ESSAYS ON ASYMMETRIC INFORMATION

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ESSAYS ON ASYMMETRIC INFORMATION

My dissertation analyzes the credible communication of seller information to buyers. My first essay, "New and Improved?", considers firms' incentives to introduce new product versions and the corresponding beliefs of consumers about such products' quality when they have no direct information about the product other than it is new. I find that consumers rationally deduce new product versions are on average better and so pay a pricing premium, in turn leading some firms to exploit the new product signal by selling new versions that are only trivially different from their older version or that require inefficiently high upgrade costs. Notwithstanding this, I show that some "new product signaling" can increase welfare by counteracting Arrow's underinvestment problem. The second essay, "Physician Overtreatment and Undertreatment with Partial Delegation", considers strategic communication from doctors selling medical services to patients. We find that communication problems stemming from misaligned incentives lead the patient to being overtreated for some health states and undertreated in others. Stronger financial incentives for doctors lead to more exaggeration and hence more skepticism, thereby leading to even more exaggeration as the doctor tries to persuade the patient to accept treatment. Insurance makes patients worry less about paying for overtreatment, thereby reducing the need for doctors to exaggerate, and making each side better off by reducing miscommunication. We also resolve an open question in the partial delegation literature by showing that the equilibrium we examine is the most informative equilibrium.

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Introduction

The existence of asymmetric information can have a profound impact on market outcomes, even leading to market failure, due to the less informed party to a transaction fearing opportunism on the part of the more informed party. The fear of adverse selection is known to hamper many large and important markets, including insurance, annuities, bank lending, and equity issuances, inter alia. Many of these same markets suffer from moral hazard problems as well when the more informed party takes an unobserved action, to the detriment of the other party. Both of these problems stemming from asymmetric information have been cited as playing a major role in the problems with subprime mortgages which in part led to the 2007–08 financial panic (Ashcraft and Scheurmann, 2008).

In my dissertation, I explore applications in which the more informed party to a transaction sends a message, from which the uninformed party must draw inference and take an action. In my first chapter I consider the incentives of firms to invest in improving their existing products when consumers aren't initially able to determine the incremental value of a "new and improved" product. Knowing they have an information advantage, firms must first decide how much research and development (R&D) effort to take and then which outcomes from its random R&D process are sufficiently valuable to merit inclusion in the product. I label these two choices as the ex-ante and ex-post investment decisions, respectively.

In the ex-post decision, a firm with a known distribution of R&D outcomes privately observes the value of the innovation it has developed and must decide whether or not to adopt it. If it does adopt, it sells a "new and improved" version of its product to consumers who cannot immediately determine how improved the product is. It is assumed to be costly to introduce a new product version, and such costs can be avoided by censoring the newly discovered innovation from the market and instead selling the old version of the product to consumers who are informed of its value. In equilibrium, the firm uses a threshold strategy whereby it adopts all sufficiently valuable innovations and rejects otherwise. Inferring this threshold, consumers correctly deduce that new products are improved on average so that they command a pricing premium.

In determining the firm's adoption threshold I show that the informational asymmetry between firm and consumer regarding the quality of new product versions will lead to a hidden type problem akin to adverse selection: firms that discover relatively marginal improvements may nonetheless adopt them and charge a pricing premium that consumers will ultimately learn is too high. In fact, firms may even introduce trivial or *harmful* product "improvements," or incur inefficiently high upgrade costs to sell a new version. This occurs because consumers form a pooled expectation over all types that sell a new version, implying low types have more incentive to adopt their innovation than under full information. That is, new product versions may be introduced to imperfectly informed consumers even though they would be unprofitable if introduced to fully informed consumers. In this sense the desire to show off quality through "new product signaling" gives firms an extra ex-post incentive to adopt innovations. It should be noted that in equilibrium consumers' beliefs about a new version's quality are consistent with the firm's adoption threshold so that on average their positive inferences about new products are correct. New versions are on average improved because of two forces that limit the hidden type problem: the up-front costs incurred to introduce a new product version and the fact that consumers eventually learn the product's quality and so an unwarranted new product premium will only be enjoyed temporarily.

Interestingly, I show that the seemingly excessive introduction of new versions may actually increase welfare if there are existing market inefficiencies that reduce ex-post investment. For example, in a full information monopoly setting Arrow (1959) showed that a firm will underinvest in product development because its private benefit from doing so is less than the social benefit. *Arrow's underinvestment problem*, as it is called, shows up in the new product introduction game when, ex-post, the firm does not adopt an innovation even when total surplus would rise if it did so. I show that this ex-post Arrow problem always exists under full information, but will be mitigated when consumers are not initially fully informed due to the new product signaling effect. Thus from the Arrow effect we expect less ex-post investment, while from the new product signaling effect we expect more. The net effect of these offsetting forces is ambiguous, but I show that if the introduction of a new product is expensive relative to the distribution of R&D outcomes, welfare will be higher under imperfect than full information. Otherwise, the new product signaling effect is too strong in that it induces excessive investment that reduces welfare.

The firm also makes an ex-ante investment decision in which it decides how much effort to put into research and development, where it is assumed that more effort leads to a better distribution of outcomes. Each effort level induces a distribution of outcomes and therefore an adoption threshold for the firm's ex-post investment decision. I show that under full information the Arrow underinvestment problem exists in an ex-ante sense as well, and that in general the effect of asymmetric information on mitigating or exacerbating this problem is ambiguous. Greater effort induces a better distribution of outcomes which tends to increase profits, but this in turn induces the (ex-post) equilibrium threshold in the subgame to fall, which I show tends to decrease expected profits. In the end, the curvature of the distribution of R&D outcomes and consumers' valuations for the product, as well as the cost of R&D effort will all determine how new product signaling effects ex-ante investment incentives. An example is provided in which both ex-ante and ex-post investment decisions are more closely aligned to that of the social planner under imperfect than full information so that expected welfare is higher when consumers are initially uninformed than if they were informed.

Throughout the chapter I verify the robustness of the model presented by showing qualitatively similar results hold for alternative model specifications. For example, in an extension I show that if consumers learn about quality through a noisy, consumption-based process then the equilibrium characterization is much the same as when they perfectly learn quality, but that the firm's adoption threshold will be lower so that more minor improvements are made. In fact, if the noise term in consumers' learning process and the firm's R&D outcomes are independent and normally distributed then the threshold rises as the variance of the noise term declines. Intuitively, the more accurate is consumer learning the less tolerance there can be for trivial improvements. I also show that an alternative one-period model can be specified in which some consumers will always be informed of product quality while others never are, is equivalent to the two-period model I present. Finally, I show that the new product signal has value even if a firm can revert to its old product version once its new version's quality has been discovered, as long as reversion is costly.

In the second chapter of my dissertation I analyze communication between a doctor and patient. This topic has received much attention because of the disparities in information and incentives that often exist between the two: doctors are usually better informed about the appropriateness of tests and treatments than are their patients and they often financially gain from offering these treatments. While there is much evidence that patients are often overtreated for medical conditions in the United States, there is a small but growing literature on patient undertreatment stemming from a lack of trust in healthcare providers. Each of these suggests a strong role of misaligned incentives and asymmetric information.

I model the situation as follows. The doctor can learn the patient's "health state" (degree of illness), while the patient only knows the distribution of states. The patient would like to be appropriately treated for his condition, and more severe illnesses require higher (more intensive) treatment, though the patient does take into account the cost of treatment. The doctor has regard for patient well-being but also derives utility from the profits earned by providing treatment, where it is assumed more intensive treatment leads to greater profits. Because the patient is aware of the doctor's incentive to exaggerate the need for treatment, he will not naively follow the doctor's advice and instead may avail himself of his outside option. Initially I model the patient's outside option to be no treatment at all, but later examine an extension in which he may seek a second opinion from a different doctor. The modeling approach here is distinct from cheap talk because the patient's set of available actions is restricted by the doctor's message (partial delegation); i.e., the patient can either accept or reject the doctor's proposed treatment but cannot prescribe to himself any treatment he wishes.

I characterize the equilibrium of this game by finding the treatment recommendations made by the doctor as a function of the true state and the patient's acceptance or rejection of treatment as a function of the recommendation he receives. I find that for relatively severe health states, the doctor will recommend his own most preferred treatment; while the patient will be able to infer the true health state is lower, his only alternative is to reject treatment entirely. He is unwilling to do so because the resulting under-treatment would be too severe. For relatively modest illnesses the doctor severely exaggerates a recommendation pooled over a large enough interval of states that the patient's posterior beliefs are sufficiently high to induce acceptance. Interestingly, the level of treatment here is higher than what even the doctor would prefer. Thus the patient is severely over-treated for such health states. Finally, the doctor recommends a pooled message for relatively low states in order to forestall rejection, which becomes an increasingly reasonable option for lower health states. Some states are undertreated in this case. In sum, I find that some illnesses are overtreated and others undertreated, but that overtreatment exists *on average*. One contribution of the equilibrium characterization is that it generalizes previous models of partial delegation (Krishna and Morgan, 2001) and finds the most informative equilibrium that satisfies the intuitive criterion.

The findings of both over- and undertreatment in a unified model with pure strategy equilibria is novel and represents a contribution to the reigning "physician induced demand" (PID) literature. This literature recognizes the information advantage physicians have over their patients and posits that doctors can induce any level of demand they wish through their treatment recommendations. One limitation of this approach is that it does not explicitly model the patient's decision making but rather assumes the patient naively follows the doctor's advice. Not surprisingly, the PID literature finds that patients are overtreated on average because they are overtreated for each illness. While such a model can easily explain empirical observations of average overtreatment, it cannot explain the existence of undertreatment. The model I present therefore complements the PID literature by providing an information transmission mechanism that can explain both overtreatment on average and the existence of some undertreatment.

Independently of losses patients incur by receiving too much average treatment, I show the average medical appropriateness of treatment declines (from either over- or undertreatment) due to the doctor's bias and patient's resulting skepticism. I find that the decline in the average appropriateness of treatment is non-trivial; indeed, its effect on welfare losses may be greater than the average overtreatment effect. I next explore how the existence of insurance can mitigate the consequences of asymmetric information between doctor and patient by introducing a moral hazard problem between the patient and insurer. Consider an insurance contract in which the patient can choose a coinsurance rate (the proportion of health expenditures for which the patient is responsible), and a competitive insurance industry that will offer this contract at its expected cost. Buying such insurance reduces the patient's ex-post cost of treatment, since the insurer pays for some portion of health expenditures. The patient is therefore more willing to undergo treatment for any health state since he is partially insulated from the marginal cost of doing so. This is the familiar ex-post moral hazard problem of health insurance. While insurers anticipate this problem and price policies accordingly, in the present context the patient's willingness to undergo more treatment implies the divergence in incentives between him and the doctor is mitigated and therefore communication is improved. In fact, I find that when health states are uniformly distributed the average level of treatment remains constant with respect to the coinsurance rate while the variance in treatment (relative to first-best) declines. Thus insurance is purely welfare improving.

Finally, it is shown that the model is robust to extensions such as the existence of naive patients and the ability of the patient to seek second opinions. If some patients are naive to the doctor's bias and thus accept all treatment recommendations, I show there will be no qualitative differences as long as such patients make up a sufficiently small proportion of the population. If this proportion is too large, though, the model reduces to classic PID in which the doctor always recommends his own most preferred treatment. I also show that if patients can seek a second opinion but incur a positive search cost to do so then the main equilibrium characterization of the paper applies in which no patient seeks a second opinion for fear of a hold-up problem by the second doctor.

In conclusion, my dissertation consists of two chapters in which asymmetric information is shown to greatly change market outcomes from their full information counterparts. In general, asymmetric information makes difficult one party communicating effectively to the other, who is rightly suspicious of being manipulated. Such cases usually result in welfare losses when compared to the first-best outcome. Interestingly, in each chapter I show such inefficiencies can be offset by other inefficiencies: Arrow's underinvestment problem (a monopoly distortion) can be offset by the new product signaling effect that arises from asymmetric information, and health insurance that induces a moral hazard and thus more closely aligns doctor and patient incentives can improve communication.

Chapter 1: New and Improved?

Eric Schmidbauer

Abstract

Are new versions of products necessarily better? We analyze product innovation by a firm that engages in research and development designed to improve an existing product, the outcome of which is uncertain. If the firm adopts the innovation its modified product appears to consumers as "new and improved," but consumers do not immediately know whether or how much the product is better. We find that new products are on average improved and therefore command a pricing premium. This induces some types to exploit the new product signal by selling new versions that are only trivially different from their older version or that require inefficiently high upgrade costs. Nevertheless, the incentive to "show off" by introducing a new product may improve total welfare by inducing more innovation adoption and thereby mitigating the standard monopoly underinvestment problem. Innovation signaling provides a rational explanation for consumer attraction to new versions of products without resort to behavioral assumptions such as a preference for "newness".

Keywords: Asymmetric information, Signaling, Innovation

JEL Classification: D82, O31

1 Introduction

How do consumers update their beliefs about a "new" or "improved" version of a product before purchase? For example, how much better will a computer perform with the newer Intel Core 2 chip than its predecessor? Should a consumer who is told "roads change by as much as 15% every year" purchase an updated map for her GPS device? Or suppose a familiar household cleanser's packaging states "WOW! Powerful New Formula," but its price has increased by 10%. Is the touted improvement in performance worth the higher price?

In each of these examples consumers are likely unaware of the exact value offered by the "new" or "improved" version of the product. This is consequential when viewed against the backdrop of the thousands of new products that are introduced every year. Whereas some of these products represent real technological breakthroughs, most are incremental improvements (Olsen, 2006). The challenge for consumers is discerning the exceptional improvements from the mundane before making a purchase decision. This often proves difficult because consumers are confronted with "...a plethora of choice, a surge of marketing communications, decreasing inter-brand differences, [and] increasing complexity of information" (Walsh, et al., 2007). Given their uncertain nature, perhaps then consumers shun new products as being inherently incomprehensible and overly risky. To the contrary, the psychology, marketing, and economics literature have documented theoretical and empirical findings of consumer *attraction* to new products.

Early studies by psychologists such as McClelland (1955) and Fiske and Maddi (1961) find such attraction while Rogers (1962) explains it via his notion of venturesomeness. Consumer behavior researchers in marketing have identified the closely related constructs of "inherent novelty seeking" and "inherent innovativeness" (Midgley and Dowling, 1978; Hirschman, 1980; Foxall, 1988), the former being "the desire of the individual to seek out novel stimuli," the latter "the predisposition to acquire new products" (Hirschman, 1984). A recent empirical article on the U.S. golf driver market quantifies this predisposition by finding that "newness" alone induces a 25% higher willingness to pay, where newness is defined as the most recent model available within a brand (Lee, 2012).

While recognizing the contribution of the marketing and psychology fields in exploring consumers' apparent preference for new products, we propose an alternative signaling model that does not require an inherent preference for newness. Making their purchase decisions under imperfect information, consumers form beliefs about new products' quality consistent with firms' new product launch strategies. We find a "newness premium" that results from the information conveyed in equilibrium by the very existence of the new product version.

In order to understand consumers' beliefs about new product versions we must first understand firms' incentives to introduce such products. Firms prefer enhancements that make their products as appealing to end-users as possible. However, easy opportunities for improvement have likely already been exploited, while technological, physical, and cost constraints limit what is feasible. Though the firm may devote significant resources to research and development, the outcome of such efforts is highly volatile and often times results in failure (Stevens and Burley, 1997). The firm might develop anything from a truly remarkable breakthrough to a mundane marginal improvement whose value does not justify the upgrade costs. In any event, the firm must decide which research outcomes to implement and which to censor from the market, knowing that some consumers may not be willing or able to become immediately informed of the new product's value.

In our model a monopolist receives a random outcome from its R&D process and must decide whether to adopt this innovation or not. The firm knows the true value of the innovation while consumers initially only observe the binary signal of whether or not the product has been modified. Consumers form beliefs about product value and buy (or not) accordingly, and then learn from product trial and other sources so that they are more informed in the second period when they repeat their purchase decision. Our main result is that while the average quality of a modified product is higher in equilibrium, the firm sometimes makes inefficient upgrades that only marginally improve the product. In making such a modification firms face a trade-off between inducing an initial "new product" premium and the loss of future sales when the true quality is revealed.

That the firm might incur upgrade costs to sell a new product version only trivially different from the old may appear to unambiguously lower welfare. Indeed, we find that if the innovation signal is relatively strong and the firm's upgrade costs relatively low that socially inefficient upgrades will be made. However, a stronger incentive to signal may result in a net gain to welfare by offsetting previously existing distortions. It is well known that under full information a monopolist has less marginal incentive to make costly upgrades than does the social planner due to the firm's inability to appropriate all of the benefits of the innovation (Arrow, 1959). In the present context, a firm may reject a product innovation whose upgrade expense is justified by the increase in welfare but not profits. By providing an additional incentive to make a product upgrade, the innovation signal alleviates Arrow's underinvestment problem and so may increase welfare.

A contribution of this article is the development of a rational model explaining consumers' reliance upon "new and improved" labels as a signal of product quality. Thus we explain an empirically common marketing practice without invoking consumers' cognitive biases or inherent preference for "newness." Interestingly, consumers rationally infer higher quality from new products notwithstanding their knowledge that the firm sometimes knowingly makes trivial or even inefficient product modifications. As a further contribution we show innovation signaling can increase welfare by alleviating the monopoly underinvestment problem through incentivizing investment in socially beneficial product upgrades that otherwise would not be made. In addition to robustness checks we also establish a sufficient condition under which the firm prefers to ex-ante commit to sell only those new versions it would sell to fully informed consumers.

1.1 Relation to prior literature

We model a situation close to that of Milgrom and Roberts (1986), who themselves formalized ideas proposed by Nelson (1970 and 1974). In their model, a monopolist has private information about its exogenously determined product quality and must choose price and dissipative advertising expenditures that induce beliefs among consumers who are uninformed in the first period but informed thereafter. As Milgrom and Roberts describe it, theirs is a model "...in which the firm's R&D effort has generated a product of some particular given quality that the firm must decide how to introduce." We instead consider the antecedent question of *whether* such a product should be introduced at all. In our context, an extant product undergoes R&D designed to improve it, though the random outcome of this process may result in a trivially different product. While keeping other relevant variables fixed we focus attention on the firm's censoring decision: will the firm incur upgrade costs to introduce the new version of the product or not? Ultimately which types do so will determine the signaling value of a "new and improved" product version.

The Milgrom and Roberts result has many variants and extensions applied to monopoly (Kihlstrom and Riordan, 1984; Wilson, 1985; Horstmann and MacDonald, 1994; Daughety and Reinganum, 1995), duopoly (Fluet and Garella, 2002; Yehezkel, 2008) and oligopoly (Janssen and Roy, 2010). Price signaling can even occur in a one-period model when some proportion of consumers is informed about product quality (Bagwell and Riordan, 1991; Linnemer, 2002). The common thread among each of these models is a firm choosing marketing variables such as price or advertising to signal its exogenous quality. We instead consider the decision to adopt or reject an exogenously determined R&D outcome as itself a marketing decision capable of signaling product quality. Because every "new and improved" product is the output of a random R&D process that has survived the firm's censoring rule, the existence of the new product version may serve as a signal of improved quality.

To a limited extent then, our firm has some control over its product's quality. However, our model differs from the endogenous quality literature that focuses on the moral hazard problem of the firm. In that literature stream, it is assumed the firm derives a cost benefit from supplying a low-quality product while purporting it is of high-quality. Consequently, a firm with both high quality and cost may suffer from consumer wariness of being cheated and thus a corresponding low willingness to pay.[1]

[1] Various mechanisms have been proposed to ameliorate this problem, including reputation or offering a brand name as collateral (Spence, 1977; Klein and Leffler, 1981; Allen, 1984; Wernerfelt, 1988), price signaling (Wolinsky, 1983) as well as risk-sharing devices such as warranties (Grossman, 1981) and money-back guarantees (Mann and Wissink, 1988). Biglaiser (1993) models middlemen as quality guarantors while Miklos-Thal and Schumacher (2013) examine the role of third-party monitors.

Our basic model differs from such models in two main respects. First, our firm's quality "choice" is limited to accepting or rejecting a random R&D outcome, not a deterministic choice as in endogenous quality models. Second, we have no difference in production costs between types, a crucial component of endogenous quality models. In our extended model we endogenize the R&D distribution but do so through an ex-ante investment that is publicly observable and therefore not subject to moral hazard.

