpone their purchase if

$$\kappa_{RD} - p_t < \delta(\kappa_{RD} - p_{t+1}),$$

where $0 \leq \delta \leq 1$ is the consumers' and RD's discount factor. Suppose for now that the market is small and Cs know who has previously bought the information from RD. Cs can then choose to purchase the information now or postpone their purchase and wait for the next period. For small markets, $\kappa_C = \kappa_{RD}$ for those Cs who bought the information, as they have been observed to do that, and hence the price for the next period will be zero.

If $(1 - \delta)\kappa_{RD} < p_1 \leq \kappa_{RD}$, we have N asymmetric pure strategy equilibria where one of the consumers buys the information in period 1 and rest of them in period 2 at price $p_2 = 0$. Therefore, if $(1 - \delta)N < 1$, RD sets $p_1 = \kappa_{RD}$ and gets one purchase in period $t = 1$. Recursively, the optimal investment in $t = 0$ is given by

$$\frac{\partial \pi}{\partial c} = \delta \kappa' - 1 = 0 \rightarrow c^*.$$

If $(1 - \delta)N \geq 1$, RD sets $p_1 = (1 - \delta)\kappa_{RD}$, and all the consumers make their purchase during $t = 1$. Optimal investment at $t = 0$ in this case is given by

$$\frac{\partial \pi}{\partial c} = \delta(1 - \delta)N\kappa' - 1 = 0 \rightarrow c^*.$$

More relevant for consumer markets, however, is the situation where the market is large and anonymous, and hence the consumers do not know who has bought the information previously and are unable to play a coordinated pure strategy equilibrium. A former buyer finds it harder than the producer to authenticate her possession of knowledge, since anyone could claim that (Hirshleifer, 1971, 1973). Therefore, every buyer is unsure who of all the others claiming to possess the information actually have it. If again the cost c is observable and the actual purchases of information are not, the producer has an advantage. The situation is best illustrated by studying the mixed strategy equilibrium, which highlights the expectation regarding any C's capability.

As before, RD is free to set the price for the first period, p_1 , but the prices for the subsequent periods depends on the Cs' mixed strategies of having already purchased the information. Note that we prevent an early exit by RD, even if such a threat could be profitable, since we assume that potential future revenues after the exit make this commitment incredible.

Let q_t be the probability that each C purchases the information during period t . For $t = 1$ we have $\kappa_C = 0$, for $t = 2$ $\kappa_C = q_1\kappa_{RD}$ and in general for any period $T - s$ $\kappa_C = \kappa_{RD} \sum_{t=1}^{T-s-1} q_t$. In that case, the market clears in T periods when $\sum_{t=1}^T q_t = 1$. In the mixed strategy equilibrium each consumer is indifferent regarding the period when to purchase, i.e.

$$\kappa_{RD} - p_1 = \delta(\kappa_{RD} - p_2) = \dots = \delta^{t-1}(\kappa_{RD} - p_t) = \dots = \delta^{T-1}(\kappa_{RD} - p_T) \quad (5)$$

This implies that the price in any period t satisfies $p_t = \kappa_{RD} - \frac{\kappa_{RD}-p_1}{\delta^{t-1}}$. The price after the first period depends on the cumulative probability of past purchases, i.e. $p_t = (1 - \sum_{i=1}^{t-1} q_i) \kappa_{RD}$. As such, the mixed strategies that support the equilibrium (5) are $q_1 = \frac{\kappa_{RD}-p_1}{\kappa_{RD}\delta}$ for the first period and $q_{t>1} = \frac{(1-\delta)(\kappa_{RD}-p_1)}{\kappa_{RD}\delta^t}$ for the subsequent periods. Since the market clears in T periods, the following price will be $p_{T+1} = \kappa_{RD} - \frac{\kappa_{RD}-p_1}{\delta^T} = 0$. This implies that $T = \left\lceil \frac{\log\left[1 - \frac{p_1}{\kappa_{RD}}\right]}{\log[\delta]} \right\rceil$, where T is the next integer greater than or equal to $\frac{\log\left[1 - \frac{p_1}{\kappa_{RD}}\right]}{\log[\delta]}$. Note that RD can always clear the market in the first period by setting $p_1 = (1 - \delta) \kappa_{RD}$, which implies that $q_1 = 1$. If the consumers are relatively patient (i.e. $\delta \geq 1/e$ as we will see later), then RD may wish to extend the trading to several periods. Based on the above mixed strategies, RD's profit function in period 1 is

$$\pi(p_1) = Np_1q_1 + \sum_{t=2}^{T-1} N\delta^{t-1}p_tq_t + N\delta^{T-1}p_Tq_T = N \left(p_1 \frac{\kappa_{RD}-p_1}{\kappa_{RD}\delta} + \sum_{t=2}^{T-1} \delta^{t-1} \left(\kappa_{RD} - \frac{\kappa_{RD}-p_1}{\delta^{t-1}} \right) \frac{(1-\delta)(\kappa_{RD}-p_1)}{\kappa_{RD}\delta^t} + \delta^{T-1} \left(\kappa_{RD} - \frac{\kappa_{RD}-p_1}{\delta^{T-1}} \right) \left(1 - \frac{\kappa_{RD}-p_1}{\kappa_{RD}\delta} - \sum_{t=2}^{T-1} \frac{(1-\delta)(\kappa_{RD}-p_1)}{\kappa_{RD}\delta^t} \right) \right)$$

where the last term imposes the restriction that exactly all the remaining consumers will purchase during the last period. The profit function further simplifies as follows:

$$\pi(p_1) = N \left(p_1 \frac{\kappa_{RD}-p_1}{\kappa_{RD}\delta} + (T-2) \frac{(1-\delta)(\kappa_{RD}-p_1)}{\delta} + \frac{(\delta^T-\delta^2)(\kappa_{RD}-p_1)^2}{\kappa_{RD}\delta^{T+1}} + \delta^{T-1} \left(\kappa_{RD} - \frac{\kappa_{RD}-p_1}{\delta^{T-1}} \right) \left(1 - \frac{\kappa_{RD}-p_1}{\kappa_{RD}\delta} + \frac{(\delta^T-\delta^2)(\kappa_{RD}-p_1)}{\kappa_{RD}\delta^{T+1}} \right) \right) \leftrightarrow \pi(p_1) = N \frac{p_1(1+(\delta-1)T)+\kappa_{RD}(\delta^T-1+T-\delta T)}{\delta} \quad (6)$$

Since $T = \left\lceil \frac{\log\left[1 - \frac{p_1}{\kappa_{RD}}\right]}{\log[\delta]} \right\rceil$ as an integer function is discontinuous, we ignore the ceiling for

now to get an approximate value and (6) becomes

$$\pi(p_1) = N \frac{p_1 \left(1 + \frac{(\delta-1)\text{Log}\left[1 - \frac{p_1}{\kappa_{RD}}\right]}{\text{Log}[\delta]} \right) + \kappa_{RD} \left(-\frac{p_1}{\kappa_{RD}} + \frac{\text{Log}\left[1 - \frac{p_1}{\kappa_{RD}}\right]}{\text{Log}[\delta]} - \frac{\delta \text{Log}\left[1 - \frac{p_1}{\kappa_{RD}}\right]}{\text{Log}[\delta]} \right)}{\delta} = \frac{N(1-\delta)(\kappa_{RD}-p_1)\text{Log}\left[1 - \frac{p_1}{\kappa_{RD}}\right]}{\delta \text{Log}[\delta]}$$

The optimal starting price for the first period is found by

$$\frac{\partial \pi(p_1)}{\partial p_1} = N \frac{(\delta-1)(\kappa_{RD}-p_1)}{\delta \kappa_{RD} \left(1 - \frac{p_1}{\kappa_{RD}} \right) \text{Log}[\delta]} + N \frac{(\delta-1)\text{Log}\left[1 - \frac{p_1}{\kappa_{RD}}\right]}{\delta \text{Log}[\delta]} = \frac{N(\delta-1) \left(1 + \text{Log}\left[1 - \frac{p_1}{\kappa_{RD}}\right] \right)}{\delta \text{Log}[\delta]} = 0$$

$$\rightarrow 1 + \text{Log} \left[1 - \frac{p_1}{\kappa_{RD}} \right] = 0 \rightarrow p_1^* = \left(1 - \frac{1}{e} \right) \kappa_{RD}$$