We focus on innovation signaling as a particular way to transmit private information from sellers to buyers, though many other mechanisms exist. Daughety and Reinganum (2008) model the choice between costly disclosure and signaling of product quality while Lizzeri (1999) explores the strategic revelation of information by certification intermediaries. In Chakraborty, Gupta and Harbaugh (2006) a seller can credibly rank the quality of different goods and in Cai, Riley and Ye (2007) a seller in an auction may signal quality through her selection of the reserve price. As in these papers we focus on quality as a vertical attribute, though sellers may also want to communicate information about horizontal attributes that affect the match value to buyers (Anderson and Renault, 2006; Armstrong, Vickers and Zhou, 2009; Anand and Shachar, 2011).

Finally, our finding that a firm may introduce a "new" version only trivially different from the old relates to prior work in which the firm degrades or otherwise denies the consumer the full value of its product. For example, Denekere and McAfee (1996) showed that firms may "crimp" their products– degrade the performance of a product and sell both the high and low quality versions– for the purpose of price discrimination between segments of consumers with different valuations for a good. Monopolists often times engage in "planned obsolescence" whereby they produce goods with uneconomically short useful lives, forcing customers to make otherwise unnecessary repeat purchases (Bulow, 1986). And in some instances firms may withhold superior-performing but lower-margin products until competitive pressures force them to introduce the product.

1.2 Imperfectly informed consumers

It should be no wonder that consumers are imperfectly informed about a product's value. The shear number of new products a consumer might confront in a given year is mind-boggling. By one estimate, approximately 30,000 new consumer products are launched annually and 80 to 95% of these end up as failures.[2] Some of these products are completely new in that they serve a market that did not previously exist, while others are enhancements of extant products. Firms engage in such innovation in order to enhance product effectiveness and appeal to consumers, as well as maintain a competitive advantage over rivals. It is for this reason that Sun Microsystems' CEO Jonathan Schwartz calls innovation "the key to survival"[3] while former Proctor and Gamble CEO A.G. Lafley asserts that innovation is "...the real source of sustainable competitive advantage and the most reliable engine of sustainable growth".[4] However, the value of such new innovations is often unclear to consumers, who face "...a plethora of choice, a surge of marketing communications, decreasing inter-brand differences, [and] increasing complexity of information" that often leads to consumer confusion (Walsh, Hennig-Thurau and Mitchell 2007).

[2] Nobel, C. (Feb 14, 2011). "Clay Christensen's milkshake marketing." *Research & Ideas*. Harvard Business School: Working Knowledge. Gourville, J. (June 2006). "Eager sellers stony buyers: understanding the psychology of new-product adoption." *Harvard Business Review*, 99–106.

[3] Schwartz, J (2006, Sept 12), "The five founding principles that drive innovation." *The Financial Times*.

[4] Lafley, A.G. and R. Charan (2008). *The Game-Changer: How You Can Drive Revenue and Profit Growth with Innovation*. New York: Crown Business.

Further confounding matters is the fact that not all product modifications improve performance. A firm may add an attribute to its product that is trivial, which is generally defined in the marketing literature as an attribute "that *appears* valuable but, on closer examination, is irrelevant to creating the implied benefit" (Carpenter, Glazer and Nakamoto 1994). For instance, one may wonder if a shampoo with provitamin ingredients such as Pantene Pro-V promotes healthy hair more than a similar product without such ingredients. It will not, according to *Consumer Reports*.[5] In its tests the consumer advocacy group found that vitamins and provitamins have no beneficial effect on hair, which after all consists of dead cells. Consider also the presence of "T25 breath fresheners" in the mouthwash Scope. A little research reveals that T25 is merely a trademark for antiseptic agents long contained in the product.[6] Finally, consider Proctor & Gamble's instant Folgers coffee brand which contain "flaked coffee crystals" that are created through a "unique, patented process." Such crystals do not provide for a more flavorful cup of coffee because the shape of the coffee particle is relevant for ground but not instant coffee (Carpenter, Glazer, and Nakamoto 1994).

Less intuitive and perhaps more rare are harmful product modifications. The German language has a word for such a concept: *schlimmbesserung*, meaning an improvement that makes things worse (Rheingold, 2000). As an example, consider the megapixel specification of a digital camera. Product review website CNET.com wrote in its 2010 "Digital Camera Buying Guide"[7]:

> Most digital cameras these days have sufficiently high resolution that

[5] *Consumer Reports* (2000). "Head games: some shampoo claims are just a lot of lather." 65(9), 18–21.

[6] United States Patent and Trademark Office (2011). T25 trademark owned by Proctor & Gamble Co., http://tarr.uspto.gov/servlet/tarr?regser=serial&entry=72190111 Accessed November 21, 2011.

[7] CNET.com (2010). "Digital camera buying guide. How many megapixels should my digital camera have?" http://reviews.cnet.com/2719-7603_7-268-2.html?tag=page;page Accessed Nov 21, 2011.

> you don't need to worry about too few pixels. You may need to worry about *too many*, however, since the resulting larger file sizes can result in slower shooting for point-and-shoot models. Given how much confusion there *still* is about this, it bears stating explicitly: **More megapixels does not necessarily mean better photo quality**...Just because last year's model had a 12-megapixel sensor and this year's replacement has a 14-megapixel sensor doesn't mean that the new one will shoot better photos than the old. In point-and-shoot cameras, manufacturers increase resolution for marketing and cost reasons, rarely for quality reasons.

For this reason CNET.com advises only the "serious amateur" who requires "professional level control" and expects to create prints "that are 8x10 inches or larger on a high-quality photo printer" to purchase a camera with 12 megapixels or higher. For all other consumers, the resolution of the camera "doesn't matter" for photo quality. Thus most non-professional users will find the performance of a camera degraded from higher resolution because the larger file sizes cause slower shooting and leave room for fewer pictures on a memory card. As is made clear from CNET's review, however, many consumers in this market appear to be unaware of this.

As another example consider Alberto Natural Silk Shampoo. The product includes silk in the shampoo and was (truthfully) advertised with "We put silk in a bottle," implying to consumers that their hair will become silky upon use. However, this advertising campaign contrasts with the admission by a company spokesman that silk "doesn't really do anything for hair".[8] If silk is added to a shampoo bottle of fixed volume then it displaces some of the non-silk product. Ceteris paribus, the consumer

[8] *Adweek.* (1986, May 19). "Silk in a Bottle." p.18.

is slightly worse off.

The legal basis for practices such as these is murky. In general, deceptive advertising or making fraudulent claims about a product is prohibited[9], but firms also enjoy broad leeway in "puffing" their products to make a sale.[10] In any event, we will be examining the existence of a new product as itself a signal of quality and regarding any specific communication by the firm about its quality as not credible (*pace* Chakraborty and Harbaugh, 2010).

1.3 Costly information acquisition

Consumers are not helpless when confronted with a purchase decision under uncertainty. Numerous outlets are available through which consumers can search for product information, including word-of-mouth communication, consumer review websites, and published materials such as *Consumer Reports.* Hawkins and Mothersbaugh (2010) distinguish search as being internal or external. Internal search consists of using relevant information from memory to solve a problem while external search is the process of seeking information outside of the consumer such as marketing materials, opinions of friends and strangers, professional product reviews, and direct experiences through product inspection and trial. External search occurs when internal search is insufficient, in which case the consumer can be said to be imperfectly informed.

Although many sources of external information are available to the consumer, the marketing literature is clear in its conclusion that "[m]ost purchases are a result of

[9]E.g., Indiana Code S24-5-0.5.1 forbids deceptive practices while S24-5-0.5-3 and S35-43-5-3 prohibit false and fraudulent advertisements.

[10]In Better Living, Inc. et al., 54 F.T.C. 648 (1957), aff'd, 259 F.2d 271 (3rd Cir. 1958), the Federal Trade Commission defined puffery as a "term frequently used to denote the exaggerations reasonably to be expected of a seller as to the degree of quality of his product, the truth or falsity of which cannot be precisely determined."

nominal or limited decision making and therefore involve limited external search immediately prior to purchase," while even for major purchases "... external information search is skewed toward limited search, with the greatest proportion of consumers performing little external search immediately prior to purchase" (Hawkins and Mothersbaugh, 2010).[11] Claxton, Fry, and Portis (1974) concur: "prepurchase search is a relatively limited activity, even in the case of major durables."

There are many plausible explanations for this. First, the information simply may not be available to a consumer. *Consumer Reports*, for example, does not review new variants of chewing gum. Second, even if reliable information regarding product quality exists, it may be too costly to obtain or its acquisition may not confer much benefit (Stigler, 1961). Here cost includes both monetary costs such as the subscription fee to review website *Angie's List* and non-monetary expenses such as physical and psychological effort. Benefits may arise from a lower price, a higher quality, a preferred style, or reduced perceived risk (Hawkins and Mothersbaugh, 2010). Third, psychological reasons such as the degree of involvement with a product category, the perceived risk of the purchase, and the amount of mental energy a consumer has available may explain why some consumers do not obtain prepurchase quality information. Finally, firms may hinder consumer acquisition of information and obscure product characteristics as a means of achieving oligopoly pricing power in an otherwise competitive market (Scitovsky, 1950; Kalayci and Potters, 2011).

Consumers may also encounter product information through non-search processes such as advertising, unsolicited word-of-mouth, media buzz, and their own subject

[11] Hawkins and Mothersbaugh (2010, p.532) cite eight studies spanning 50 years, two product categories, four services, and two countries that show "remarkable consistency" in terms of the limited amount of external information search that consumers perform.

matter expertise. In such instances the consumer does not actively seek product information but may nonetheless acquire it through his usual day-to-day actions. We assume that such information does not arise or is of trivial importance. This assumption is clearly more reasonable for some products than others: while the introduction of Apple Inc.'s iPhone 5 was met with wide public chatter and media anticipation, Colgate's latest iteration of toothpaste with a "burst of freshness" did not garner such a response.

For all the reasons given here we assume that consumers are initially unwilling or unable to determine the increase in value of a new product. Over time, consumers learn the level of quality through various sources including their personal consumption experience.

1.4 New product development

The censoring decision the firm makes in our model is a common one within any firm that undertakes R&D effort to develop or improve a product. However, because these decisions occur internal to the firm they are often obscured from external observation. To get an estimate of how many failures are culled within the firm, Stevens and Burley (1997) collected data on patent activity, project activity in large companies, venture capitalist activity, and independent inventor activity. They divide the product development process into seven stages:

> [I]t takes about 3,000 raw ideas (Stage 1) to come up with 300 ideas on which the idea generator is willing to take minimal action, such as performing a few simple experiments, filing a patent disclosure or discussing them with management (Stage 2)....Approximately 125 of the 300 ideas in Stage

> 2 advance to Stage 3 to become a small project, usually having a high probability of receiving a patent (if applicable). Approximately nine projects survive to Stage 4 and develop into significant projects (large development efforts). Four of these advance to Stage 5 to become major development efforts. Of the four major developments, approximately 1.7 are commercially launched (Stage 6). Of 1.7 projects commercially launched, on average only one (59 percent) is typically commercially successful (Stage 7).

As these data demonstrate, firms frequently censor ideas or products they ultimately determine will not be commercial successes. Such endogenous censoring is a key component of our model and serves as the basis from which consumers form their beliefs about a new product version's quality. Note we assume firms know the value of their product improvement so that the costly decision to introduce a new version may signal quality. For modeling simplicity we assume the firm perfectly observes the value of its improvement, thus abstracting from the uncertainty firms often have over the demand they face (Stage 7).

The rest of the article proceeds as follows. Section 2 explains our assumptions and introduces our base model in which consumers perfectly learn from their consumption experience. In Section 3 we establish the existence of equilibria while in Section 4 we discuss welfare results. In Section 5 we allow for an ex-ante investment stage in which the firm can influence its distribution of R&D outcomes. Section 6 extends the model to the case of imperfect, "noisy" consumer learning about product quality. We then conclude and discuss areas for future research.

2 Model

Consumers indexed by i have unit demand for a monopolist's product in each of two periods and i.i.d. heterogeneous valuations v_i with continuous density g and distribution function G with full support on some interval $[0, \overline{v}]$ for $\overline{v} \in (0, \infty]$. The firm has no marginal or fixed costs of production but can add an attribute or otherwise modify its product for a one-time fixed cost of M (and no additional marginal cost) by accepting the realization a of its research and development random variable A. Hence the firm's innovation signal is binary: either it sells a new version or not. A is continuous with full support[12] on $(\underline{a}, \overline{a}) \subseteq \mathbb{R}$ and has exogenous density f and distribution F which is log-concave. Both f and g are common knowledge. In a subsequent section we endogenize the distribution of A by allowing the firm to choose R&D effort level. We assume $\overline{a}$ is high enough that such a type will always add its attribute and that $\underline{a} \leq -\overline{v}$. As will be made clear in our formulation of the consumer's utility function, this latter condition allows for the possibility of a *harmful* R&D outcome.[13]

The exogenous investment cost M can be thought of as the cost to alter production facilities or product rollout costs such as marketing expenditures; we assume it is independent of the realization of A. Potential consumers know the distribution of A but not its realization, and there is no credible direct way the firm can provide this information. For simplicity we assume A is a common value attribute and first period

[12] It suffices to have $\Pr[A > 0] > 0$ and $\Pr[A < 0] > 0$ to establish the propositions that follow. In particular, a mass point at 0 can be accommodated.

[13] In reality we infrequently observe outcomes $a < 0$ because they do not survive the firm's internal censoring rule. This is one interpretation of Stevens and Burley's (1997) findings that the vast majority of R&D projects are ultimately abandoned. Requiring further that $\underline{a} \leq -\overline{v}$ simplifies the presentation of the results.

consumers buy if and only if

$$E[U_i] = v_i + E_\mu[A] - p \geq 0, \tag{1}$$

where p is the price charged and $E_\mu[A]$ is consumers' expectation of A given their beliefs μ. Thus the addition of an attribute does not change the dispersion of the distribution of consumers' valuations and so results in a shift in demand.[14] We initially assume all consumers learn the realization of A at the end of the first period, through either their own perfectly informative consumption experience, word-of-mouth communications, or product review websites.[15,16] Therefore second period consumers are fully informed and buy if and only if

$$U_i = v_i + a - p(a) \geq 0. \tag{2}$$

As an extension in Section 6 we specify learning from consumption as an imperfect, noisy process in which second period consumers Bayesian update their beliefs after observing the sum $a + \epsilon$, where ϵ is a mean zero error term.

Utility maximization gives rise to the function $q(E_\mu[A], p) = 1 - G(p - E_\mu[A])$, which represents the proportion of consumers that buy each period at price p given their posterior expectation $E_\mu[A]$. Note that first period consumers know their valuation of an unmodified product and in this case we use $a = 0$ in the equations above. Thus all consumers begin the game informed and become uninformed only if the firm introduces

[14] Hence we do not analyze rotations in demand (Johnson and Myatt, 2006).

[15] Thus there is no role for strategic buying to acquire information. See Grossman, Kihlstrom and Mirman (1977) for treatment of this subject.

[16] Just as price and advertising may signal quality in a one-period setting in which some consumers are informed (Bagwell and Riordan, 1991; Linnemer, 2002), so too can the innovation signal, as shown in the Appendix in which the role of second period informed consumers is replaced with a proportion of first period consumers informed of the firm's R&D outcome. The current model allows innovation signaling to be analyzed separately from price signaling.

a new version of its product. This feature of the model differs from many other signaling games and simplifies its structure. We also initially assume the firm must commit to selling the same (old or new) product in both periods, but later allow for the firm to sell a "new and improved" product in period 1 and revert to its old product in period 2 at a fixed cost of $R \geq 0$.

Our equilibrium concept is perfect Bayesian equilibrium subject to a restriction on off-the-equilibrium-path beliefs explained below. In general consumers can form beliefs about the firm's type given its decision to sell a new or old product and its price. However, by construction in our case there is no means by which price can serve as a signal: there are no cost differences across types nor do benefits vary by the assumption that *all* consumers learn each firm's type at the end of the first period.[17] We can therefore reasonably expect consumer beliefs to be invariant to price and thus assume that off the equilibrium path consumers do not update their beliefs about firm type based on price.

3 Results

We show that a firm's binary decision to implement an R&D outcome or not involves a simple trade-off between inducing a "new product" premium in the first period by paying up-front modification costs M and selling to consumers who will be fully informed of the product's value in the second period. For a low enough type a, the modification costs and potential decline in second period profits exceed the benefits conferred by

[17] As discussed in Banks and Sobel (1987), without such type-dependent payoff differences standard forward-induction refinements do not apply. In Milgrom and Roberts (1986) price (and advertising) may signal exogenously determined product quality because of their requirement that consumers purchase the product in order to learn its type.

the new product premium and thus the firm censors its R&D outcome. Though uninformed, first period consumers place a demand premium on new products because they know the firm needs to earn profits from informed consumers in period 2 in order to recoup the modification cost M.

When consumers have expectation $E_{\mu}[A]$, let $\pi(E_{\mu}[A]) = \max_p \{p \cdot q(E_{\mu}[A], p)\}$ and $p_{E_{\mu}[A]} = \arg\max_p \pi(E_{\mu}[A])$ be the maximum profits attainable and the profit maximizing price, respectively, and let δ be the discount factor between periods. The following proposition shows that a unique partially separating equilibrium exists if

$$\pi(E[A]) - M \leq (1 + \delta)\ \pi(0), \tag{3}$$

while a unique pooling equilibrium exists otherwise. Intuitively, equation 3 says that the firm prefers consumers buy its old product in both periods over selling only in period 1 to consumers with beliefs equal to the unconditional mean of A. That is, in order for a partially separating equilibrium to exist low enough types must be deterred from selling a new product by the prospect of losing sufficient sales in the second period.

Proposition 1 *In the unique equilibrium there exists a threshold c^* such that the firm modifies its product whenever $a > c^*$ and otherwise does not. In period 1 all "new and improved" types charge the same high price $p^H = p_{E[A|A>c^*]}$ while all unmodified types charge the low price $p^L = p_0$. In period 2 each type charges its full information monopoly price. When condition 3 holds the equilibrium is partially separating and otherwise $c^* = \underline{a}$ so that all types sell a new product.*

Proof The firm uses a threshold strategy because higher types always have more incentive to sell a new version for any given beliefs. For the same reason an equilibrium involving mixed strategies cannot exist. Consider a candidate equilibrium in which there is a threshold type-c firm which should be indifferent to selling a new version or not. By backwards induction it receives a discounted payoff of $\delta\ \pi(c)$ in period 2. In period 1 any modifying type will price pool on $p^H = p_{E[A|A>c]}$ provided off-the-equilibrium-path beliefs following an unexpected price are not greater than $E\,[A \mid A > c]$, a condition satisfied because prices do not affect beliefs.

Let the gains and losses to the threshold type-c firm from modifying its product be $G(c)$ and $L(c)$, respectively. A gain is derived from first period consumers who are uninformed and is the increase in payoffs from selling the new version instead of the old: $G(c) = \pi(E\,[A \mid A > c]) - \pi(0)$. The loss is the cost M to modify the product plus the discounted decline in profits, if any, from second period informed consumers: $L(c) = M + \delta\ [\pi(0) - \pi(c)]$.

Note that G is continuous and monotonically increasing in c while L is continuous and monotonically decreasing in c. By the assumption that $\overline{a}$ is high enough that type $a = \overline{a}$ will always modify its product, we conclude that $G(c) > L(c)$ for high enough c and thus $G(c)$ and $L(c)$ either cross at a unique point or not at all. Equation 3 is the necessary and sufficient condition for a unique crossing and is derived by setting $G(c) < L(c)$ in the limit as $c \to \underline{a}$. ■

See Figure 1 for a visual depiction of the proof. Reading from right to left, as c decreases the G curve decreases and the L curve increases towards their respective asymptotes. As pictured, if the L asymptote exceeds the G asymptote (i.e., if condition 3 is satisfied) then the two curves have a unique intersection at the equilibrium value c^*. Otherwise there is a pooling equilibrium in which all firm types adopt the innovation. Note that off-the-equilibrium-path beliefs with respect to the product launch decision

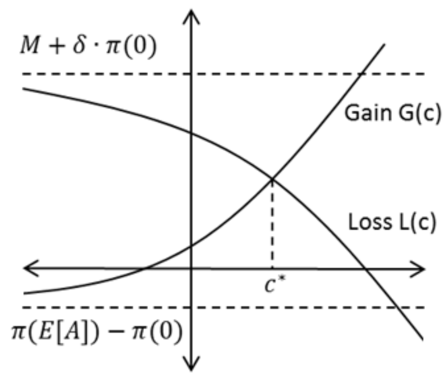


Figure 1: A visual depiction of the proof to Proposition 1

either do not exist or are trivial. With partial separation both possible actions occur in equilibrium and so no action is off the equilibrium path. In a pooling equilibrium a defector does not modify and so the product remains in its old form, the quality of which consumers already know.[18] Off-the-equilibrium path beliefs are invariant with respect to price, as discussed in footnote 17.

Proposition 1 characterizes the use of the innovation signal in equilibrium while its proof makes clear the following remark.

Remark 1 *In equilibrium* $E[A \mid A > c^*] > 0$*. That is, new products are on average improved.*

We therefore conclude there will be a new product demand and pricing premium in the first period. This together with the fact that uninformed consumers always have a more favorable belief about the threshold type than do informeds, implies the attribute adoption threshold c^* must be less than the threshold $\widehat{c}$ that prevails when

[18] One may also hypothesize a "no new products" equilibrium in which any new product is believed to be the lowest type ($E_\mu[A] = \underline{a}$) by first period consumers. However, such an "equilibrium" fails by our assumption that the highest type $\overline{a}$ is high enough it will always modify its product, i.e., $\overline{a}$ is such that $\delta \cdot \pi(\overline{a}) - M > (1 + \delta) \cdot \pi(0)$.

consumers are fully informed in both periods. Thus types $a \in (c^*, \widehat{c})$ exploit uninformed consumers' beliefs about new products by making a product improvement that would otherwise be unprofitable had all consumers been informed. We explore the welfare effects of such signaling in Section 4.

The extra incentive for types to incur investment cost M provided by first period uninformed consumers has implications for firm use of trivial and harmful product modifications. Here we define a product modification as *trivial* if the new product price premium exceeds the value a of the new attribute. Note that while our definition involves a trade-off between attribute value and price, the marketing literature generally defines a trivial attribute purely in terms of its value without consideration of price (e.g., Carpenter, Glazer, and Nakamoto, 1994).

Definition 1 *The attribute a is trivial if $\Delta p \equiv p^H - p^L \geq a \geq 0$ and useful if $a > \Delta p$.*

Remark 2 *The signaling power of a new product may be so strong that the firm will add a trivial attribute.*

Remark 1 implies the new product price premium Δp is strictly positive so that any type $a \in [0, \Delta p]$ that modifies is trivial. Consider an example where $A \sim U[-0.5, 0.5]$, $M = \frac{1}{20}$, $\delta = \frac{9}{10}$ and $q = 1 - p + E[A]$. This implies $c^* \approx -0.125$ and $\Delta p \approx 0.094$ so that $a \in [0, 0.094]$ are trivial attributes while $a > 0.094$ are useful. Note that marginal consumers who purchase a new product containing a trivial attribute will ex-post regret doing so because equation (2) will be violated. Pushing these concepts further leads us to our next definition and remark.

Definition 2 *The attribute a is schlimmbesserung if $a < 0$.*

Remark 3 *The signaling power of a new product may be so strong that the firm will add a schlimmbesserung attribute.*

Thus a firm that adds a schlimmbesserung attribute *pays* cost M to make its product *worse*. Clearly such a tactic will be profitable only if first period uninformed consumers have a sufficiently high posterior over new products. In such cases the first period increase in profits must outweigh two costs: first, the usual product modification cost M and second, a new cost resulting from a decline in second period profits. Such a decline occurs when consumers are informed that $a < 0$ so that profits $\pi(a)$ are less than if the firm had sold its old product and earned $\pi(0)$. It may now be clear why our original formulation of the loss function $L(c)$ in the proof of Proposition 1 included the decline in profits from second period consumers. With $c^* \approx -0.125$, attributes $a \in [-0.125, 0)$ are schlimmbesserung whereas $a < -0.125$ will be censored by the firm in equilibrium. Generally, schlimmbesserung attributes will be adopted whenever $G(0) > L(0)$, or

$$\pi(E[A \mid A > 0]) > \pi(0) + M. \tag{4}$$

Intuitively, the presence of schlimmbesserung attributes requires the prior distribution of A to be sufficiently favorable and modification costs M to be sufficiently low. Notice from condition (4) that the sign of c^* is not a function of δ. However, an increase in δ does magnify the effect of the second period on the equilibrium determination of c^*. Thus when (4) holds an increase in δ increases the potency of the second period decline in profits and so has the equilibrium result of increasing c^* towards 0. Conversely, when (4) fails an increase in δ magnifies the second period increase in profits and therefore reduces c^*.

Product reversion

Before analyzing welfare we first relax the assumption that the product cannot be "unmodified" in period 2. This may occur due to a contracting environment that requires the firm sell the same product in both periods, uneconomically large fixed reversion costs, or a lag in the publicly observable production process so that a decision to revert in period 2 must be initiated in period 1. Nonetheless, there are many plausible scenarios where reverting may be possible. Assume the firm can revert to its old product in period 2 for a fixed cost of $R \geq 0$ that does not depend on A.

It is clear that the ability to revert to the unmodified product in period 2 will only be exercised by a firm that has adopted a schlimmbesserung attribute, as all other types $a \geq 0$ have no incentive to revert when $R \geq 0$. Knowing this, consumers ought to have revised their beliefs in period 1 about the expected quality of a "new and improved" product. Recall that a new type $a < 0$ firm forgoes profits of $\pi(0) - \pi(a)$ in the second period. However, having the ability to revert caps at R this cost and thus when $\pi(0) - \pi(a) \geq R$ the firm will pay R to revert to its old product and otherwise will keep its product as "new and improved" and suffer the resulting loss in period 2 profits. In essence, the type $a \in [c^*, 0)$ firm either accepts its market punishment in period 2 or pays a fee of R to avoid this punishment. For notational convenience we define the highest reverting type a_r as solving

$$\pi(0) - \pi(a_r) = R \tag{5}$$

and we note that $a_r < 0$. By allowing product reversion the loss incurred from modifying a product becomes $L(c) = M + \delta \min\{R, \pi(0) - \pi(c)\}$, which is continuous in

c and non-decreasing as c decreases. This leads to substantially the same findings as before but with a new partially separating condition.

Proposition 2 *Let there be a fixed reversion cost* $R \geq 0$*, independent of* A*. Then Proposition 1 holds and no types revert when* $c^* \geq 0$*. If* $c^* < a_r$ *then types* $a \in [c^*, a_r]$ *revert in the second period. The separating condition becomes:*

$$\pi(E(A)) - M \leq \delta \ \min\{\pi(0), R\} + \pi(0) \tag{6}$$

Proof The proof of Proposition 1 applies with the minor modification that $L(c) = M + \delta \ \min\{R, \ \pi(0) - \pi(c)\}$. Types $a \in [c^*, a_r]$ revert by the discussion above. ■

Allowing reversion to the old product does not qualitatively change the results of the model, though pooling is easier to sustain because of the ceiling on the cost the firm incurs from selling a schlimmbesserung product. If the ceiling binds, it induces more types to modify in period 1 and thus implies a weaker new product signal. In Figure 2 imposing a ceiling drops the equilibrium threshold value from c to c' and therefore implies $E(A \mid A > c) > E(A \mid A > c')$.

Remark 4 *The equilibrium threshold* c^* *is weakly increasing in reversion cost* R*. When some types revert lowering* R *implies a weaker new product signal and a higher probability of a schlimmbesserung attribute.*

Finally, note that a new product fails to provide a positive signal only when both the introduction and retraction of an attribute are costless; i.e., $M = R = 0$. In this case $E(A \mid A > c^*) = 0$ so that being perceived as new no longer confers any demand premium and thus $p^H = p^L$.

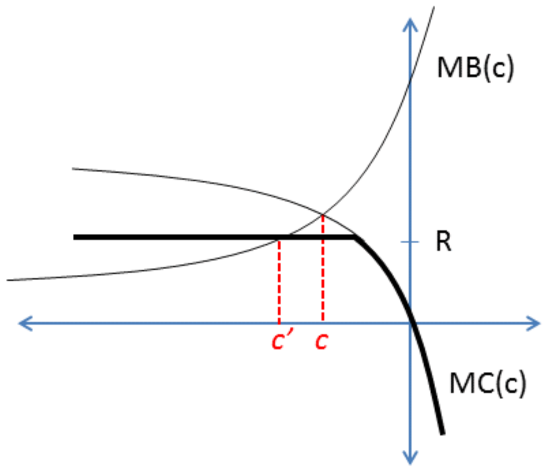


Figure 2: Costly product reversion when $M = 0$ and $R > 0$.

In the next section we consider the welfare effects of trivial and schlimmbesserung attributes and will have use of the following definition: the type threshold a social planner would employ when weighing the welfare effects of a new product against the initial investment M required to adopt a new attribute.

Definition 3 *Let $\bar{c}$ be the adoption threshold that maximizes ex-ante welfare. We define attributes $a < \bar{c}$ as inefficient and $a \geq \bar{c}$ as efficient.*

Thus we contemplate a social planner committing the firm to an adoption threshold, conditional on uninformed consumers' inferences and the firm's pricing decisions in our two-period model. As we will show, this threshold that maximizes the sum of ex-ante profits and consumer surplus could be higher or lower than the firm's threshold c^*. In the present example $\bar{c} = 0.047$, so attributes $a \in (-0.125, 0.047)$ are inefficient and will be added. Notice there may exist attributes that are both efficient and trivial, as discussed later.

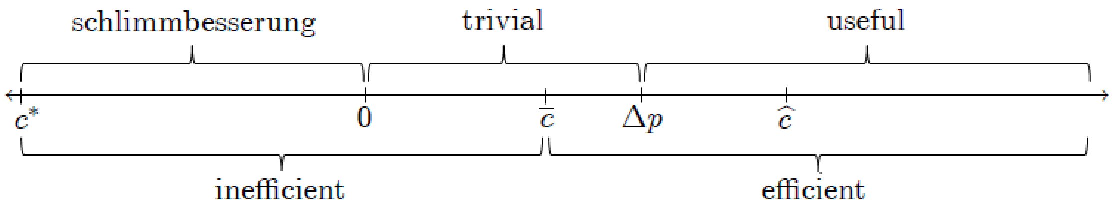


Figure 3: Existence ranges for $A \sim U[-0.5, 0.5]$, $M = \frac{1}{20}$, $\delta = \frac{9}{10}$ and $q = 1 - p + E[A]$.

Table 1 below summarizes the definitions from this section and indicates when useful, trivial, or schlimmbesserung attributes might exist. Figure 3 illustrates the existence ranges for these attribute types for the example under consideration. In the example $\overline{c} < \Delta p < \widehat{c}$ though this need not hold in general.

Table 1: Definitions

Symbol	Meaning	Notes
c^*	Adoption threshold	If $c^* < 0$, *schlimmbesserung* occurs
$\widehat{c}$	Full information adoption threshold	$c^* < \widehat{c}$
$\overline{c}$	Social planner's adoption threshold	$\overline{c} < \widehat{c}$, $\overline{c} \lesseqgtr c^*$
Δp	New product price premium	$a \in [0, \Delta p]$ are *trivial*, $a > \Delta p$ useful

4 Welfare

We have found that the incentive to signal a "new and improved" product leads firms to adopt new attributes that in a full information environment do not justify the firm's modification costs, and that may be trivial or even schlimmbesserung. Given this result it might seem welfare must be lower than if consumers could immediately learn the exact quality of a new attribute. However, even with full information the firm's adoption decision is already inefficient. As Arrow (1959) showed, a firm does not consider the gains to consumer surplus from adopting an innovation so it will tend to underinvest, which in our context corresponds to not adopting an innovation if the profit gain is less than M even if the total gain in profits and consumer surplus is higher than M. Given this problem, the signaling incentive to adopt a new innovation and receive a demand and pricing premium from uninformed consumers might on average lead to higher rather than lower efficiency.[19]

To see how the signaling effect can mitigate or even reverse the Arrow underinvestment problem, first consider the monopolist's adoption decision when consumers are fully informed in both periods. The type-a monopolist modifies its product whenever its increase in profits, as seen in regions B, C and D in the left panel of Figure 4, exceed modification costs M. Recall the type $\widehat{c}$ firm is indifferent to adoption whereas types $a > \widehat{c}$ strictly prefer to adopt the attribute. In contrast, a social planner that takes monopoly pricing to fully informed consumers as given is indifferent to adoption when the increase in total surplus from selling the new product, as seen in regions E, D and C in the left panel of Figure 4, equals M. Because the social planner has regard for consumer surplus his threshold must be less than the monopolist's and the planner strictly prefers adoption for the type $\widehat{c}$ firm.

The same incentives underlying the monopoly underinvestment problem arise in our model with asymmetric information but they are counteracted by the incentive to signal to first period uninformed consumers. First consider the equilibrium determination of

[19] This second-best problem can readily arise with signaling games. For instance, if education has positive externalities then the signaling incentive to overeducate can raise rather than lower total welfare.

the investment threshold c^* and hypothesize $c^* = \widehat{c}$. But then the type $\widehat{c}$ firm must strictly prefer investment because of the demand premium it receives from first period consumers who infer quality $E[A \mid A > \widehat{c}]$ and so buy more of the new product at a higher price than they would if informed. The resulting higher profits imply we must instead have $c^* < \widehat{c}$. The right panel of Figure 4 displays this argument graphically by drawing the informed demand curve for a new product of type $\widehat{c}$. Additional purchases by uninformed consumers reduce the deadweight loss of monopoly in region F_1, whereas the price premium consumers pay results in a transfer of regions E_2 and T to the firm. Therefore the type $\widehat{c}$ firm must strictly prefer adoption of the new attribute.

The determination of the social planner's preferred threshold is more complicated because it involves ex-ante consideration of a type's investment on the new product demand premium enjoyed by all other modifying types. Thus, in the right panel of Figure 4 although the type $\widehat{c}$ firm facing uninformed first period consumers prefers investment in part due to the reduction in deadweight loss F_1, it does not consider this investment's effects on higher types that might have been realized. In fact, a lower type investing implies a weaker new product signal and therefore a lower demand premium for all other modifying types. The planner, on the other hand, considers such externalities because he prefers a threshold that maximizes ex-ante welfare (conditional, we are supposing, on monopoly pricing and imperfect information). This fact, together with the planner's indifference to transfers $E_2 + T$ but regard for consumer surplus E_1, implies we cannot make any general comparison of the planner's threshold to the firm's.

What then can we conclude about welfare? When the new product premium derived from uninformed consumers is high relative to the cost of sending the new product signal, i.e., the distribution of A is sufficiently favorable relative to M, overinvestment can result. This can be seen in the example in Figure 3 where the incentive to signal is so strong that even schlimmbesserung attributes are adopted. However, with a weaker incentive to signal the net gain can be positive as seen in Example 1 below. In this case trivial attributes are sometimes adopted by the firm, but the loss to consumers from such attributes is a transfer to the firm and overall expected welfare rises as the underinvestment problem is mitigated.

Example 1 *We take the example presented in Figure 3 and change it by increasing* M *and allowing costly reversion. Specifically, let* $q = 1 - p + E[A]$, $A \sim U\left[-\frac{1}{2}, \frac{1}{2}\right]$, $M = \frac{1}{4}$, $\delta = \frac{9}{10}$, *and* $R = \frac{1}{20}$. *Then in period 1 all types greater than* $c^* \approx 0.136$ *modify their products and charge a price* $p^H \approx 0.659$ *and types* $a \in [c^*, \Delta p) \approx [0.136, 0.159)$ *are trivial. No types revert to their old product and each type charges its own full information monopoly price in period 2. Notwithstanding the addition of some trivial types the monopoly underinvestment problem is mitigated as total expected welfare is higher under imperfect information (*0.814*) than full information (*0.812*).*

The preceding examples lead us to the following proposition. Loosely speaking, welfare is higher when consumers are initially uninformed if the new product signaling effect does not go too far in solving Arrow's underinvestment problem by encouraging the excessive introduction of new versions, as would happen if, for example, new versions were free to introduce ($M = 0$).

Proposition 3 *Total expected welfare is higher when consumers are initially uninformed of product quality than when they are fully informed if and only if the adoption cost is sufficiently high.*

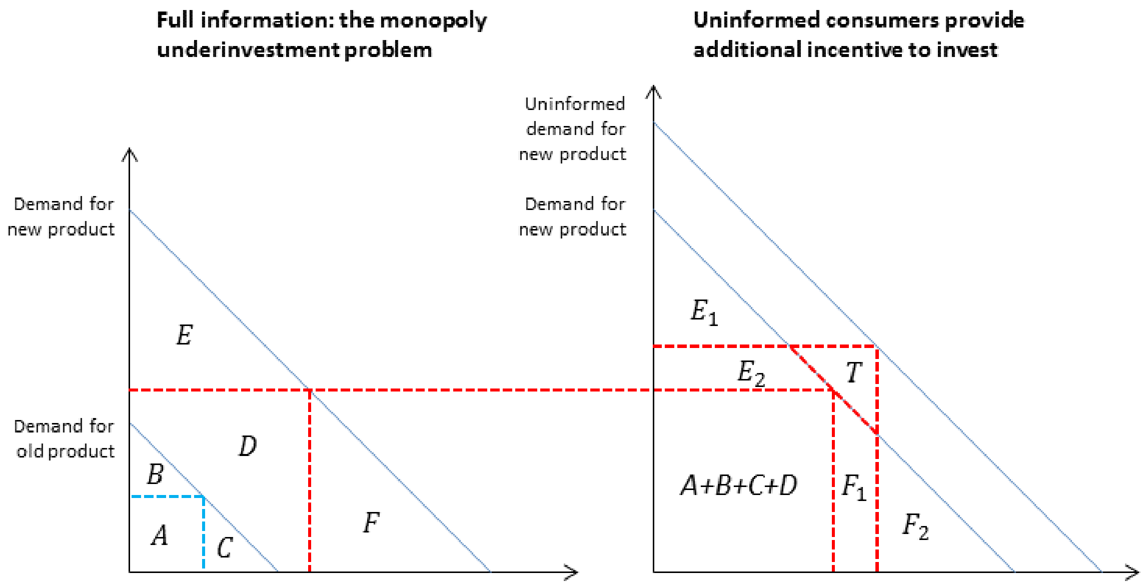


Figure 4: The signaling effect induces marginal types below $\widehat{c}$ to invest and decreases deadweight loss by region F_1. Note: $E = E_1 + E_2$ and $F = F_1 + F_2$.

Proof Consider the equilibrium thresholds $\widehat{c}$ and c^* as a function of the adoption cost M. The equilibrium condition that the threshold type is indifferent to introducing a new version implies

$$(1+\delta)\ \pi(\widehat{c}) = (1+\delta)\ \pi(0) + M = \pi\left(E\left[A \mid A > c^*\right]\right) + \delta\ \pi(c^*).$$

By the fact that $c^* < \widehat{c}$ we must also have $c^* < \widehat{c} < E\left[A \mid A > c^*\right]$. In addition, each of these terms is increasing in M. Finally, the log-concavity of f implies $E\left[A \mid A > c^*\right] - c^*$ is decreasing in c^* (Bagnoli and Bergstrom, 2005), and thus in M, so that the difference between the thresholds $\widehat{c}$ and c^* decreases in M. Since the planner's threshold $\bar{c}$ contemplates consumer surplus, $\frac{\partial \bar{c}}{\partial M} < \frac{\partial \widehat{c}}{\partial M}$ so that the difference between $\widehat{c}$ and $\bar{c}$ increases in M, and thus $\bar{c} < c^* < \widehat{c}$ for sufficiently high M. ∎

Finally, the right panel of Figure 4 can help resolve a seeming oddity that first appeared in Figure 3: the existence of types that are both efficient and trivial. Let the informed demand curve for a type $a \in [\bar{c}, \Delta p]$ be given in the right panel of 4. Then marginal purchasing consumers make transfer payment T to the firm and therefore ex-post regret buying such a product because of the trivial attribute. Nonetheless, because the type is efficient the increased output and resulting reduction in deadweight loss F_1 increase expected welfare.

Since the firm may sell a product with an inefficient improvement, including even a degraded product, the question naturally arises as to whether it would prefer committing not to sell such products.