As the market clears in the first period if $p_1 = (1 - \delta)\kappa_{RD}$, $p_1^* = \left(1 - \frac{1}{e} \right) \kappa_{RD} \geq (1 - \delta)\kappa_{RD}$. In other words if $\delta < 1/e$ then $p_1^* = \left(1 - \frac{1}{e} \right) \kappa_{RD}$ and otherwise $p_1^* = (1 - \delta)\kappa_{RD}$. In the first case, the maximum profit will thus be $\pi(p_1^*) = \frac{N(\delta-1)\kappa_{RD}}{\delta e \text{Log}[\delta]}$ and the market clears in $T = \left\lceil -\frac{1}{\text{Log}[\delta]} \right\rceil$ periods. As can be expected, a high time-sensitivity of information, low δ , clears the market faster. Lastly, the optimal investment in period 0 is given by $\Pi = \delta\pi, \frac{\partial \Pi}{\partial c} = \frac{N(\delta-1)}{e \text{Log}[\delta]} \kappa' - 1 = 0 \rightarrow c^*$.

Figures illustrating the situation are in the appendix. As Fig. 1 shows, with $p_1^* = (1 - \delta)\kappa_{RD}$, RD's rate of appropriation, $\frac{\pi(p_1^*)}{N\kappa_{RD}} = \frac{(\delta-1)}{\delta e \text{Log}[\delta]}$, depends linearly of δ . Nevertheless, this is the optimal choice when $\delta < 1/e$, since the market would clear in one period anyway. If the consumers are more patient, then $p_1^* = \left(1 - \frac{1}{e} \right) \kappa_{RD}$ is optimal, since while the profit decreases with increasing δ some of the social value is always appropriated.

The importance of the result is that it challenges a central thesis of the microeconomics of information, as expressed here by Hirshleifer (1973, p. 35, emphasis in the original): “Unpatented information is safeguarded by secrecy, which is always compromised by sale. The key problem for the existence of a market in such information is the prevention of unauthorized *resale*.” Here we have shown that unrestricted resale of information does not remove all the market power from the original information producer. Even when the consumers (and RD) are very patient (i.e. $\delta \rightarrow 1$), using L'Hôpital's rule we find that RD's revenue is $\lim_{\delta \rightarrow 1} \frac{N(\delta-1)\kappa_{RD}}{\delta e \text{Log}[\delta]} = \frac{N\kappa_{RD}}{e}$ and it is thus able to appropriate a considerable share of the social value of the information even in the worst case.

Fig. 2 illustrates how it takes longer for the market to clear when the discount rate is higher. Similarly as in Fig. 3, the red line illustrate the values with continuous time and the green piece-wise lines with the actual ceiling function. In Fig. 3 we see that the optimal price that we solved assuming continuous time is relatively good approximation of what it is in the case of discrete time. Fig. 3 present the rate of appropriation for three values of the discount factor, 0.4, 0.6 and 0.8, and the higher the factor (and the lower the appropriation rate) the more closely the piecewise function follows the continuous one. An interesting feature of our result is that even without heterogeneity and subsequent price discrimination we may observe

a decreasing price and a gradual social dispersion of new knowledge over time as illustrated in Fig 4a and 4b.

4 Concluding remarks

The starting point of this paper was to argue that the demand for undisclosed information depends on the seller's capability and reliability and on the relevance of the information to the buyer. When all three are positive, the demand for information exists and Arrow's information paradox does not hold. As the same difficulties in assessing the value of information persist in subsequent resale of information, the original producer of the information can have a competitive advantage that retains some of the market power even when nothing prevents costless resale as such. When the pool of customers consists of rival firms, this advantage is due to the lack of reliability between the firms. Even when the strategic value of information is absent but the market is anonymous, the original seller is perceived to be more capable, i.e. it is more probable that it actually has the information than any other anonymous seller claiming likewise. As such, we consider this framework to yield an economic interpretation as to why knowing the source of information is indeed important. The framework is not only relevant for studying actual markets for nonproprietary information, but also for understanding the role of IPR in other markets or why some markets for information do not exist at all.