Proposition 4 *The firm's expected profits are higher when it commits to using the full information threshold $\widehat{c}$ than without commitment.*

Proof First note that by construction more favorable beliefs about a results in a vertical shift in demand, thereby resulting in a higher price charged and quantity sold. Thus revenues $\pi(a)$ are convex in a. Now let $t = \frac{F_A(\widehat{c}) - F_A(c^*)}{1 - F_A(c^*)}$ and $1 - t = \frac{1 - F_A(\widehat{c})}{1 - F_A(c^*)}$ and recall that $c^* < \widehat{c}$. We restrict ourselves to $a > c^*$ for otherwise types never add an attribute. Additionally, when $a > \widehat{c}$ second period profits are invariant to commitment and so it suffices to show

$$\begin{aligned} & t\ \pi(0) + (1-t)\ \ [\pi(E[A \mid A > \widehat{c}]) - M] + \delta\ \left[t\ \pi(0) + \frac{\int_{\widehat{c}}^{\infty} \pi(a)\ f_A(a) da}{1 - F_A(c^*)}\right] \\ > \ \ & \pi(E[A \mid A > c^*]) - M + \delta\ \frac{\int_{c^*}^{\infty} \pi(a)\ f_A(a) da}{1 - F_A(c^*)}. \end{aligned} \tag{7}$$

Below we use the substitution $(1+\delta)\ \pi(\widehat{c}) = (1+\delta)\ \pi(0) + M$. Condition (7) holds if and only if $\pi(E[A \mid A > c^*])$ is less than

$$\begin{aligned}
& (1-t)\ \pi(E[A \mid A > \widehat{c}]) + t\ [(1+\delta)\ \pi(0) + M] \\
& -\delta\ \frac{\int_{c^*}^{\widehat{c}} \pi(a)\ f_A(a)da}{1 - F_A(c^*)} \\
= \ & (1-t)\ \pi(E[A \mid A > \widehat{c}]) + t\ \pi(\widehat{c}) \\
& +\delta \left[t\pi(\widehat{c}) - \frac{\int_{c^*}^{\widehat{c}} \pi(a) f_A(a)da}{1 - F_A(c^*)} \right]. \qquad (8)
\end{aligned}$$

It thus suffices to show

$$(1-t)\ \pi(E[A \mid A > \widehat{c}]) + t\ \pi(\widehat{c}) > \pi(E[A \mid A > c^*]). \qquad (9)$$

By the weak convexity of π, the left hand side of (9) is

$$\begin{aligned}
& \geq \ \pi\left(t\ \widehat{c} + (1-t)\ E[A \mid A > \widehat{c}]\right) \\
& = \ \pi\left(\frac{\int_{c^*}^{\widehat{c}} \widehat{c}\ f_A(a)da + \int_{\widehat{c}}^{\infty} a\ f_A(a)da}{\int_{c^*}^{\infty} f_A(a)da}\right) \\
& > \ \pi\left(\frac{\int_{c^*}^{\infty} a\ f_A(a)da}{\int_{c^*}^{\infty} f_A(a)da}\right) \\
& = \ \pi\left(E[A \mid A > c^*]\right), \qquad (10)
\end{aligned}$$

where the final inequality holds because the non-committing firm sometimes sells a product with an attribute $a < \widehat{c}$. ■

Proposition 5 *The firm's expected profits are higher when consumers are fully informed than when they are initially uninformed.*

Proof The proof is similar to that above. Without loss of generality we let $M = 0$

and $\delta = 1$ (see line 7 above and the equilibrium substitution used below it). Let Π_{FI} and Π_{II} be the first period payoffs under full and imperfect information, respectively. We may condition on $a \geq c$ since lower realizations imply $\pi(0)$ in either case.

$$\begin{aligned} \Pi_{FI} &= \frac{\int_c^0 \pi(0)\ f(a)da + \int_0^{\overline{a}} \pi(a)\ f(a)da}{1 - F(c)} \\ &> \frac{\int_c^{\overline{a}} \pi(a)\ f(a)da}{1 - F(c)} \qquad (11) \\ &> \pi\left(\frac{\int_c^{\overline{a}} a\ f(a)da}{1 - F(c)}\right) = \Pi_{II} \qquad (12) \end{aligned}$$

where the last line follows from the convexity of π and Jensen's inequality. Second period profits are higher under full information when $a \in (c, 0)$ (since $\pi(0) > \pi(a)$) and are equal otherwise. ■

These two propositions demonstrate the net effect of new product signaling on the firm's profits. When facing imperfectly informed consumers, the firm is tempted by the immediate gains from accepting an R&D outcome that would otherwise be unprofitable had consumers been informed. However, the modest benefit accrued from doing so does not last since consumers eventually learn the product's quality. In addition, such marginal types impose a negative externality on higher types: real and significant improvements made to the product are not initially rewarded enough because consumers anticipate that the firm will occasionally introduce trivial or inefficient new products. The net effect is the firm's ex-ante profits are higher if it either it could commit not to introduce such marginal products or if consumers were initially informed. For this reason a firm has incentive to educate its customers about a new product's features if such communication would be deemed credible.

5 Extension: ex-ante investment

We now extend the model by allowing the firm to choose its R&D effort level which in turn implies a distribution of R&D outcomes. If, loosely speaking, greater effort induces a "better" distribution of outcomes, how much effort will the firm exert? Does the answer to this question change if consumers are fully informed instead of imperfectly informed? That is, although expected profits are higher under full than imperfect information, which grow faster with effort and therefore would induce a higher equilibrium effort level?

Formally, we add a stage to the beginning of the game in which the firm chooses effort level $e \in [0, \infty)$ which incurs a cost $C(e)$ with $C' > 0$, $C'' > 0$ and $C(0) = 0$. It is assumed that effort level e is publicly observable and maps into distributions of R&D outcomes in a known way[20]; here we specify that effort e induces distribution $A(e) \equiv A + e$, where A is the distribution when no effort is exerted. Thus effort induces a better distribution in the sense of statewise dominance, a stronger condition than first-order stochastic dominance.[21] The rest of the game then proceeds as usual. Thus the firm chooses an effort level which induces the subgame that is described in Section 2. The firm's problem then is to choose e so that profits in the subgame net of the cost of effort is maximal.

In this section we examine investment in an ex-ante sense, whereby greater R&D

[20] The public observability of R&D effort levels is reasonable for firms that are publically traded or issue publically traded debt and thus publish financial statements that would document such expenditures. That effort maps into a known distribution of outcomes requires consumers to know how the capabilities of the firm interact with the inherent randomness of the R&D process.

[21] The first-order stochastic dominance of one random variable over another is not sufficient to ensure a change in the equilibrium threshold. This is true generally of options, where an improvement to the states for which the option would not be exercised confers no additional value on the option. Since it is natural to suppose the firm's behavior is continuous in its effort, we make the stronger assumption of statewise dominance.

effort induces a better distribution of outcomes. In contrast, in the previous section we discussed ex-post investment in which the firm decided to accept a realized R&D outcome or not at some cost. Without loss of generality, we henceforth assume $M = 0$ and $\delta = 1$.

5.1 Preliminaries

In this subsection we explore the equilibrium effect of effort on the subgame and establish results that lead to the main proposition of this section. When necessary, we denote by $c(e)$ the equilibrium threshold induced by $A(e)$, which has support on $[\underline{a} + e, \overline{a} + e]$.

Lemma 1 *(i). Under imperfect information, a better distribution of outcomes induces a lower equilibrium threshold c^* but a higher new product signal.*

(ii). Under full information, the equilibrium threshold $\widehat{c}$ is invariant to the distribution of R&D outcomes.

(iii). Under both full and imperfect information, the firm derives a benefit from a better distribution of R&D outcomes.

Proof (i). Of immediate concern is effort e inducing a better distribution. We proceed in the proof by considering the effects of a chosen e on the subgame that follows (i.e., the determination of c^* or $\widehat{c}$), where $C(e)$ is sunk. Restating the lemma more formally, if $e_2 > e_1$ then $c(e_2) < c(e_1)$ but $E[A(e_2) \mid A(e_2) > c(e_2)] > E[A(e_1) \mid A(e_1) > c(e_1)]$.

For any fixed c, $E[A \mid A > c]$ is greater when $A(e_2)$ is the relevant random variable than when $A(e_1)$ is. This follows because if the type $c(e_1)$ is indifferent to selling a new product version when $A(e_1)$ is the distribution of R&D outcomes, then this same type must strictly prefer to sell a new version when $A(e_2)$ is the relevant random variable, and thus we must have $c(e_2) < c(e_1)$.

We now argue that $E[A(e_2) \mid A(e_2) > c(e_2)] > E[A(e_1) \mid A(e_1) > c(e_1)]$. Suppose instead they are equal. But then the type $c(e_2)$ cannot be indifferent when $A(e_2)$ is the R&D distribution as the first period payoffs match that when $c(e_1)$ and $A(e_1)$ are used but the second period payoffs must be lower since $c(e_2) < c(e_1)$. Since $c(e_1)$ is indifferent given $A(e_1)$, we deduce type $c(e_2)$ strictly prefers not to become new and improved given $A(e_2)$. Thus the true equilibrium value $c^*(e_2)$ must be greater than this conjectured value of $c(e_2)$ and thus $E[A(e_2) \mid A(e_2) > c(e_2)] > E[A(e_1) \mid A(e_1) > c(e_1)]$.

(ii). Inferences about the new product's quality, which are affected by the distribution of outcomes, are no longer needed since consumers directly observe the realization of the R&D process. Thus the determination of the indifferent type $\widehat{c}$ depends only on the payoff conditional on being this type; i.e., $A(e)$ appears nowhere in the equilibrium condition $2\pi(\widehat{c}) - M = 2\pi(0)$.

(iii). The proof is obvious for the case of full information. For the case of imperfect information, again consider arbitrary $e_2 > e_1$. We claim the profits expected under $A(e_2)$ exceed that under $A(e_1)$, where $C(e)$ is ignored. First, note that under $A(e_2)$ all types $a \geq c(e_1)$ are better off since $E[A(e_2) \mid A(e_2) > c(e_2)] > E[A(e_1) \mid A(e_1) > c(e_1)]$. Next, types $a \in (c(e_2), c(e_1))$ (those types that sell a new product under $A(e_2)$ but not under $A(e_1)$) receive a higher payoff than type $c(e_2)$, who itself is indifferent to selling a new product. Thus these types earn a higher payoff under $A(e_2)$ than when they sell the old product under $A(e_1)$. Types $a \leq c(e_2)$ are indifferent between $A(e_1)$ and $A(e_2)$ because in either case they sell their old product version. ■

Lemma 2 *Let* $A \sim [\underline{a}, \overline{a}]$, $\pi' > 0$, $\pi'' > 0$. *Define Jensen's difference as* $E[\pi(A)] - \pi(E[A])$ *and* $A(e) = A + e$. *Then Jensen's difference*

(i) increases in e *if* $\pi''' > 0$.

(ii) decreases in e *if* $\pi''' < 0$.

(iii) is constant in e, *decreases in* $\underline{a}$, *and increases in* $\overline{a}$ *if* $\pi''' = 0$.

Proof We first prove the statements regarding e:

$$\begin{aligned} & \frac{\partial}{\partial e}\left(\int_{\underline{a}}^{\overline{a}} \pi(a+e)\ f(a)da\right) - \frac{\partial}{\partial e}\left(\pi\left(\int_{\underline{a}}^{\overline{a}} (a+e)\ f(a)da\right)\right) \\ = & \int_{\underline{a}}^{\overline{a}} \pi'(a+e)\ f(a)da - \pi'\left(\int_{\underline{a}}^{\overline{a}} (a+e)\ f(a)da\right) \end{aligned}$$

which is just Jensen's difference for π'. Thus by Jensen's inequality the line above is positive when π' is convex, negative when π' is concave, and constant when π' is both; i.e., $\pi''' > 0$, $\pi''' < 0$, and $\pi''' = 0$ respectively.

To prove the statement in (iii) regarding endpoints $\underline{a}$ and $\overline{a}$, we note that $\pi''' = 0$ implies π is a polynomial of the form $\pi(a) = k_1 a^2 + k_2 a + k_3$ where k_i are positive constants by our assumptions on π' and π''. We now claim that Jensen's difference is proportional to the variance of A:

$$\begin{aligned} & \int \left(k_1 a^2 + k_2 a + k_3\right) f(a)da - \left(k_1 E[A]^2 + k_2 E[A] + k_3\right) \\ = & \ k_1 \int a^2 f(a)da + k_2 \int a f(a)da + k_3 - k_1 E[A]^2 - k_2 E[A] - k_3 \\ = & \ k_1 \left(E\left[A^2\right] - E[A]^2\right) \\ = & \ k_1 Var[A] \end{aligned}$$

Since it is well known that "truncation reduces the variance compared with the variance in the untruncated distribution" (Greene, 2008), $Var[A]$ and thus Jensen's difference increases in $\overline{a}$ and decreases in $\underline{a}$. ■

5.2 Marginal benefit from R&D effort

We are ultimately interested in understanding the ex-ante investment decision of the firm facing imperfectly informed ("II") customers, and for this purpose we employ two benchmark cases: that of a firm facing fully informed ("FI") consumers and a social planner ("SP"). We define MB_i^j be the expected marginal benefit from ex-ante investment to j derived in period i, where $j = FI, II$, or SP and $MB^j = MB_1^j + MB_2^j$. In many cases determining who invests mores reverts to comparing this term for different j. To begin with, we compare the investment incentives of a social planner to a firm in a full information setting and find a result analogous to that found previously regarding ex-post investment. Specifically, $MB_i^{SP} > MB_i^{FI}$ and thus

Remark 5 *Arrow's underinvestment problem also exists in the ex-ante sense.*

The result is not surprising and derives from the fact that a social planner places weight on consumer surplus in addition to firms' profits so that $MB_i^{SP} > MB_i^{FI}$. This together with the fact that the social cost equals the private cost of R&D effort implies the planner would choose a higher ex-ante investment level than the firm.

Given the ex-ante underinvestment problem, we now proceed to determine whether the informational asymmetry of our game exacerbates or mitigates this phenomenon. In general this will depend on the curvature of π and $f(a)$ as well as $[\underline{a}, \overline{a}]$, the support of A. We examine several cases to develop the intuition of the general tradeoffs involved.

First, we suppose the distribution of R&D outcomes is favorable enough that bad outcomes never occur.

Lemma 3 *Suppose* $\underline{a} \geq 0$. *Then the marginal benefit from ex-ante investment under full information is:*

(i) higher than the MB under imperfect information when $\pi''' > 0$

(ii) lower than the MB under imperfect information when $\pi''' < 0$

(iii) equal to the MB under imperfect information when $\pi''' = 0$

Proof Since $a < 0$ is not possible the payoffs to the FI and II firm are identical in the second period and it suffices to consider only the first. $MB_1^{FI} > MB_1^{II} \iff \frac{\partial}{\partial e} E\left[\pi\left(A\right)\right] - \frac{\partial}{\partial e}\pi\left(E\left[A\right]\right)$ is increasing in e; that is, if Jensen's difference increases in e. The inequality is reversed when the difference decreases in e, and it becomes equality when the difference is constant in e. The results now follow from Lemma 2. ∎

Thus when only positive realization are possible, the curvature of the profit function alone determines whether FI or II enjoys a higher MB from ex-ante investment and the distribution of outcomes is not relevant.

Remark 6 *The lemma above holds as well if we exogenously forbid schlimmbesserung from occurring.*

We now suppose negative realizations can occur and that a pooling equilibrium exists in the subgame. The results are somewhat weaker in that the curvature of $f(a)$ becomes relevant in some instances.

Lemma 4 *Suppose* $\underline{a} < 0$ *and a pooling equilibrium exists. Then the marginal benefit from ex-ante investment under full information is:*

(i) ambiguous with respect to the MB under imperfect information when $\pi''' > 0$

(ii) lower than the MB under imperfect information when $\pi''' \leq 0$

Proof (ii). First, note $MB_2^{II} > MB_2^{FI}$ since investment only improves the firm's payoff if the R&D realization if it is adopted. In a pooling equilibrium with e effort, the type-a FI firm's second period payoff is $\pi(\max\{0, a+e\})$ while for the II firm it is $\pi(a+e)$. Thus II firm derives a benefit from effort for all realizations while the FI derives no benefit from those realizations it will ultimately reject.

It now suffices to show $MB_1^{II} \geq MB_2^{II}$ when $\pi''' \leq 0$, since then $MB_1^{II} \geq MB_2^{II} > MB_2^{FI} = MB_1^{FI}$. Let TB_i^j be the total benefit, defined analogously to MB_i^j. Thus is suffices to show $TB_1^{II} - TB_2^{II} = -\left[\int \pi(a) f(a)da - \pi\left(\int af(a)da\right)\right]$ is weakly increasing in effort. The result holds when $\pi''' \leq 0$ by Lemma 2.

(i). By example. Let $A + e \sim U\left[-\frac{1}{2}+e, \frac{3}{2}+e\right]$ and suppose $\pi(a) = \left(a+\frac{1}{2}\right)^n$ for $n \geq 1$. Note that this function is non-negative and increasing for $a \geq -\frac{1}{2}$, as required and when $e \in \left[0, \frac{1}{2}\right]$ there is a pooling equilibrium in the subgame.[22] Profits (ignoring the cost of effort) under full information are

$$\begin{aligned} & \left(\frac{-\left(-\frac{1}{2}+e\right)}{2}\pi(0) + \int_0^{\frac{3}{2}+e}\frac{\pi(a)}{2}da\right) \times 2 \\ = & \left(\frac{1}{2}-e\right)\left(\frac{1}{2}\right)^n + \int_0^{\frac{3}{2}+e}\left(a+\frac{1}{2}\right)^n da \end{aligned}$$

[22] We require $e \leq \frac{1}{2}$ so that negative realizations can occur. Pooling occurs because when $e = 0$ we have $\pi(E[A]) + \pi(\underline{a}) > 2\pi(0)$, which becomes $\pi\left(\frac{1}{2}\right) + \pi\left(-\frac{1}{2}\right) > 2\pi(0)$ and the inequality holds for all $n > 1$ since the left hand side equals 1 always while the right hand side is $2\left(\frac{1}{2}\right)^n = \left(\frac{1}{2}\right)^{n-1} \leq 1$ for $n \geq 1$. Pooling must also then occur for $e > 0$.

while the marginal benefit from effort is

$$MB^{FI} = \frac{\partial \pi^{FI}}{\partial e} = (2+e)^n - 2^{-n} \tag{13}$$

Under imperfect information profits are

$$\begin{aligned} & 1 \times \pi \left(\frac{1}{2} + e \right) + \int_{-\frac{1}{2}+e}^{\frac{3}{2}+e} \frac{\pi(a)}{2} da \\ = & \left(\frac{1}{2} + e + \frac{1}{2} \right)^n + \int_{-\frac{1}{2}+e}^{\frac{3}{2}+e} \frac{\left(a + \frac{1}{2}\right)^n}{2} da \end{aligned}$$

and thus the marginal benefit from effort is

$$MB^{II} = \frac{\partial \pi^{II}}{\partial e} = n(e+1)^{n-1} + \frac{1}{2}\left((2+e)^n - e^n\right) \tag{14}$$

The example is consistent with the results in Lemma 4(ii) when $1 \leq n \leq 2$ and establishes the ambiguity asserted in part (i). For example, suppose $n = 3$. Then $\pi''' > 0$ and it can be shown from lines 13 and 14 that $MB^{FI} > MB^{II}$ for all $e \in \left[0, \frac{1}{2}\right]$. Suppose instead $n = 2.1$. Then $\pi''' > 0$ again, but now lines 13 and 14 imply there exists (e.g., $e = \frac{1}{2}$) an $e \in \left[0, \frac{1}{2}\right]$ such that $MB^{II} > MB^{FI}$ so that for this level of e marginal investment is more valuable to the II firm than the FI firm. ■

We see from the proof of the lemma that in a pooling equilibrium the II firm always derives a benefit from R&D effort due to the fact that *schlimmbesserung* is made less likely. Thus a firm has an additional incentive to invest under II so as to convince consumers *schlimmbesserung* is unlikely to occur. Such a motive is absent under FI since *schlimmbesserung* will not occur in this context regardless of the distribution of outcomes.

This intuition carries over to the final case we treat, that of a separating equilibrium, but with a complication. Although statically *schlimmbesserung* becomes less likely with greater investment because probability mass is shifted towards more favorable outcomes, in equilibrium this very fact causes the adoption threshold to fall (Lemma 1(i)) thus allowing for more instances of *schlimmbesserung*. The net effect of these forces is largely ambiguous so that more stringent conditions are required to make a comparison of the full and imperfect information settings.

Lemma 5 *Suppose* $\underline{a} < 0$ *and a separating equilibrium exists. Then the marginal benefit from ex-ante investment under full information is:*

(i) greater than the MB under imperfect information when $\pi''' = 0$ *and* f *is non-increasing.*

(ii) ambiguous with respect to the MB under imperfect information otherwise.

Proof (i). We establish the result for each period. For the second period, it suffices to show the expected amount by which profit under FI exceeds that under II $\int_c^0 (\pi(0) - \pi(a))\ f(a)\, da$ increases in effort. This follows since higher e implies both a lower equilibrium c and, because f is non-increasing, more weight is given to this interval.

For the first period, we make use of the proof of Proposition 5. Fix c^* at its equilibrium level when $e = 0$. Then by Lemma 2(iii) higher effort weakly strengthens the inequality in line 12 (each side of the inequality grows at the same rate so that the absolute difference increases). Higher effort actually induces a lower threshold c^*, and by Lemma 2(iii) the inequality in line 12 is further strengthened if we allow c to re-equilibriate. Finally, the inequality in line 11 strengthens by the same argument that applies to the second period.

(ii) By example. Let $A+e$ have an increasing triangular distribution with density $f(a) = \frac{a+1-e}{2}$ on $[-1+e, 1+e]$ and suppose $\pi(a) = a$. Then expected profits under full information are:

$$\begin{aligned} & \left(\int_{-1+e}^{0} 0\left(\frac{a+1-e}{2}\right) da + \int_{0}^{1+e} a\left(\frac{a+1-e}{2}\right) da\right) \times 2 \\ = & \int_{0}^{1+e} a\,(a+1-e)\, da \end{aligned}$$

where this expression is valid for $0 \leq e \leq 1$. Differentiating with respect to e we find the marginal benefit from R&D effort

$$2(1+e) + \int_{0}^{1+e} (-a)\, da \tag{15}$$

Under imperfect information we find the equilibrium threshold to be

$$c^{*} = \frac{2}{5}e + \frac{1}{5}\sqrt{3}\sqrt{3e^{2} - 16e + 8} - \frac{7}{5}$$

where this expression is valid when separation occurs[23]; that is, when the lowest realization is less than the threshold c^{*}:

$$-1 + e < c^{*} = \frac{2}{5}e + \frac{1}{5}\sqrt{3}\sqrt{3e^{2} - 16e + 8} - \frac{7}{5} \tag{16}$$

[23] We solve:

$$\begin{aligned} \pi\left(E\left[A|A>c\right]\right) + \pi(c) &= 2\pi(0) \\ E\left[A|A>c\right] + c &= 0 \\ \frac{\int_{c}^{1+e} a\left(\frac{a+1-e}{2}\right) da}{\int_{c}^{1+e} \left(\frac{a+1-e}{2}\right) da} + c &= 0 \end{aligned}$$

a solution to which is $c = \frac{2}{5}e + \frac{1}{5}\sqrt{3}\sqrt{3e^{2} - 16e + 8} - \frac{7}{5}$. We reject the root $\frac{2}{5}e - \frac{1}{5}\sqrt{3}\sqrt{3e^{2} - 16e + 8} - \frac{7}{5}$.

The condition is satisfied and thus separation occurs for $e \in \left[0, \frac{1}{3}\right)$, while pooling occurs when $e \geq \frac{1}{3}$.

Next, $\pi(a) = a$ implies $E[\pi(A)] = \pi(E[A])$ and thus first period profits equal second period profits under imperfect information. We calculate total profits under II as

$$
\begin{aligned}
& 2\left(\int_{-1+e}^{c} 0\left(\frac{a+1-e}{2}\right) da + \int_{c}^{1+e} a\left(\frac{a+1-e}{2}\right) da\right) \\
= & \int_{c}^{1+e} a(a+1-e)\, da
\end{aligned}
$$

Differentiating with respect to e we find the marginal benefit from R&D effort:

$$
2(1+e) - c(e)\, c'(e)\left[c(e)+1-e\right] + \int_{c(e)}^{1+e} (-a)\, da \tag{17}
$$

We seek to find when the expression in line 17 exceeds that in line 15. This occurs if and only if

$$
-c(e)\, c'(e)\left[c(e)+1-e\right] + \int_{c(e)}^{0} (-a)\, da > 0 \tag{18}
$$

We first note that $\int_{c(e)}^{0} (-a)\, da = \frac{c(e)^2}{2} > 0$. Also, $c(e) < 0$ in any equilibrium[24] while $c'(e) < 0$ by Lemma 1(i). Thus $c(e) + 1 - e \leq 0$ would be sufficient to establish line 18, but this is exactly the negation of the separating condition in line 16. We proceed by noting that $c(e) + 1 - e = 0$ when $e = \frac{1}{3}$ so that pooling just binds but line 18 is satisfied. Since this inequality is strict and left hand side of line 18 is continuous in e, there exists $e < \frac{1}{3}$ in the neighborhood of $\frac{1}{3}$ such that line 18 is still satisfied. That is, the marginal benefit from effort is higher under imperfect than full information for

[24] Recall we are assuming $M = 0$.

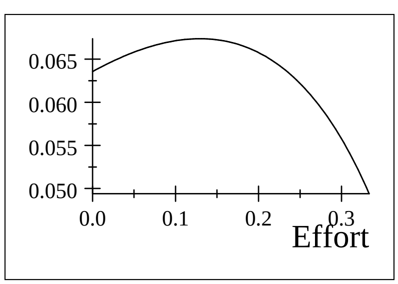
such effort levels.[25] ∎

We now provide some brief intuition for the result just established. In the preceding example $MB^{FI} > MB^{II}$ for $e = 0$ and in the neighborhood. However, as e is increased the region of *schlimmbesserung* increases and so too does MB^{II} since the mass assigned to the region will fall. Eventually, this effect wins out and $MB^{II} > MB^{FI}$. When e gets sufficiently high the adoption threshold will drop to $\underline{a}$ so that separation no longer occurs and Lemma 4's result for a pooling equilibrium applies.

This last remark illustrates the importance of the cost function $C(e)$ in determining which Lemma applies. Trivially, if $e = 0$ implies a separating equilibrium then Lemma 5 applies if $C(e) = \infty$ for all e while Lemma 3 would apply if $C(e) = 0$ on a sufficiently large interval $[0, k]$. More generally, the cost of effort function can help to determine whether ex-ante investment is greater under II or FI, as the next example illustrates.

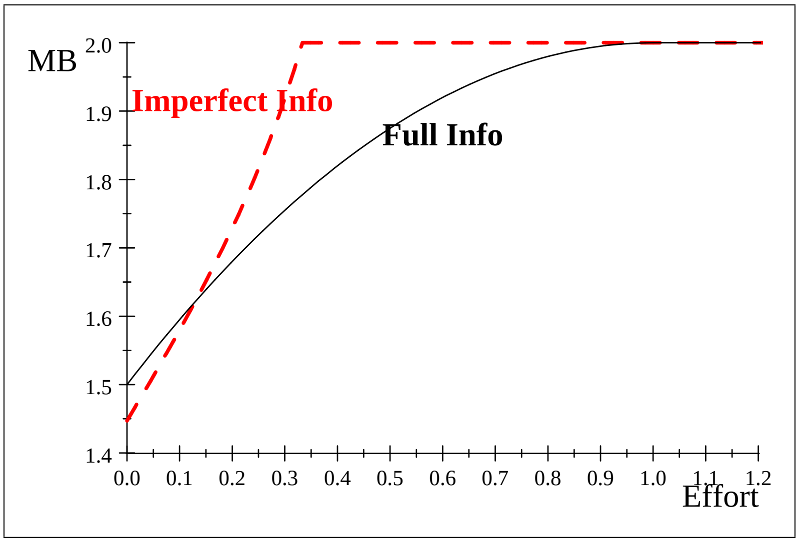
Example 2 *We reexamine the example given in the proof of Lemma 5(ii): let $A + e$ have an increasing triangular distribution with density $f(a) = \frac{a+1-e}{2}$ on $[-1 + e, 1 + e]$ and suppose $\pi(a) = a$. By plotting the respective marginal benefits from ex-ante investment, MB^{FI} and MB^{II}, we find that we cannot make general statements about which information structure will lead to greater investment without having a specified*

[25] With the help of software we can numerically calculate that line 18 holds for $e \in \left(0.129\,43, \frac{1}{3}\right)$.



Difference in profits between the full and imperfect information firm as a function of effort.

cost function $C(e)$. The kink in MB^{II} occurs when pooling begins ($e = \frac{1}{3}$).



The marginal benefit from ex-ante investment (effort) in general depends on the current level of effort.

Proposition 6 *In the full game that includes an ex-ante investment decision, the firm chooses an investment level that maximizes profits in the subgame net of R&D expenditures. Arrow's underinvestment problem exists in the ex-ante sense as well as ex-post, but whether the existence of imperfectly informed consumers exacerbates or mitigates this problem is in general ambiguous, depending on the curvature of the demand function, cost of R&D effort function, and distribution of R&D outcomes.*

Example 3 *We revisit Example 1 in which it was demonstrated welfare may be higher under imperfect than full information due to the new product signal alleviating the ex-post underinvestment problem. We add an ex-ante investment stage to this example to demonstrate that the new product signal may also mitigate the ex-ante underinvestment problem and reconfirm that total welfare may be higher under imperfect than full information in the complete game.*

Let $q = 1 - p + E[A]$, $A \sim U\left[-\frac{1}{2} + e, \frac{1}{2} + e\right]$, $M = \frac{1}{4}$, $\delta = \frac{9}{10}$, $R = \frac{1}{20}$, *and the increasing and convex cost of effort is given by* $C(e) = \frac{1}{16 \ln 2}\left(2^{4e} - 1\right)$. *Then the ex-ante underinvestment problem is mitigated as the imperfect information firm chooses an investment level of* $e^*_{II} \approx 0.665 > 0.628 \approx e^*_{FI}$ *which is greater than that chosen by the full information firm. Total welfare is higher under imperfect information (*1.331*) than full information (*1.304*). The Appendix contains further details.*

6 Extension: imperfect learning

In the previous sections we assumed a simple learning structure that enabled all consumers to determine the value of the new product attribute A after the first period. Learning occurred from personal consumption experiences or secondary sources such as word-of-mouth communications or product review websites. Whereas such information was not available to consumers in the first period when the product was new, it is assumed by the second period it is widely available at no cost. This implies strategic consumption in the first period for the purpose of information acquisition will not occur.

We now conceptualize learning as an imperfect process from which much, though not all, of consumers' uncertainty about a product's value is resolved. Such products are of practical interest and lay along a continuum between two theoretical extremes: Nelson's (1970) experience good, for which all uncertainty is resolved after consumption and Darby and Karni's (1973) credence good, for which the consumer learns nothing from consumption. In this section we allow for imperfect, or noisy, learning from consumption and other sources and show that the main result from the perfect learning model generalizes to this context.

We operationalize noisy learning by assuming each consumer receives a common signal $X \equiv a + \epsilon$ after the first period that contains information about the realization of A, denoted a, as well as an independent mean zero error term ϵ whose distribution is common knowledge. We assume f and h, the densities of A and ϵ respectively, are continuous with full support on $\mathbb{R}$ and h is log-concave so that consumers' posterior mean $E[A \mid X = x]$ is increasing in the noisy signal x.[26,27] Including a common error term is justified on the grounds that consumers, whether or not they made a first period purchase, may receive the same information from influential experts, product review websites, blogs, or word-of-mouth communication. For this reason we assume the firm observes the realization of ϵ as well. For simplicity of analysis, we only consider the subgame in which the R&D distribution has already been determined.

Before proceeding to the proposition we establish a lemma which, roughly speaking, says that very low threshold types that sell a new product expect a bad outcome in the second period.

Lemma 6 $E_{X|A=c}[\pi(E[A \mid A > c, X])] \to 0$ *as* $c \to -\infty$.

Proof Let $f_X(x)$ denote the density of X. Because $f_X(x) = h(x - c)$, the expected

[26] The assumption of full support simplifies the presentation of the results.

[27] This ensures $L(c)$ is monotonic and thus a unique attribute adoption threshold strategy exists. The independence of A and ϵ implies $f_{X,A}(y_1, y_2) = h(y_1 - y_2) \cdot f(y_2)$. Consumers' posterior mean is increasing in x when X and A are affiliated, a sufficient condition for which is (Milgrom and Weber, 1982), for all y_1 and y_2, $\frac{\partial^2}{\partial y_1 \partial y_2} \log[h(y_1 - y_2) \cdot f(y_2)] \geq 0 \Longleftrightarrow \frac{\partial h}{\partial y_1}(y_1 - y_2) \cdot \frac{\partial h}{\partial y_2}(y_1 - y_2) - \frac{\partial^2 h}{\partial y_1 \partial y_2}(y_1 - y_2) \cdot h(y_1 - y_2) \geq 0$, which is equivalent to the log-concavity of h.

profits to the threshold type-c firm $E_{X|A=c}[\pi(E[A \mid A > c, X])]$ equal

$$
\begin{aligned}
& \int_{-\infty}^{t} \pi(E[A \mid A > c, X])\ h(x-c)dx + \int_{t}^{\infty} \pi(E[A \mid A > c, X])\ h(x-c)dx \\
\equiv\ & J^{t^-} + J^{t^+},
\end{aligned}
$$

where J^{t^-} integrates over all signals less than t while J^{t^+} integrates over signals greater than or equal to t. For any t we can select c low enough so as to assign as much mass to signals less than t as we wish. That is, $\forall t$, $H(t-c) \to 1$ as $c \to -\infty$, and thus t and c can be selected to assign arbitrarily large mass to arbitrarily negative values of the signal. This implies $J^{t^+} \to 0$ because its mass is pinched to 0 and $J^{t^-} \to 0$ because $E[A \mid A > c, X = x] \to -\infty$ and thus $\pi(E[A \mid A > c, X = x]) \to 0$ as c and x approach $-\infty$. ■

We next show that the results from Proposition 1 generalize to this context, though second period pricing and reversion decisions are now a function of the consumers' noisy signal rather than the firm's true type. We also incorporate our earlier brief discussion of reverting the product in period 2 at cost R at this time and define the highest reverting type as a_r which solves $\pi(0) - \pi(a_r) = R$.

Proposition 7 *Let consumers learn about product quality from noisy signal $X = a+\epsilon$. In the unique equilibrium there exists a threshold c^* such that the firm modifies its product whenever $a > c^*$ and otherwise does not. In period 1 all "new and improved" types charge the same high price $p^H = p_{E[A|A>c^*]}$ whereas all unmodified types charge the low price $p^L = p_0$. In period 2 all modified types charge the optimal price given X and the firm reverts its product whenever $E[A \mid A > c^*, X] < a_r$. The separating* *condition becomes*

$$\pi\left(E\left[A\right]\right) - M \leq \delta \ \min\left\{\pi\left(0\right), R\right\} + \pi\left(0\right) \tag{19}$$

Proof This proof generalizes Proposition 1 by both adding imperfect learning. The first period gain $G(c)$ to the type-c firm from modifying its product is identical to that in the perfect learning case, as no learning has yet occurred in the first period. The type c's expected loss L is the modification cost M plus the expectation of lesser of R and the difference in profits earned between rejecting the product modification and accepting it, where the expectation is taken with respect to the distribution of possible signals the type-c's consumers receive:

$$L(c) = M + \delta \ E_X \left[\min\left\{R, \pi(0) - \pi(E\left[A \mid A > c, X\right])\right\}\right], \tag{20}$$

where $X = a + \epsilon$ and the firm knows $a = c$ but ϵ is stochastic. First suppose R is never the minimum in equation (20). Observe that $E_X\left[\pi(E\left[A \mid A > c, X = c + \epsilon\right])\right]$ is monotonically increasing in c. This follows from the fact that $c_1 < c_2 \rightarrow \forall\epsilon$, $E\left[A \mid A > c_1, X = c_1 + \epsilon\right] < E\left[A \mid A > c_2, X = c_2 + \epsilon\right]$. Thus $L(c)$ is continuous and non-increasing in c. If instead R is sometimes the minimum in equation (20) then the integration with respect to X is taken of the constant R over some interval of signals and of the term $\pi(0) - \pi(E\left[A \mid A > c, X\right])$ on the remaining interval. By the arguments above and the fact that R is a constant and thus non-increasing in c we again conclude $L(c)$ is continuous and non-increasing in c. The proof of Proposition 1 now applies and the unique crossing condition is found by taking the limit $c \rightarrow -\infty$ of $G(c) < L(c)$. Thus by Lemma 1 partial separation occurs if and only if equation (19) holds. ■

Example 4 *We extend Example 1 by allowing imperfect learning from the noisy signal $X = a + \epsilon$ where a is the firm's true type and $\epsilon \sim U[-0.1, 0.1]$. As before, let $q = 1 - p + E[A]$, $A \sim U\left[-\frac{1}{2}, \frac{1}{2}\right]$, $M = \frac{1}{4}$, $\delta = \frac{9}{10}$, and $R = \frac{1}{20}$. Then in period 1 all types greater than $c^* \approx 0.106$ modify their products and charge price $p^H \approx 0.651$ whereas types below this threshold continue selling their existing product and charge $p^L = \frac{1}{2}$. In period 2 consumers form a posterior mean from signal x and the firm charges a price accordingly. No types revert to their old product because $c^* \geq 0$.*

Noting that the attribute adoption threshold in Example 1 was 0.136, we see that noisy learning encourages adoption of weak attributes due to a lower expected second period loss $L(c)$. This in turn implies a weaker innovation signal in the sense that adoption of an innovation has a less favorable impact on expected quality. These results are general phenomena, which we state in the proposition below.

Proposition 8 *The attribute adoption threshold is lower and the innovation signal is weaker when learning is noisy than when it is perfect.*

Proof The gain $G(c)$ is realized in the first period and therefore is not directly affected by the learning structure. The second period loss, however, is affected. For any non-degenerate prior and any realization of the noisy signal X, the posterior mean $E[A \mid A > c, X] > c$. That is, if the firm's true type is c then regardless of the signal received consumers' posterior expectation will always be more favorable when learning is noisy than when it is perfect. Therefore integrating the firm's profits over X preserves the inequality:

$$E_X\left[\pi\left(E[A \mid A > c, X]\right)\right] > E_X\left[\pi\left(c\right)\right] = \pi\left(c\right). \tag{21}$$

This implies the second period cost $L(c)$ in line (20) is weakly lower with noisy learning and therefore so too is the adoption threshold. Finally, a lower adoption threshold implies a weaker new product signal; i.e., $c_1 < c_2 \Rightarrow E[A \mid A > c_1] < E[A \mid A > c_2]$. ■

We now make a stronger assumption on the distribution of outcomes and signals in order to find that as learning from consumption becomes easier, firms apply a more stringent standard to releasing new products.

Proposition 9 *Let learning be imperfect with both noise and R&D outcomes normally distributed. Then the equilibrium threshold increases as the variance of the noise term decreases.*

Proof More formally, let $A \sim N(\mu, \sigma^2)$ and $\epsilon \sim N(0, \sigma_\epsilon^2)$*; the claim is* c^* weakly increases as σ_ϵ^2 *decreases.* Consider the error terms ϵ_i with variance $\sigma_{\epsilon_i}^2$ for $i = 1, 2$ where $\sigma_{\epsilon_1}^2 < \sigma_{\epsilon_2}^2$. Let $X_i = c + \epsilon_i$ be the noisy signal consumers receive when facing the threshold type-c firm given error term ϵ_i and define L_i by using X_i in equation (20). Then $E_{X_1}[\pi(E[A \mid A > c, X_1])] < E_{X_2}[\pi(E[A \mid A > c, X_2])]$ implies $L_2(c) \leq L_1(c)$, thus establishing the result. ■

Remark 7 *When learning is imperfect with both noise and R&D outcomes normally distributed, schlimmbesserung attributes are less likely to exist as the variance of the noise term decreases.*

The economic interpretation of Proposition 9 is intuitive. A higher variance for ϵ implies a more noisy consumption experience so that learning is difficult while a lower variance allows for better learning from experience and thus increases the likelihood that consumers will detect the firm's true type. Knowing this, firms are deterred on the margin from making relatively minor modifications when σ_ϵ^2 is low so that c^* increases. In particular, as σ_ϵ^2 decreases the firm optimally responds by choosing larger c^* so that $\Pr(\{A \in (c^*, 0]\})$ decreases.

This remark is of interest because of its potential empirical validation. Future research might seek to estimate σ_ϵ^2 by product category, quantify the benefits (or costs) of product enhancements made in these categories, and compare the proportion of harmful to total product enhancements across the estimated levels of σ_ϵ^2. Relatively higher proportions of harmful modifications in product categories for which learning is difficult is consistent with our model.