The central element that our approach provides for analyzing competition in information markets of various kinds is the quality (i.e. truthfulness) of information. For instance, the long dominance of *Encyclopædia Britannica* in the English language encyclopedia market can largely be attributed to its excellent reputation for authoritative and trustworthy content (Evans & Wurster, 2000). Later the market leader became challenged by Microsoft Encarta (now discontinued) and Wikipedia. However, the fact Britannica still exist today when the same type of information is available for free can arguably be attributed to its higher quality. Yet, it has been claimed that the difference in accuracy between Britannica and Wikipedia has greatly diminished (Giles, 2005). Understanding well the criticality of such claims to its revenues, Britannica has forcefully attempted to refute them (Encyclopædia Britannica, 2006).

While this paper gave examples where the markets for information can function without IPR, it is clearly the case that this outcome requires various conditions to hold. Otherwise the

outcome is the no-trade equilibrium. While this could be viewed as a weakness of the model, we consider it as strength to the extent that the model illuminates the real fragility of markets for information. If we reserve the assumption of testimonial foundationalism, for example, i.e. that every indifferent seller would never honestly disclose the information, then no trade would emerge. Nevertheless, when a sufficient number of potential sellers have intrinsic preference for honesty, there can be a market for information. In a related manner in implementation theory, even a small preference for honesty has been found to eliminate unwanted equilibria (Matsushima, 2008). Sincere sellers may, furthermore, signal their type, which prompts us to consider the importance of reputation in repetitive markets for information. Subsequent applications could consider, for example, the news industry or credit rating agencies. A dynamic model would be a relevant extension in this regard but that is left for subsequent research.

Similarly, a complete welfare analysis and comparison to markets for proprietary information would require further specifications to our model. In the case where the buyers are firms, we should also factor in the welfare of their customers. In the case where the buyers are final consumers, we would need to introduce heterogeneity in order to analyse the comparative welfare gains and losses. In both cases, IPR could also create a patent race and duplication of effort when there is more than one potential inventor. As such, this paper is merely a starting point for what we perceive to be a relevant line of research.

Appendix

Relevance of a process innovation in an N firm symmetrical Cournot oligopoly

Proposition 1. Relevance of a process innovation in an N firm symmetrical Cournot oligopoly has the properties $\theta'(n) < 0$ and $\theta''(n) = 0$ depending on the number of firms, n , that have acquired the marginal cost reducing, $\bar{c} \rightarrow \underline{c}$, technology.

Proof. Suppose that there are N firms that face linear inverse demand curve, $P = a - bQ$, where Q is the sum of their output and P its market price. Initially, each firm has a constant marginal cost \bar{c} , but has now the option to purchase technology that enables production with a lower marginal cost \underline{c} . The difference between the marginal costs is not assumed to be large enough to affect the number of output producing firms. When n is the number of all firms that

have the new technology, including firm i if it chooses so, the profits for firm i under the two marginal costs are

$$\pi_{\bar{c}}^i(q_{\bar{c}}^i, n) = \left(a - \bar{c} - bq_{\bar{c}}^i - b \left((N - n - 1)q_{\bar{c}}^{-i} + nq_{\underline{c}}^{-i} \right) \right) q_{\bar{c}}^i \quad (7)$$

$$\pi_{\underline{c}}^i(q_{\underline{c}}^i, n) = \left(a - \underline{c} - bq_{\underline{c}}^i - b \left((N - n)q_{\bar{c}}^{-i} + (n - 1)q_{\underline{c}}^{-i} \right) \right) q_{\underline{c}}^i \quad (8)$$

The first order conditions of (7) and (8) with respect to output q^i are

$$q_{\bar{c}}^i = \frac{a - \bar{c}}{2b} - \frac{(N - n - 1)q_{\bar{c}}^{-i} + nq_{\underline{c}}^{-i}}{2} \quad (9)$$

$$q_{\underline{c}}^i = \frac{a - \underline{c}}{2b} - \frac{(N - n)q_{\bar{c}}^{-i} + (n - 1)q_{\underline{c}}^{-i}}{2} \quad (10)$$