7 Conclusion

Previous research has proposed consumer preferences for "venturesomeness" or novelty to explain the high value consumers place on new products. We instead explain this phenomenon through the information revealed by the existence of a new product that has survived a firm's endogenous censoring rule. We explore the interaction between consumers' rational beliefs about "new and improved" products and a firm's incentive to introduce such products to consumers who are initially uninformed but later become better informed of the product's value. We find that product "newness" alone rationally signals higher quality on average and hence confers a pricing and demand premium.

This premium induces the firm to adopt attributes that would prove unprofitable had all consumers been informed. A new product may only be trivially different from its older version in the sense that its improvement in performance does not justify its higher price. The new product demand premium from uninformed consumers may even be so high that a firm will fail to censor a schlimmbesserung attribute ("improvement for the worse") from its R&D process in order that its product appear as new, notwithstanding the existence of better informed consumers in future periods. However, consumers rationally infer a weaker new product signal the higher the likelihood trivial and schlimmbesserung attributes are added.

Given this result, it may seem that innovation signaling arising from imperfect information will result in lower ex-ante welfare than when consumers are fully informed. However, full information suffers from its own problems: a monopolist has less marginal incentive to improve its product than does the social planner due to its desire to maximize profits, not welfare. The demand premium provided by the innovation signal alleviates this underinvestment problem by incentivizing the monopolist to adopt new attributes it otherwise would not, thus possibly improving welfare. The incentive to show-off with a new product may be too great though, "over-solving" the underinvestment problem and lowering welfare.

We show the robustness of these results by extending the model to a noisy learning environment in which initially uninformed consumers become better, though not perfectly, informed of the new product's value in the second period when they make their repeat purchase decision. This gives the firm even more incentive to adopt marginal attributes so that the attribute adoption threshold is lower and the new product signal is weaker when consumers learn through a noisy process rather than a perfect one. We also endogenize the R&D distribution and investigate how the motive to signal quality through selling a new version affects the ex-ante investment decision. Other potential extensions of the model include allowing the monopolist to concurrently sell the old and new versions of its product, and generalizing the model to an oligopoly context.

8 Appendix

Equivalence to a one-period model with some informed consumers

While our model contemplates a two-period setting in which initially uninformed consumers learn about quality and so are informed in the second period, the propositions of this paper have analogues in a one-period model in which consumers start with different information sets. This might occur because some consumers have subject-matter expertise relating to the product while others do not (experts versus non-experts). Or perhaps some consumers have low information acquisition costs (unmodeled) while others find it prohibitively costly to acquire information about new products but do know that other consumers are informed. Such a model can be shown to be equivalent to our two-period model in the case where the firm can price discriminate between the informed and uninformed consumers. If price discrimination is not possible, new product signaling may still exist but matters are complicated by the potential for price signaling.[28] Finally, the noisy learning aspect of the two-period model manifests itself as an imperfectly informed expert who draws a noisy but informative signal about the new product's quality while non-experts are unable to do so.

The logic of the equivalence between these two models is as follows: whereas in the two-period model the consumers in the second period served as a deterrent against very low types selling a "new and improved" product, in the one-period model informed consumers serve this same role. Thus a one-period model with consumers distributed on $[0, \overline{v}]$ according to g, of which a randomly selected proportion α are informed and

[28] Loosely, charging a high uniform price to informed and uninformed consumers alike is costly to a low quality firm if the proportion of informed consumers is high. If informed consumers are sufficiently rare, then such price signaling may fail while our existence results regarding new product signaling nonetheless persist.

$(1-\alpha)$ are uninformed is equivalent to a two-period model with consumers distributed on $[0, \overline{v}]$ according to $g' \equiv (1-\alpha)\ g$ and discount factor $\delta = \frac{\alpha}{1-\alpha}$. In period 1 there is a mass of $\int_0^{\overline{v}}(1-\alpha)\ g = (1-\alpha)$ consumers and in period 2 a discounted mass of $\delta \int_0^{\overline{v}}(1-\alpha)\ g = \alpha$ consumers. Note that when $\alpha > \frac{1}{2}$ we must *mathematically* allow for $\delta > 1$. The preceding discussion leads us to the following Proposition:

Claim 1 *The one-period model in which $1-\alpha$ of the mass g of consumers is uninformed is equivalent to a two-period model in which the entire mass $g' = (1-\alpha)\ g$ of consumers is uninformed in period 1 and informed in period 2, with discount factor $\delta = \frac{\alpha}{1-\alpha}$. Prior propositions apply in the one-period model and the separating condition of Proposition 1 becomes:*

$$(1-\alpha)\ \pi(E(A)) - M \leq \pi(0)) \tag{22}$$

The claim has intuitive appeal: as α increases so that the firm is facing a more informed set of consumers the equilibrium value of c increases and thus more lower-valued product modifications are censored. Equation 22 is true when the firm prefers to sell its old product to the entire set of consumers than selling the average new product to uninformed consumers only. We offer this alternative specification as a robustness check to our model.[29]

[29] Indeed, one may combine the two models so that in period 1 the proportion α_1 of consumers is informed while in period 2 α_2 is informed. It is natural to suppose $0 \leq \alpha_1 < \alpha_2 \leq 1$, either by a simple exogenously imposed learning rule or a more elaborately designed learning structure. In either event the preceding propositions can be shown to generally hold.

Details for Example 3 Let $q = 1 - p + E[A]$, $A \sim U\left[-\frac{1}{2} + e, \frac{1}{2} + e\right]$, $M = \frac{1}{4}$, $\delta = \frac{9}{10}$, $R = \frac{1}{20}$, and the increasing and convex cost of effort is given by $C(e) = \frac{1}{16 \ln 2}\left(2^{4e} - 1\right)$. Note this implies the revenue function is $\pi(a) = \left(\frac{1+a}{2}\right)^2$. We find the full information ("FI") firm's threshold:

$$\begin{aligned}(1+\delta)\,\pi(\widehat{c}) - M &= (1+\delta)\,\pi(0) \\ \widehat{c} &= \frac{1}{19}\sqrt{551} - 1 \approx 0.235\,44\end{aligned}$$

For $0 \leq e \leq \frac{1}{2} + \widehat{c} \approx 0.735$ some realizations will not be adopted by the FI firm, and expected profits in this case are

$$\begin{aligned}&(1+\delta)\int_{-\frac{1}{2}+e}^{\widehat{c}} \pi(0)\ \ f(a)\,da + \int_{\widehat{c}}^{\frac{1}{2}+e} [\pi(a) - M]\ \ f(a)\,da + \delta \int_{\widehat{c}}^{\frac{1}{2}+e} \pi(a)\ \ f(a)\,da \\ =\ & \frac{19}{120}e^3 + \frac{57}{80}e^2 + \frac{11}{32}e + \frac{29}{1140}\sqrt{551} - \frac{5}{64}\end{aligned}$$

while the marginal benefit from investment is

$$MB^{FI} = \frac{19}{40}e^2 + \frac{57}{40}e + \frac{11}{32}.$$

When $e > \frac{1}{2} + \widehat{c} \approx 0.735$, the distribution of outcomes will be so favorable that the FI always accepts each realization. In this case profits to the FI firm are

$$\begin{aligned}&\int_{-\frac{1}{2}+e}^{\frac{1}{2}+e} [\pi(a) - M]\ \ f(a)\,da + \frac{9}{10}\int_{-\frac{1}{2}+e}^{\frac{1}{2}+e} \pi(a)\ \ f(a)\,da \\ =\ & \frac{19}{40}e^2 + \frac{19}{20}e + \frac{127}{480}\end{aligned}$$

which implies the marginal benefit from investment is

$$MB^{FI} = \frac{38}{40}e + \frac{19}{20}$$

In summary,

$$MB^{FI} = \begin{cases} \frac{19}{40}e^2 + \frac{57}{40}e + \frac{11}{32} & for \quad 0 \leq e < \frac{1}{2} + \frac{1}{19}\sqrt{551} - 1 \\ \frac{38}{40}e + \frac{19}{20} & for \quad e \geq \frac{1}{2} + \frac{1}{19}\sqrt{551} - 1 \end{cases} . \tag{23}$$

We now turn to the imperfect information ("II") firm. The equilibrium threshold c^* found by solving

$$\begin{aligned} \pi\left(E\left[A|A > c\right]\right) + \delta\pi\left(c\right) - M &= \left(1+\delta\right)\pi\left(0\right) \\ \left(\frac{1 + \frac{1}{2}\left(\frac{1}{2} + e + c\right)}{2}\right)^2 + \frac{9}{10}\left(\frac{1+c}{2}\right)^2 - \frac{1}{4} &= \frac{19}{10} \times \frac{1}{4} \end{aligned}$$

which implies that[30]

$$c^* = \frac{1}{46}\sqrt{2}\sqrt{-180e^2 - 540e + 2263} - \frac{5}{23}e - \frac{61}{46}$$

Separation occurs in the subgame when $-\frac{1}{2} + e < c^*$, which corresponds to $0 \leq e <$

[30]We reject the root $-\frac{5}{23}e - \frac{1}{46}\sqrt{2}\sqrt{-180e^2 - 540e + 2263} - \frac{61}{46}$.

$\frac{1}{38}\sqrt{2114}-\frac{29}{38}\approx 0.447$. We now calculate the II firm's profits when there is separation:

$$\begin{aligned}
& (1+\delta)\int_{-\frac{1}{2}+e}^{c}\pi(0)\ f(a)\,da+\int_{c}^{\frac{1}{2}+e}[\pi(a)-M]\ f(a)\,da+\delta\int_{c}^{\frac{1}{2}+e}\pi(a)\ f(a)\,da \\
= & \frac{65\,981}{194\,672}e+\frac{57\,089}{3893\,440}\sqrt{2}B-\frac{19}{5840\,160}B^{\frac{3}{2}}+\frac{311\,847}{486\,680}e^2+\frac{103\,949}{730\,020}e^3 \\
& -\frac{95}{194\,672}\sqrt{2}e^2B-\frac{285}{194\,672}\sqrt{2}eB+\frac{8665}{389\,344}
\end{aligned}$$

where $B=\sqrt{-180e^2-540e+2263}$, which implies the marginal benefit from investment is $MB^{II}=$

$$\frac{2159\,950\sqrt{2}e-2494\,776Be-831\,592Be^2-659\,810B+461\,700\sqrt{2}e^2}{-1946\,720B}+\frac{102\,600\sqrt{2}e^3+2547\,375\sqrt{2}}{-1946\,720B}.$$

When $e\geq\frac{1}{38}\sqrt{2114}-\frac{29}{38}\approx 0.447$ there is pooling and we find profits for the II firm as

$$\begin{aligned}
& \int_{-\frac{1}{2}+e}^{\frac{1}{2}+e}[\pi(a)-M]\ f(a)\,da+\delta\int_{-\frac{1}{2}+e}^{\frac{1}{2}+e}\pi(a)\ f(a)\,da \\
= & \frac{19}{40}e^2+\frac{19}{20}e+\frac{127}{480}
\end{aligned}$$

which implies

$$MB^{II}=\frac{38}{40}e+\frac{19}{20}$$

In summary, the marginal benefit from effort is

$$\begin{cases}\frac{-\left(2159\,950\sqrt{2}e-2494\,776Be-831\,592Be^2-659\,810B+461\,700\sqrt{2}e^2+102\,600\sqrt{2}e^3+2547\,375\sqrt{2}\right)}{1946\,720B}, & e<0.447\\ \frac{38}{40}e+\frac{19}{20}, & e\geq 0.447\end{cases}\tag{24}$$

We now solve for the optimal ex-ante investment level under full and imperfect information, denoted e_{FI}^{*} and e_{II}^{*} respectively. Given $C(e) = \frac{1}{16\ln 2}(2^{4e}-1)$, the marginal cost of investment is $MC(e) = \frac{2^{4e}}{4}$. We set this equal to MB^{FI} found in line 23 and solve $\frac{2^{4e}}{4} = \frac{19}{40}e^2 + \frac{57}{40}e + \frac{11}{32}$ to find $e_{FI}^{*} \approx 0.628$. Similarly we equate $MC(e)$ and MB^{II} found in line 24 and solve $\frac{2^{4e}}{4} = \frac{38}{40}e + \frac{19}{20}$ to find $e_{II}^{*} \approx 0.665$.

We now calculate the FI firm's expected profits when $e_{FI}^{*} = 0.628$.

$$\begin{aligned} & \left(\frac{19}{120}e^3 + \frac{57}{80}e^2 + \frac{11}{32}e + \frac{29}{1140}\sqrt{551} - \frac{5}{64}\right) - C(e) \\ \approx \; & 0.631 \end{aligned}$$

Consumer surplus in this case is found using the facts that $q = 1-p+a$ and $\widehat{c} \approx 0.235$, and $e_{FI}^{*} = 0.627978$ implies $A \sim U[0.127978, 1.127978]$.

$$\begin{aligned} & 2\left(\frac{1}{8}\int_{0.127978}^{0.235\,44} da + \int_{0.235\,44}^{1.127978} \frac{1}{2}\left(\frac{1+a}{2}\right)^2 da\right) \\ = \; & 0.672\,74 \end{aligned}$$

so that total surplus under FI is

$$TS^{FI} = 1.303\,7.$$

We now calculate profits and consumer surplus under II. Expected profits given $e_{II}^{*} = 0.665$ are

$$\begin{aligned} & \left(\frac{19}{40}e^2 + \frac{19}{20}e + \frac{127}{480}\right) - C(e) \\ \approx \; & 0.626\,66 \end{aligned}$$

Expected consumers surplus is calculated using $q = 1 - p + a$, and $e^*_{II} = 0.665486$ implies $A \sim U[0.165486, 1.165486]$. Also, since $e^*_{II} > 0.446\,80$ there is pooling which implies in the first period consumers have beliefs $E(A) = 0.665486$. Thus in the first period $p = 0.832\,74 = q$ and consumer surplus in this period is

$$\begin{aligned} CS_1^{II} &= \int_{0.165486}^{1.165486} \left(\int_0^{0.832\,74} ((1 - q + a) - 0.832\,74)\, dq \right) da \\ &= 0.346\,73 \end{aligned}$$

while in the second period it is

$$\begin{aligned} CS_2^{II} &= \int_{0.165486}^{1.165486} \frac{1}{2} \left(\frac{1+a}{2} \right)^2 da \\ &= 0.357\,15 \end{aligned}$$

Thus $CS^{II} = 0.346\,73 + 0.357\,15 = 0.703\,88$ and we find

$$TS^{II} = 1.\,330\,5$$

and thus total surplus is higher under II than FI. ■

Chapter 2: Physician Overtreatment and Undertreatment with Partial Delegation

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Abstract

The physician induced demand literature finds that doctors tend to overtreat patients for financial gain. We analyze this phenomenon when patients are rationally skeptical of doctors' motives and can reject a proposed treatment. We find the classic physician induced demand approach understates patients' welfare loss: treatment on average is excessive but also less medically appropriate, and the latter effect may dominate. Inappropriate treatment arises from the doctor's strategic misdiagnosis to forestall rejection, but this problem can be attenuated by insurance which better aligns incentives and improves communication. We resolve an open question in the partial delegation literature by showing that a generalization of the Krishna and Morgan (2001) equilibrium is the most informative equilibrium that survives the intuitive criterion in a setting that nests both our and their model.

Keywords: physician induced demand, over-utilization, non-compliance, partial delegation, cheap talk

JEL Classification: D82, I10

1 Introduction

Excessive treatment is a widely recognized problem in the United States health care market, with estimates of avoidable clinical care at 30% of total health care spending.[1] An often cited cause of this phenomenon is the financial incentive of doctors to prescribe more treatment than is medically prudent (Emanuel and Fuchs, 2008). Doctors prescribe medicines with a higher markup when they profit from dispensing medicine (IIzuka, 2007), perform more caesarean deliveries when fee differentials between normal and cesarean childbirths are higher (Gruber et al., 1999), and are more likely to recommend radiation treatment for cancer when the prescription is self-referring (GAO, 2013).

The physician induced demand (PID) hypothesis posits that due to their informational advantage doctors can induce higher preferences for treatment by overstating the severity of a patient's condition (Evans, 1974; McGuire, 2000). While this theory predicts overtreatment, its implication of a fully compliant patient is inconsistent with findings that physicians' orders are often ignored due to a lack of trust (Brownlie et al., 2008), specifically when the patient suspects a doctor's financial motive (Chen and Vargas-Bustamante, 2013).

When patients are rationally skeptical of doctors' motives it is no longer clear that the PID hypothesis holds. If the doctor expects the patient to be suspicious of the diagnosis, might the doctor propose a weaker instead of stronger treatment to keep the proposed treatment from being rejected? Or might the doctor exaggerate the

[1] New England Healthcare Institute (Feb 2008), "Waste and inefficiency in the U.S. health care system" and Thomson Reuters (Oct 2009), "Where can $700 billion in waste be cut annually from the U.S. healthcare system?" *White Paper.* Robert Kelley, Vice President of Healthcare Analytics Thomson Reuter.

diagnosis even more to make the patient too scared to reject the treatment? Is the equilibrium incentive to under- or overtreat constant across all health states or are some illnesses more likely to be under- or overtreated than others? Finally, would a policy of reducing the financial incentives of doctors, such as reducing reimbursements, banning self-referrals, or instituting tort reform, improve the welfare of patients?

To address these questions, we model the interaction between an informed doctor and an uninformed patient as a game of partial delegation (e.g., Gilligan and Krehbiel, 1987; Krishna and Morgan, 2001). The doctor observes the health of the patient and prescribes a treatment, which the patient may either accept or reject in favor of whatever treatment is available without the doctor's prescription.[2] Thus the doctor plays both the role of an informed expert and an authority that determines the set of available options. The doctor and patient agree on the medical prudence of a treatment, but disagree due to financial considerations. Additional treatment is more costly for the patient and is more profitable for the doctor, so that for any illness the doctor prefers more treatment than the patient.

We find that on net the patient undergoes more treatment in equilibrium than he would prefer, so the PID hypothesis holds. In fact, the average treatment is exactly what would ensue if the patient blindly followed the doctor's orders as in the classic approach to PID without patient skepticism. More importantly, we demonstrate that the classic PID hypothesis significantly understates the welfare impact of doctors' financial incentives by ignoring strategic considerations. Patients not only receive too much treatment but the treatment they receive is also on average less medically appropriate.

Less appropriate treatment arises from the doctor altering his diagnosis to over-

[2] In the main model the outside option is no treatment. In a later section we allow the patient to seek out a second opinion.

come patient skepticism. For mild illnesses, the doctor prescribes a minimal treatment to avoid being rejected and for intermediate illnesses, the doctor exaggerates the diagnosis to induce the patient to accept a high treatment. This leads to under- and overtreatment in that for some illnesses the patient receives less treatment than either he or the doctor would prefer and for other illnesses he receives more treatment than either would prefer. The presence of over- and undertreatment is important for patient welfare: although it turns out not to impact the *level* of average treatment, it reduces the average medical *appropriateness* of treatment. The impact of the doctor's financial incentive on patient welfare through the medical appropriateness of treatment is of a similar magnitude, and sometimes larger, than the impact through treatment level. We demonstrate the existence of over- and undertreatment regions is robust to model extensions in which patients may seek a second opinion or in which some consumers naively accept all treatment recommendations.

As fees for medical services increase, both overtreatment and undertreatment also increase. A higher fee increases the distance between the doctor's and patient's preferred treatments, which exacerbates the doctor's incentive to strategically misdiagnose and leads to less appropriate treatment. We use this principle to investigate the effect of actuarially fair insurance on treatment. A patient who purchases insurance reduces his ex-post cost of medical services, bringing his incentives closer to the doctor's and leading to more effective communication and thus more appropriate treatment. On the other hand, having insurance makes a patient less likely to reject treatment, for which he must pay ex-ante with a higher premium. We demonstrate that when the patient's health state is distributed uniformly, the former communication effect dominates the latter moral hazard effect and the patient prefers full insurance. Thus even risk neutral patients find insurance valuable as a means to reduce the doctor's incentive to strategically misdiagnose.

Our paper is related to the work of Pitchik and Schotter (1987) and De Jaegher and Jegers (2001) who analyze a cheap talk game in which doctors make a recommendation to skeptical patients who can obtain any available treatment. The authors depart from the standard Crawford and Sobel (1982) framework by assuming that the doctor prefers the maximal treatment regardless of the patient's health and that doctors and patients have a different ordering over treatments. No pure strategy equilibrium can be supported and instead there exists an equilibrium in mixed strategies in which under- and overtreatment occur. Since in our model the doctor's preferred treatment depends on the patient's health, patients are not free to choose among all treatments, and the preference ordering adheres to the Crawford Sobel paradigm, we obtain qualitatively different predictions. For example, an increase in the patient's out-of-pocket price of the high treatment in De Jaegher and Jegers (2001) increases patient welfare while we find the opposite in our setting. Finally, other factors affecting the doctor's incentive to overprescribe treatment have been explored, including the role of reputation (Dranove, 1988) and second opinions (Rochaix, 1989; Pitchik and Schotter, 1993).

We model the doctor-patient relationship in a partial delegation framework since it captures the common situation where patients have veto-power over treatments but do not have the authority to unilaterally pursue their own treatment. Alternatively, communication could be modeled within a cheap talk framework where the patient has decision-making power and the physician acts solely as an advisor; e.g., when the patient discusses over-the-counter medicine with a pharmacist. In this case the Crawford and Sobel (1982) model predicts that communication is noisy so there is both over- and undertreatment, but that average treatment is no higher or lower than without communication; i.e., there is no PID overall. At the other extreme the relationship could be modeled as full delegation (Dessein, 2002) where the patient cedes all decision-making power to the doctor; e.g., when a patient is institutionalized. In this case patient skepticism is irrelevant and the doctor always gets his preferred choice so there is always PID as in the classic approach without any variation due to strategic diagnosis. Comparing these approaches, partial delegation not only captures what is arguably the typical doctor-patient relationship, but is the only one of the three standard frameworks that features non-trivial PID.

In addition to applying partial delegation to the issue of PID, we also contribute to the general literature on partial delegation models in which a principal delegates decision making authority to an informed agent but retains the right to veto in favor of the status quo option. Of particular relevance is Krishna and Morgan's (2001) analysis of legislative rules that models an informed but biased committee comprised of homogeneous members that makes policy proposals to an uninformed legislature.[3] For a range of values of the status quo they compare the informativeness of equilibria under cheap talk versus partial delegation. While they find a partial delegation equilibrium that dominates all cheap talk equilibria, whether or not this equilibrium is the best partial delegation equilibrium has remained an open question. Our strategic environment differs from theirs in that the status quo in our model is no treatment while in their model the status quo is a moderate policy in the interior of the action space. In a general setting that nests both models, we characterize the set of equilibria which

[3] Gilligan and Krehbiel (1987; 1989) were the first to posit an informational rationale for rules that restrict amendments to committee proposals, while Krishna and Morgan followed up on their analysis.

survive the intuitive criterion and identify the most informative equilibrium.[4] In the process we confirm that Krishna and Morgan's equilibrium is most informative given their status quo assumption, thereby providing additional justification for the use of their equilibrium in other contexts where it is applied.

The rest of the paper proceeds as follows. In Section 2 we review the medical literature on the existence of and explanations for both over- and undertreatment. Section 3 outlines the model while Section 4 characterizes the most informative equilibrium that survives the intuitive criterion and explores comparative statics on policy variables affecting the financial incentives of doctors and patients. In Section 5 we explore the role of health insurance as a means for a patient to commit to accepting the doctor's treatment. Section 6 confirms that over- and undertreatment persist even when patients can obtain a second opinion or some proportion of patients always naively comply with a doctor's recommendation. Section 7 concludes.

2 Medical literature on over- and undertreatment

> ...up to one-third of the over $2 trillion that we now spend annually on health care is squandered on unnecessary hospitalizations; unneeded and often redundant tests; unproven treatments; over-priced, cutting-edge drugs; devices no better than the less expensive products they replaced; and end-of-life care that brings neither comfort nor cure (*Dartmouth Medicine*, 2007).

Discussion of overtreatment in the United States health care market is commonplace

[4] Marino (2007) uses the intuitive criterion in a partial delegation setting, though the exercise is to check the criterion is satisfied by a particular equilibrium rather than characterizing the full set.

and so we do not relay the litany of statistics here again. However, we do briefly explore reasons for this overtreatment. As with undertreatment subsequently discussed below, it is difficult for the researcher observe whether a given treatment was inadequate or excessive as this requires knowledge of the patient's true health state. This should be kept in mind in the discussion below.

Emanuel and Fuchs (2008) suggest four main drivers of overutilization attributable to physicians. First, they posit a medical culture in which meticulousness, not efficiency, is rewarded; a "more is better" mindset does not adequately consider the cost of care. Second, the fee-for-service payment system incentivizes physicians to perform unnecessary tests and procedures. This is compounded by significantly higher reimbursements for tests and procedures than evaluation and management of conditions. Third, the abundance of new medical devices and pharmaceuticals forces physicians to rely upon potentially biased industry marketing reps for information. Finally, physicians engage in defensive medicine to shield themselves from claims of malpractice.

Some researchers have even proposed that excess supply causes overutilization; thus, for example, more aggressive care for chronically ill patients in cities like Los Angeles and Miami is caused by "more hospital beds per capita, more medical specialists, and more internists" (*Dartmouth Medicine*, 2007). Patients also play their part in overtreatment, be it due to a patient bias for high technology over high touch, the affects of direct-to-consumer marketing, and the moral hazard introduced by a third-party payment system (Emanuel and Fuchs, 2008).

The medical and health economics literature has studied the physician's influence on a patient's actions though the notion of "physician-induced demand." McGuire (2000) offers the following definition: "physician-induced demand (PID) exists when the physician influences a patient's demand for care against the physician's interpretation of the best interest of the patient." Evans (1974) provided the first theoretical model of PID, variants of which (McGuire and Pauly, 1991; Gruber and Owings, 1996) remain popular among empiricists testing for evidence of the phenomenon. In these models, the doctor can alter a patient's preferences for the quantity of treatment through his level of inducement. While the doctor's utility is increasing in income (and thus the quantity of treatment provided), it is decreasing in inducement due to a psychological cost of misleading his patient. Empirical studies of PID predominantly use this framework to test physician responses to changes in the doctor to population ratio or to fee changes. A limitation of the Evans paradigm is its lack of explicit consideration of the patient's decision making process, which is central to our analysis below.

There is also an extensive medical literature on patient "non-adherence" or "non-compliance" with a physician's recommendations, possibly leading to undertreatment. Generally speaking, compliance can be defined as the extent to which a patient's behavior coincides with medical or health advice (Vermeire et al., 2001). Recent studies on prescription drug non-compliance found that 22% of all prescriptions are never filled (Fischer et al., 2010) while this rate was slightly higher for newly prescribed drugs (Fischer et al., 2011). One meta-analysis of patient compliance to a range of treatment regiments (e.g., medication, screening, exercise, health behavior, appointment, diet) found an average non-adherence rate of about 25% (DiMatteo, 2004b) while another concluded that "poor compliance is to be expected in 30-50% of all patients, irrespective of disease, prognosis, or setting" (Vermeire et al., 2001).

Numerous explanations and correlates for non-compliance have been proposed: cost; demographic variables; the duration of the treatment, the number of medications prescribed and frequency of dosing; salience / mindfulness; direct-to-consumer advertising; side-effects; complexity of the regimen and poor physician communication; illness severity; lack of transportation to medical facilities; lack of social support; depression; and, though difficult to measure, the nature of the doctor-patient relationship (Bowman et al, 2004; Dellande et al, 2004; DiMatteo, 2004a and 2004b; DiMatteo et al., 2000; DiMatteo et al, 2007; Hausman, 2004; Vermeire et al., 2001; Wosinska, 2005; Wroth and Pathman, 2006; Zolnierek and DiMatteo, 2009). More generally, compliance is influenced by the perceived costs, benefits, and efficacy of care (Becker and Maiman, 1975) as argued by the well-known Health Belief Model:

> Compliance is thought to be determined by the knowledge and attitudes of the patient. Patients must believe that they are vulnerable or susceptible to the disease or its consequences, that they actually have it, and that the consequences of the disease on their well-being could be serious. They must believe that by following a particular set of health recommendations the threat or severity of the condition will be abolished or reduced (Vermeire et al., 2001).

The centrality of patient beliefs to the compliance decision underscores another crucial factor: patient trust in a physician. Trust has been shown to affect patients' utilization of medical services (Ling et al., 2006; Miller et al., 2001; Mollborn et al., 2005) and adherence to therapeutic regimens (Stepanikova and Cook, 2008). The latter includes accepting and adhering to a prescription drug schedule (Altice et al., 2001; Kerse et al., 2004; Thom et al., 1999); adherence to behavioral advice about smoking, alcohol use, seat belt use, diet, exercise, stress, and safe sex practices (Safran et al., 1998); willingness to undergo invasive testing (Collins et al., 2002); and intentions to comply with physician advice generally (Keating et a, 2002; Thom et al., 2002).

Trust in physicians is often strained by patients' perception of bias. The pharmaceutical industry in particular is viewed with suspicion (Goff et al., 2008). Surveys of the public reveal that a majority believe their doctor receives gifts from the pharmaceutical industry and that those with such beliefs are more likely to report low physician trust (Grande et al., 2012). In addition, doctors with higher self-reported ties to industry have higher patient non-compliance with treatment recommendations (Chen and Vargas-Bustamante, 2013). Patients might be wise to consider their doctor's financial motives in recommending a particular treatment. For example, researchers have found that larger fee differentials between cesarean and normal childbirth for the Medicaid program leads to higher cesarean delivery rates (Gruber, Kim, and Mayzlin, 1999). In this paper we argue that doctor bias and the resulting lack of trust by patients is a key friction undermining the credible transmission of information from doctor to patient.

3 Model

A patient's health state θ is distributed uniformly on $[0, 1]$, with higher values corresponding to more serious illnesses. A doctor observes the realization of θ and makes a recommendation $m \geq 0$ for treatment. The patient knows only the distribution of θ and can either take the prescribed treatment $a = m$ or a status quo $a = 0$ representing no treatment.

Payoffs for the doctor and patient are

$$u_d(a\ |\theta) = -\frac{1}{2}(\theta - a)^2 + (p - c)\, a,$$
$$u_p(a\ |\theta) = -\frac{1}{2}(\theta - a)^2 - pa.$$

The first term in each payoff reflects the medical prudence of a treatment, on which both the doctor and patient agree. The second term captures financial incentives, whereby the patient pays the doctor a price p for each unit of treatment and the doctor incurs a marginal cost c. Both p and c are exogenous and we assume that $p \geq c$. For any health state θ the doctor's preferred treatment is

$$a_d^*(\theta) = \theta + (p - c)\,,$$

and the patient's preferred treatment is

$$a_p^*(\theta) = \theta - p.$$

Preferences closely resemble those in standard cheap talk (e.g., Crawford and Sobel, 1982) and delegation (e.g., Krishna and Morgan, 2001; Dessein, 2002) models in which the preferred action of the doctor exceeds that of the patient by a fixed amount captured by a "bias" parameter, and the loss from suboptimal actions is quadratic. By explicitly incorporating financial incentives here, we can perform comparative statics on the price and cost of treatment, and later on insurance, that would not be feasible with a standard reduced-form bias parameter.

We solve for a perfect Bayesian equilibrium, namely a strategy $m(\theta)$ for the doctor and a strategy $a(m)$ and posterior distribution $F_m(\theta)$ for the patient so that strategies are mutual best responses and beliefs are formed by Bayes rule whenever possible. For the purpose of equilibrium characterization it will be sufficient to consider the patient's posterior expectation $\mu(m) \equiv \int \theta \; dF_m(\theta)$ conditional on message m.

4 Equilibrium and Comparative Statics

Under the strict notion of PID the doctor induces his preferred treatment for every health state. We begin this section by demonstrating this notion of PID does not survive when patients are skeptical and can reject treatment.

Lemma 1 *There is no equilibrium in which $a(\theta) = \theta + (p - c)$ for all θ.*

This follows from the fact that in such a conjectured equilibrium, the patient perfectly infers his health. Specifically, when the doctor prescribes action $p - c$, the patient understands that his health is $\theta = 0$, for which his outside option is best and thus he rejects. While the strict notion of PID does not survive, we will show it may still exist in this context if it is interpreted in terms of average treatment.

Next we characterize our equilibrium and restrict attention to parameters for which doctor and patient preferences are sufficiently aligned, namely we assume $3p - c \leq \frac{1}{2}$ throughout the paper.[5]

Proposition 1 *Let $3p - c \leq \frac{1}{2}$. Then $m(\theta)$, $a(m)$, and $\mu(m)$ constitute a perfect*

[5] Parameters outside this range can still support equilibria with information transmission but lead to corner solutions that complicate the analysis and are omitted for clarity. In Appendix A, we remove this parameter restriction when solving for the full set of equilibria that survive the intuitive criterion.

Bayesian equilibrium when defined as follows. The doctor prescribes

$$m(\theta) = \begin{cases} p - c & \text{if } 0 \leq \theta < 3p - c \\ 7p - 3c & \text{if } 3p - c \leq \theta \leq 6p - 2c \\ \theta + p - c & \text{if } 6p - 2c < \theta \leq 1 \end{cases}$$

The patient accepts treatment if and only if prescribed as above and has beliefs

$$\mu(m) = \begin{cases} 0 & \text{if } 0 \leq m < p - c \\ \frac{3p-c}{2} & \text{if } m = p - c \\ \frac{m-(p-c)}{2} & \text{if } p - c < m < 7p - 3c \\ \frac{9p-3c}{2} & \text{if } m = 7p - 3c \\ m - (p - c) & \text{if } 7p - 3c < m \end{cases}$$

The proof that this constitutes a perfect Bayesian equilibrium is a special case of the more general equilibrium characterization in Appendix A and therefore omitted here. An example of the equilibrium for particular values of p and c is depicted in Figure 1. The two dashed lines represent preferred actions: the line below represents the patient's preferences and the line above the doctor's. For mild illnesses the patient receives a single minimal treatment that is less than what the doctor prefers and, for some states, also less than what the patient prefers. For intermediate illnesses, the patient receives a large treatment that is higher than his and even the doctor's preferred action. For sufficiently serious illnesses, the patient receives the treatment preferred by the doctor.

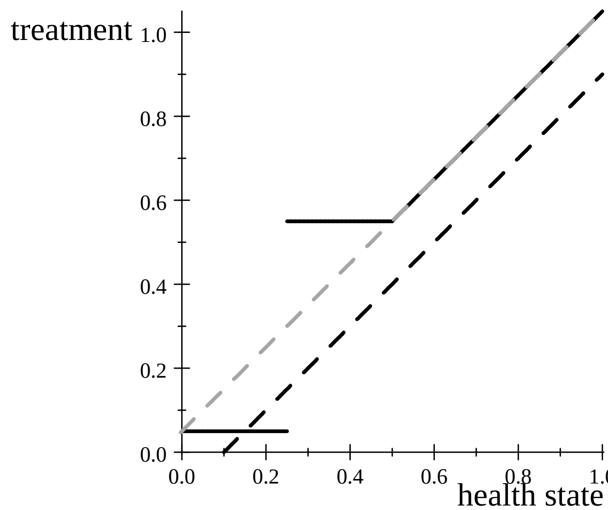


Figure 1: In solid, equilibrium treatment when $p = 0.1$ and $c = 0.05$. In dark dashed, the patient's preferred treatment as a function of the health state. In light dashed, the doctor's preferred treatment as a function of the health state.

Treatments in the intervals $a \in (0, p - c) \cup (p - c, 7p - 3c)$ are off-the equilibrium path and thus admit a variety of beliefs. The particular beliefs above were chosen for concreteness and we will later show they satisfy the intuitive criterion.

The logic behind the equilibrium reflects the fact that the patient has the option of no treatment and is skeptical of the doctor's motives. The patient accepts a significant treatment only when he infers from the diagnosis that he is quite sick. This accounts for the fact that in equilibrium intermediate treatments $a \in (p - c, 7p - 3c)$ are rejected. When the doctor's preferred treatment falls in this range, he must choose whether to overstate beyond his financial incentive or conversely to understate and induce a minimal treatment instead of being rejected altogether. In equilibrium the doctor does both: he induces a single minimal treatment for relatively healthier states ($0 \leq \theta \leq 3p - c$) and a single overly strong treatment for relatively sicker states ($3p - c \leq \theta \leq 6p - 2c$).

The doctor's inability to customize his diagnosis based on his information reduces average treatment appropriateness, and in this way patient's skepticism exacerbates the effect of the doctor's financial incentives.

Equilibrium Selection

It is well-known that in games of communication, and in particular in our partial delegation setting, there is a multiplicity of equilibria. For example, there exists a trivial equilibrium in which the patient accepts only zero treatment, which is supported by off the path beliefs that any prescription for a strictly positive treatment is made when the doctor observes $\theta = 0$. While this particular equilibrium does not survive standard refinements, the equilibrium set contains other non-trivial equilibria which may not be ruled out so easily.

The issue of equilibrium selection has played an important role in this literature, namely related to the question of whether partial delegation or cheap talk is the better communication mechanism. Gilligan and Krehbiel (1987, 1989) identify a partial delegation equilibrium and a cheap talk equilibrium and demonstrate that depending on parameter values either can dominate the other. Krishna and Morgan (2001) follow up on this work by finding a different partial delegation equilibrium that dominates all cheap talk equilibria, thus concluding that partial delegation is the better protocol. However, the authors leave open whether the equilibrium they find is most informative. Since the aim of our work is not to compare mechanisms but rather to explore equilibrium properties, the unresolved question of selection in the partial delegation framework is central to our analysis.

Our approach is to focus only on equilibria that survive the Cho and Kreps (1987) intuitive criterion, and of this set select the equilibrium which is most informative, defined as follows:

Definition 1 *The informativeness of an equilibrium is* $Var[\theta - a(\theta)]$.

Krishna and Morgan provide justification for informativeness as an appropriate metric by which to measure equilibria. In our model and the Crawford and Sobel framework in general, the quadratic loss function implies that the preferences of the doctor and the patient can be decomposed into preferences over the average treatment and the variance of treatment. Conditional on average treatment, both the doctor and patient are better off when variance is reduced, thus the set of treatment allocations which minimize variance can be thought of as a Pareto frontier. Under cheap talk, all equilibria are associated with the same expected treatment, hence if welfare is the weighted sum of the utilities of the doctor and the patient, maximizing informativeness is equivalent to maximizing welfare regardless of the weights. In the partial delegation environment, different equilibria may be associated with different expected actions, thus moving to an equilibrium with less variance but a different expected treatment may harm either the doctor or the patient. However, the move to less variance is a move toward the Pareto frontier, and since in our specification preferences are quasilinear in health and money, this move would make both parties better off given an appropriate cash transfer.[6]

Using both the intuitive criterion and informativeness for equilibrium selection, we obtain the following results.

[6] An alternative approach is to rank equilibria based on a specific weighted average of the utilities of the doctor and patient. The choice of such weights would be arbitrary, especially given that both parties have some control over the treatment decision.

Proposition 2 *The equilibrium in Proposition 1 is the most informative equilibrium that survives the intuitive criterion.*

Proposition 3 *The closed rule equilibrium in Proposition 8 in Krishna and Morgan (2001) is the most informative equilibrium that survives the intuitive criterion in their parameter range.*

The proof of both of these propositions is obtained by characterizing the most informative equilibrium that survives the intuitive criterion in a more general setting which nests both our model and the model of Krishna and Morgan (2001). In particular, the framework allows for a fuller range of treatment preference parameters and a status quo of zero as in our model or interior status quo as in Krishna and Morgan (2001). The details can be found in Appendix A.

Equilibrium Properties

Lemma 1 demonstrates that the strict notion of the PID hypothesis, in which the doctor induces his preferred action for every illness, does not survive in our setting with skeptical patients. However, the following corollary demonstrates that PID still holds in our context when reinterpreted in terms of average treatment.

Corollary 1 *In the equilibrium in Proposition 1,* $E[a(\theta)] = E[\theta] + (p - c)$.

Stated differently, the expected treatment in equilibrium is exactly what would ensue if the doctor could induce his preferred treatment for every illness. An empirical analysis which finds an increased average treatment level in the presence of doctors' financial incentives is thus consistent both with the classic notion of PID and with our partial delegation framework. However, due to the information loss associated with partial delegation, the classic PID model understates the welfare effect of doctor's financial incentives, and we explore this here in more detail.