In the Nash equilibrium (9) and (10) are the best responses to each other and as the output choices of firms with the same marginal cost are the same, these can be presented as

$$q_{\bar{c}}^* = \frac{a - \bar{c}}{2b} - \frac{(N - n - 1)q_{\bar{c}}^* + nq_{\underline{c}}^*}{2} \quad (11)$$

$$q_{\underline{c}}^* = \frac{a - \underline{c}}{2b} - \frac{(N - n)q_{\bar{c}}^* + (n - 1)q_{\underline{c}}^*}{2} \quad (12)$$

(11) and (12) give us the optimal output levels in both cases, such that

$$q_{\bar{c}}^* = \frac{a - \bar{c} - n(\bar{c} - \underline{c})}{b(N + 1)} \text{ and } q_{\underline{c}}^* = \frac{a - \underline{c} + (N - n)(\bar{c} - \underline{c})}{b(N + 1)}.$$

To comply with our earlier assumption, the \bar{c} firms nevertheless produce a positive output $a - \bar{c} - n(\bar{c} - \underline{c}) > 0$ for all $n \in N$, i.e. $n \leq N < \frac{a - \bar{c}}{\bar{c} - \underline{c}}$. Then, the equilibrium profits are

$$\pi_{\bar{c}}(q_{\bar{c}}^*, n) = \left(a - \bar{c} - bq_{\bar{c}}^* - b \left((N - n - 1)q_{\bar{c}}^* + nq_{\underline{c}}^* \right) \right) q_{\bar{c}}^* = \frac{(a - \bar{c} - n(\bar{c} - \underline{c}))^2}{b(N + 1)^2} \quad (13)$$

$$\pi_{\underline{c}}(q_{\underline{c}}^*, n) = \left(a - \underline{c} - bq_{\underline{c}}^* - b \left((N - n)q_{\bar{c}}^* + (n - 1)q_{\underline{c}}^* \right) \right) q_{\underline{c}}^* = \frac{(a - \underline{c} + (N - n)(\bar{c} - \underline{c}))^2}{b(N + 1)^2} \quad (14)$$

Finally, relevance is the difference between these two profits (13) and (14) such that

$$\theta(\bar{c}, \underline{c}, n) \equiv \pi_{\underline{c}}(q_{\underline{c}}^*, n) - \pi_{\bar{c}}(q_{\bar{c}}^*, n) = \frac{(\bar{c} - \underline{c})(2a - \bar{c} - \underline{c} + (\bar{c} - \underline{c})(N - 2n))}{b(N + 1)}$$

$$\text{and } \frac{\partial \theta}{\partial n} = -\frac{2(\bar{c} - \underline{c})^2}{b(N + 1)} < 0, \frac{\partial^2 \theta}{\partial^2 n} = 0. \blacksquare$$

Figures

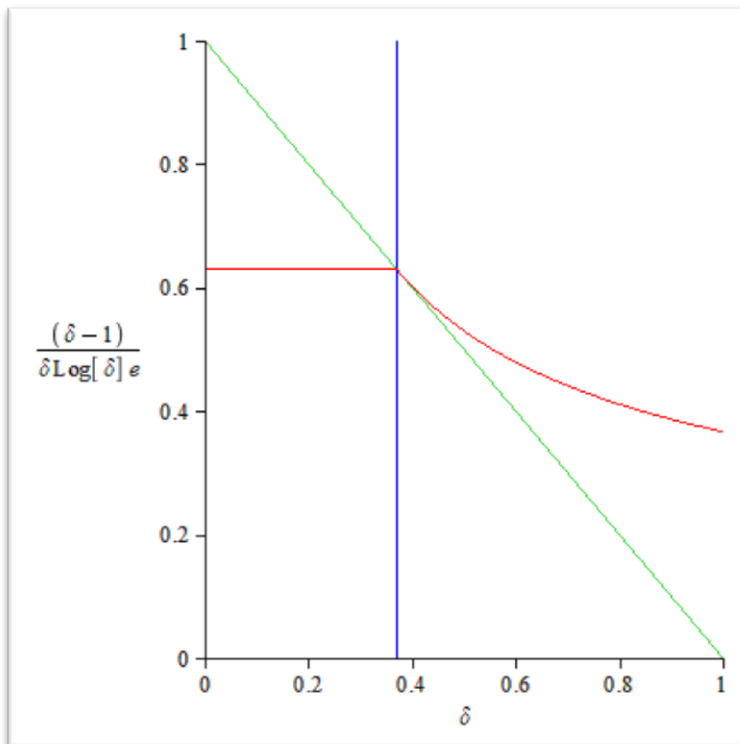


Fig. 1. RD's rate of appropriation when $p = (1 - \delta)$ or $p = (1 - 1/e)$.

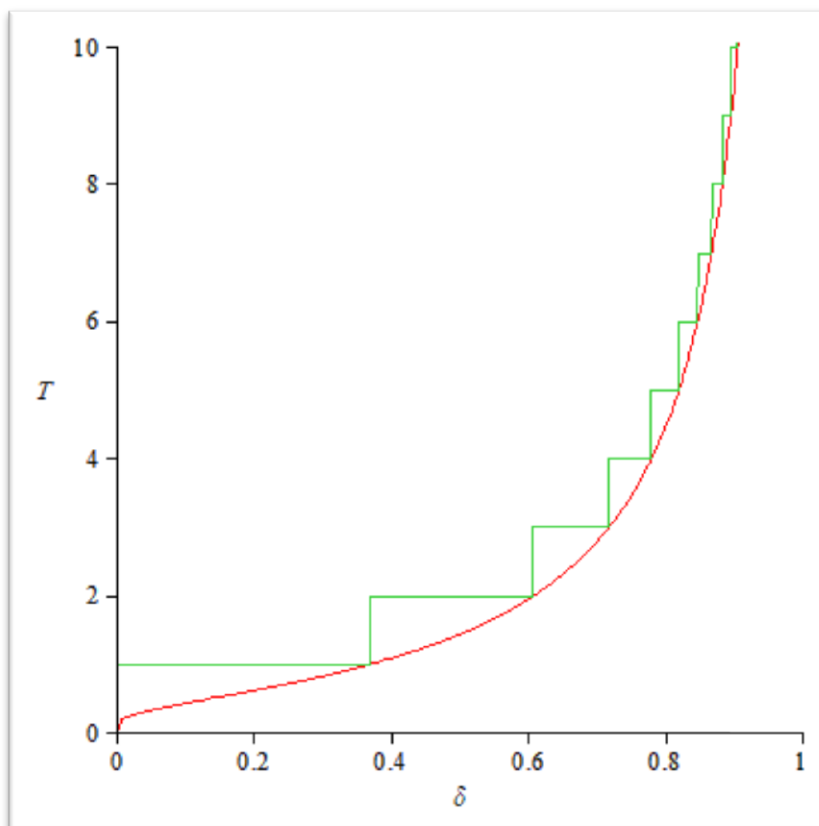


Fig. 2. Market clearing in the equilibrium, $T = \left\lceil -\frac{1}{\text{Log}[\delta]} \right\rceil$, $T = -\frac{1}{\text{Log}[\delta]}$.

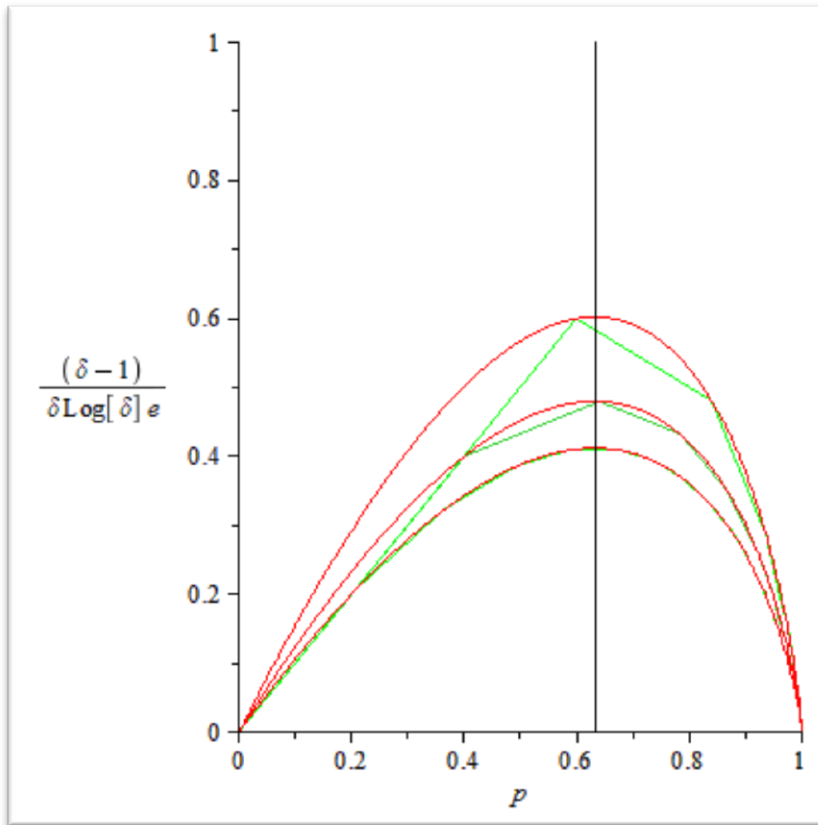


Fig. 3. RD's rate of appropriation as a function of the first period price

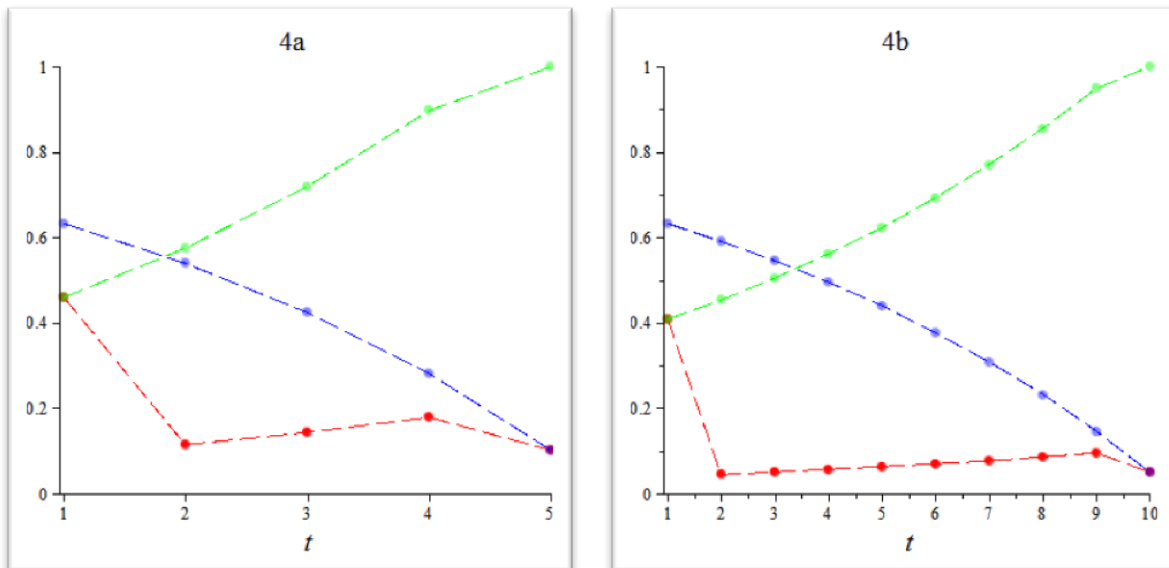


Fig. 4a and b. The equilibrium values of q_t , $\sum q_t$ and p_t over time when $\kappa_{RD} = 1$ and $\delta = 0.8$ (4a) or $\delta = 0.9$ (4b).

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