Definition 2 *State θ is overtreated if $a(\theta) > a_d^*(\theta)$ and undertreated if $a(\theta) < a_p^*(\theta)$.*

Thus an illness is overtreated if the treatment exceeds that preferred by the doctor and undertreated when it falls below that preferred by the patient. We use weak definitions of over- and undertreatment by remaining agnostic about the relative weights on the utilities of the doctor and patient. Alternatively, one may construct a sharper definition of over- and undertreatment by defining a benchmark that would be chosen by a social planner. For example, a social planner that weighs the medical prudence of an action against its true cost would have a utility $u_{sp}(a|\ \theta) = -\frac{1}{2}(\theta - a)^2 - ca$ and an optimal treatment plan $a_{sp}^*(\theta) = \theta - c$. It is clear that the existence of over- and undertreatment under our weak definition implies the existence of over- and undertreatment with respect to this benchmark, in fact with respect to any benchmark in which the preferred action falls between the preferred actions of the doctor and patient.

In Figure 1, undertreatment occurs for some states for which the minimal treatment ($a = p - c$) is undertaken and overtreatment occurs for all states for which the high treatment ($a = 7p - 3c$) is undertaken. More generally, we show that over- and undertreatment are guaranteed to occur for all parameters p and c admissible in Proposition 1.

Corollary 2 *In the equilibrium in Proposition 1 both under- and overtreatment exist. Namely, states $\theta \in (2p - c, 3p - c]$ are undertreated and $\theta \in (3p - c, 6p - 2c)$ are overtreated.*

Proof By construction of the equilibrium in Proposition 1, it can be verified that for health states near but below the state $\theta = 3p - c$ at which there is a discontinuity in treatment, the equilibrium treatment of $p - c$ is below that preferred by the patient. For all states above $\theta \in [3p - c, 6p - 2c)$ the treatment is greater than that preferred by the doctor. ■

The notions of over- and undertreatment help us understand the informational effects of a doctor's financial incentives beyond their effect on average treatment level. For any two treatment plans $a_1(\theta)$ and $a_2(\theta)$ for which $E[a_1(\theta)] = E[a_2(\theta)]$, both the doctor and the patient prefer plan $a_1(\theta)$ whenever it has less over- and undertreatment than $a_2(\theta)$. This is because plan $a_1(\theta)$ induces actions that are closer to those preferred by both the doctor and patient than treatment plan $a_2(\theta)$, and thus we refer to it as more appropriate.

The connection between over- and undertreatment and patient welfare can be formally established by decomposing the effect of doctors' financial incentives on equilibrium treatment. First, denote by $U_p(a(\theta)) \equiv E[u_p(a(\theta)|\theta)]$ the patient's expected utility from following treatment plan $a(\theta)$. Recall that $a_p^*(\theta)$ and $a_d^*(\theta)$ are the patient's and doctor's first best treatment plans, and let $a_{eqm}(\theta)$ be the equilibrium treatment plan. The equilibrium utility loss for the patient relative to his first best can be expressed as

$$\underbrace{U_p(a_p^*) - U_p(a_{eqm})}_{\text{Total Welfare Loss}} = \underbrace{U_p(a_p^*) - U_p(a_d^*)}_{\substack{\text{Loss from} \\ \text{Classic PID}}} + \underbrace{U_p(a_d^*) - U_p(a_{eqm})}_{\substack{\text{Loss from} \\ \text{Treatment Appropriateness}}}$$

The first term on the right hand side describes the difference in the patient's utility between obtaining his or the doctor's first-best treatments. We label this term the classic PID effect since Corollary 1 established that the average equilibrium treatment is the same as if the doctor induced his preferred treatment for every state. Because it is never optimal for the doctor to induce over- or undertreatment as we have defined them, the impact of these outcomes must be contained in the second term of the decomposition, which we now demonstrate is strictly positive.

Corollary 3 *The loss in treatment appropriateness is strictly positive; that is,*

$U_p(a_d^*) - U_p(a_{eqm}) > 0.$

Proof The patient's expected utility from any treatment profile $a(\theta)$ can be expressed as the sum of two terms:

$$U_p(a(\theta)) = -\frac{1}{2}E[(a(\theta) - \theta)^2] - pE[a(\theta)].$$

Moving from the doctor's first-best treatment profile to the equilibrium treatment profile constitutes a mean preserving spread in $a(\theta) - \theta$. Thus for equilibrium treatments the first term is larger than and the second term is equal to that under the doctor's first-best treatment profile. ■

Corollary 3 confirms that by ignoring treatment appropriateness classic PID understates the impact of a doctor's financial incentives on patient welfare. In fact, we now show that treatment appropriateness can be a more important consideration than treatment level.

Corollary 4 *When the marginal cost of treatment c is high, treatment inappropriateness harms patient welfare more than treatment level; that is,*

$U_p(a_p^*) - U_p(a_d^*) < U_p(a_d^*) - U_p(a_{eqm})$.

The proof is included in Appendix B, however here we provide a brief sketch. Conjecture a situation in which the doctor fully passes through an increase in cost c. Since the doctor's markup $p - c$ is unchanged, his preferred treatment remains unchanged and by extension so does the average treatment undertaken in equilibrium. However, since the patient's price of treatment increases, the incentives of the doctor and patient diverge and this leads to less appropriate treatment. When c is increased sufficiently in this margin-neutral way, the loss from ineffective treatment can surpass the loss from the treatment level.

Our results about the expected level of treatment in Corollary 1 and the expected appropriateness of treatment in Corollary 3 can be understood in the context of how the partial delegation environment is situated between pure cheap talk (Crawford Sobel, 1982) and full delegation (Dessein, 2002). With cheap talk, the patient is unrestricted in his choice of treatment and for every diagnosis maximizes expected utility conditional on his posterior. Because the patient's posterior is correct, it is as if the patient chooses his first best treatment on average, thus there is no PID, but because communication is coarse the patient sometimes chooses ineffective treatment.[7] The other extreme is full delegation, in which the patient has no choice and must accept the doctor's preferred action. There is no noise, which causes treatment to be appropriate, and PID exists in the strict sense. Under partial delegation, the doctor is neither simply an advisor nor the decision maker, instead he makes a take-it-or-leave-it offer. Again, the patient's posterior is correct in equilibrium but his optimal treatment is not available. Instead, the doctor constructs the offer so as to make the patient indifferent between

[7] This argument follows formally when optimal treatment is linear in patient beliefs, as it is in the quadratic loss specification.

accepting and rejecting, extracting the surplus from the interaction and on average inducing his preferred treatment.[8] With partial delegation, PID exists in terms of average treatment and noisy communication reduces treatment effectiveness. Thus partial delegation is the only communication protocol in which the doctor's financial incentives affect treatment both through average level and average effectiveness.

Comparative Statics

Our model has two parameters, p and c, that correspond to policy interventions such as changes in reimbursement rates, subsidies for medical supplies, changes in medical technology, etc. Here we explore the impact of such interventions on the utilities of the doctor and the patient. In addition, we track the impact on the total level of over- and undertreatment, which we define as the ex-ante probability that a state with over- or undertreatment occurs.[9]

Proposition 4 *The following table summarizes the effect of p and c on patient and doctor utility, overtreatment, and undertreatment.*

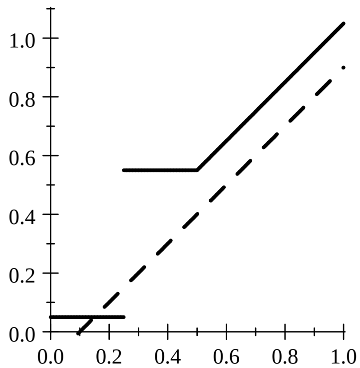
Increase in	$U_{patient}$	U_{doctor}	*Overtreatment*	*Undertreatment*
p	$-$	$+/-$	$+$	$+$
c	$+$	$-$	$-$	0
p *and* c	$-$	$-$	$+$	$+$

[8] The analogy holds for mild and intermediate illnesses; for severe illnesses the doctor can induce his preferred treatment without having to make the patient indifferent to rejecting.

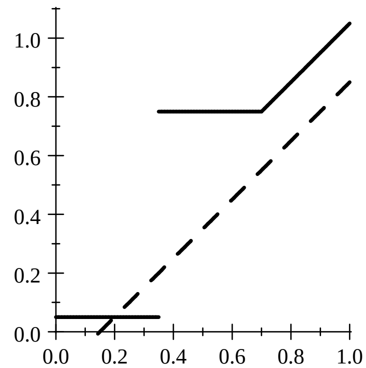
[9] An alternative definition is the patient's utility loss relative to his first best in regions of undertreatment and the doctor's utility loss relative to his first best in regions of over-treatment. In our equilibrium this definition induces the same ranking of treatment plans and we use ours for simplicity.

These results are derived in Appendix B by using the closed form solution of the equilibrium in Proposition 1. Consider first the table's top two rows. An increase in p affects patient utility in three ways. First, its direct effect is to raise the patient's total health expenditure if treatment remains unchanged. It also has an indirect PID effect whereby a higher price causes the doctor to induce higher average treatment. Finally, an increase in p exacerbates the difference in doctor and patient preferences, thus causing less appropriate treatment through more over- and undertreatment. The net effect of a higher p on patient welfare is thus unambiguously negative. The effect of p on the utility of the doctor can similarly be decomposed into the three separate effects. The direct effect is positive while the PID effect is zero because the doctor always obtains his preferred average treatment in equilibrium. Because treatment effectiveness declines, the net effect on the doctor's utility is ambiguous.

A similar logic applies to the effect of c on the utilities of the doctor and patient. A seemingly surprising result emerges: a higher cost c of treatment increases the welfare of the patient. This follows within the model since a higher c corresponds to closer doctor and patient preferences. However, this particular comparative static assumes none of the cost increase is passed through to patients. In the other extreme, costs can be fully passed through as considered in the third row of the results table and in Figure 2. Recall that a higher p decreases treatment effectiveness while a higher c increases it. As seen in the table, the net effect of an increase in p on over- and undertreatment is stronger than the countervailing effect of an (equal magnitude) increase in c. This stems from the fact that when a cost increase is fully passed through the doctor's profit margin and hence preferences remain unchanged while the patient faces a higher price and so prefers less treatment. On net, preferences diverge further so that treatment is less appropriate and the expected utilities of the doctor and patient decline.



In solid, equilibrium treatments when $p = 0.1$ and $c = 0.05$. In dashed, the patient's preferred treatment as a function of state.



In solid, equilibrium treatments when $p = 0.15$ and $c = 0.1$. In dashed, the patient's preferred treatment as a function of state.

5 Insurance: Moral Hazard and Communication

While doctors' financial incentives are often cited as a cause of rising health care costs, another commonly identified culprit is that most patients pay for treatment with the aid of health insurance (DOJ and FTC report, 2004). Although insurance companies actively manage coverage to deny unnecessary medical procedures, much of the decision-making power still rests with the patient, who faces a fraction of the full charge for a medical service and may not fully internalize its cost (van Dijk et. al., 2013). The patient may thereby undergo unnecessary procedures, i.e., the moral hazard of insurance.

On the other hand, in light of the results of the previous section, a patient that pays only a fraction of the treatment cost has incentives that are more closely aligned with those of the doctor, which should result in more appropriate treatment on average. In the ensuing analysis, we explore the trade-off between moral hazard and treatment effectiveness and demonstrate that treatment effectiveness dominates.

We augment the model by introducing an ex-ante stage, at which a patient purchases an insurance contract. The contract specifies the patient's coinsurance rate $\gamma \in [0, 1]$ and premium $P(\gamma)$, so that the patient's expected utility is

$$u_p(\gamma) = -\frac{1}{2}(\theta - a(\theta))^2 - \gamma pa - P(\gamma).$$

When a policy with coinsurance rate γ has been purchased the premium $P(\gamma)$ is sunk and the patient prefers a weakly higher treatment for all health states than without insurance:

$$a_p^*(\theta) = \theta - \gamma p.$$

We assume that the insurance market is competitive and $P(\gamma)$ is actuarially fair, thus

$$P(\gamma) = (1 - \gamma)pE[a(\theta \mid \gamma)].$$

Conditional on a treatment plan insurance does not save the patient money: his ex-post payment is reduced and instead shifted to a sunk payment up-front. However, the purchase of insurance commits the patient to be more likely to accept treatment, thereby potentially changing the amount and effectiveness of treatment he receives in equilibrium. To formalize this, we characterize an equilibrium of the doctor and patient interaction with insurance:

Proposition 5 *Let $3p - c \leq \frac{1}{2}$ and $\gamma \in [0,1]$. Then $m(\theta)$, $a(m)$, and $\mu(m)$ constitute a perfect Bayesian equilibrium when defined as follows. The doctor prescribes*

$$m(\theta) = \begin{cases} p - c & \text{if } 0 \leq \theta < (1+2\gamma)p - c \\ (3+4\gamma)p - 3c & \text{if } (1+2\gamma)p - c \leq \theta \leq (2+4\gamma)p - 2c \\ \theta + p - c & \text{if } (2+4\gamma)p - 2c < \theta \leq 1 \end{cases}$$

The patient accepts treatment if and only if prescribed as above and has beliefs

$$\mu(m) = \begin{cases} 0 & \text{if } 0 \leq m < p - c \\ \frac{(1+2\gamma)p-c}{2} & \text{if } m = p - c \\ \frac{m-(p-c)}{2} & \text{if } p - c < m < (3+4\gamma)p - 3c \\ \frac{3(1+2\gamma)p-3c}{2} & \text{if } m = (3+4\gamma)p - 3c \\ m - (p-c) & \text{if } (3+4\gamma)p - 3c < m \end{cases}$$

Note that the equilibrium described in the previous section is a special case of the equilibrium with insurance in which $\gamma = 1$. Figure 3 illustrates the effect of more insurance (lower γ). Region A depicts health states for which treatment increases as the result of added insurance and thus corresponds to the moral hazard effect. Region B depicts health states for which the patient undergoes less treatment when buying more insurance. This effect arises because a patient with lower coinsurance is less likely to reject, and consequently the doctor's incentive to overstate his diagnosis is reduced. Figure 3 thus demonstrates that the moral hazard effect on average treatment is offset

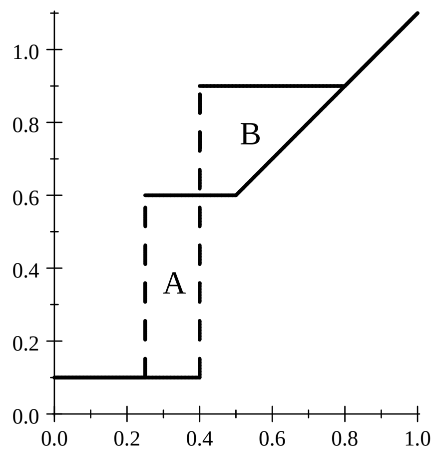


Figure 2: A decrease in γ (more insurance) increases expected treatment by the area of region A but decreases it by the area of region B. For $\theta \sim U[0,1]$ these two exactly balance so that expected treatment is constant.

by the reduction in overtreatment stemming from a closer alignment of doctor and patient incentives.

The proof of Proposition 6 below shows that the expected level of equilibrium treatment is independent of γ. In fact, as in the previous section the average treatment remains $E[\theta] + (p - c)$, that which would ensue if the doctor induced his first-best treatment for every illness. This demonstrates that an increase in the coinsurance γ rate merely reallocates health expenditures from ex-ante to ex-post, while keeping the sum of these two expenditures constant. This implies that the effect on doctor and patient welfare is entirely through the effect on communication, and communication is best when doctor and patient incentives are closest, i.e., the patient is fully insured.

Proposition 6 *Full insurance (i.e., $\gamma = 0$) is preferred by both the doctor and patient.*

The proof can be found in Appendix B. In contrast to a full information context in which one would find insurance increases the medical action taken for every health state, we find it increases treatment for states that were previously undertreated and reduces treatment for previously overtreated states. Therefore the gains in patient utility derive from a better matching of treatments to health states while total health expenditures are constant. For his part, the doctor's expected profits from treatment are constant in the coinsurance requirement though he too gains from the better matching of treatments to health states.[10]

6 Extensions

Naive Patients

We have demonstrated that when all patients are rationally skeptical, doctors' financial incentives lead to over- and undertreatment which hurt both the doctor and the patient. On the other hand, the classic PID model may be interpreted as one in which all patients are naive in blindly following the doctor's orders. As a robustness check, in this section we allow for a proportion of naive patients and explore whether over- and undertreatment remain.

Proposition 7 *For a sufficiently small proportion of naive patients, the equilibrium in Proposition 1 survives. Consequently there exists over- and undertreatment.*

See Appendix B for the proof. The existence of naive patients gives the doctor a new treatment option. For instance, the doctor that was indifferent between inducing the minimally accepted treatment $p - c$ and the inflated treatment $7p - 3c$ now has

[10] Our result is reminiscent of Dessein (2002) in which he investigates whether a principle could gain from using an intermediary with a given bias of his choosing.

the option of inducing his preferred treatment between the two but only from naive patients. When the number of naive patients is small, this option is strictly worse that the other two, thus his incentives do not change qualitatively.

When there is a large enough number of naive patients, the doctor may eventually deviate and induce his most preferred treatment from the naives while being rejected by the rational patients. Solving for the equilibrium set when the number of naive patients is large is tedious and beyond the scope of this work. However, we can quite easily obtain the following result.

Proposition 8 *When there is a positive measure of rational patients, there exists no separating equilibrium.*

Proof Conjecture a separating equilibrium and note that since all equilibria are monotone in induced treatment (Lemma 2, Appendix A), there must exist a largest type $\hat{\theta}$ such that all treatments proposed by types $\theta < \hat{\theta}$ are rejected by the $1 - \alpha$ rational patients. Then, a type just below $\hat{\theta}$ can misreport a slightly higher illness and in doing so reduce his utility from treating naive patients marginally while increasing his utility from now treating rational patients discretely. ■

The proposition above guarantees pooling regions, which we believe ought to lead to regions of over- and undertreatment as in our main model.

It is also interesting to consider the limiting case in which all patients are naive, as would be under classic PID. Here the equilibrium is fully separating and there is no information loss. Compared to the equilibrium in Proposition 1, both outcomes have the same expected treatment however the equilibrium with all naive patients has more appropriate treatment and is therefore preferred by the doctor and patient. This finding is similar to Dessein (2002) who demonstrates that full delegation is superior to Krishna and Morgan's (2001) closed rule model for low levels of bias.

Second Opinions

Our model has assumed thus far that the patient's only alternative to a doctor's recommendation is of taking no action at all. In reality, patients often have the option to consult a second or third doctor for an additional opinion and alternative treatment options. For simplicity and to retain focus on the communication game we do not consider doctors with heterogeneous levels of expertise but rather the possible effect of competition between homogenous doctors on doctor-patient communication.

If the patient can visit multiple doctors costlessly then a fully separating equilibrium exists. Each doctor recommends the patient's preferred action while the patient visits every doctor and accepts treatment only if all recommendations are the same. If recommendations diverge the patient believes the true health state is zero and rejects. From the perspective of the doctor, if his competitors send fully separating recommendations he gains nothing by misrepresenting his information, as this induces the patient immediately to reject.

It is more realistic however that getting a second opinion has some positive cost. Then a fully separating equilibrium in which each doctor recommends the patient's preferred action cannot exist, since if it did no patient would incur search costs to obtain a second opinion. But given no patient searches, each doctor has incentive to deviate for every state. Instead, there exists an equilibrium in which all doctors prescribe as in Proposition 1. The patient does not search since his perceived return to doing so is zero, and instead also follows his strategy in Proposition 1.

The no-search result is an application of the "Diamond paradox" which states there is no equilibrium in which search occurs when the cost of search is positive (Diamond, 1971). The existence of a search cost brings about a hold-up problem that allows each doctor to behave as a monopolist: a doctor offering a second opinion can infer what message the first doctor sent and undercut it by some small amount $\varepsilon > 0$ less than the search cost. Anticipating this, the patient does not search in the first place. Note that in a different setting Krishna and Morgan (2001b) reach the similar conclusion that no additional information can be gained by visiting a second expert, while Pitchik and Schotter (1993) find doctor opportunism can be competed away only if a sufficiently large proportion of consumers have no search costs.

7 Conclusion

The classic theory of physician induced demand posits that financially incentivized doctors overprescribe medical services to patients who accept the doctor's orders. When allowing for patients to be rationally skeptical of the doctor's motives we discover the classic PID approach understates the negative welfare effects of the doctors' incentives. Though patients are skeptical, in equilibrium doctors still induce the same average treatment as they would if patients blindly accepted the doctors' first-best treatment, thus confirming that PID still exists in our context. However, we also discover an informational effect in which the prescribed treatment is on average less appropriate, stemming from doctors strategically misdiagnosing to convince patients to accept treatment. We find that the informational effect is of a similar magnitude as the classic PID effect, and sometimes may be the dominant effect.

We use our framework to conclude health insurance reduces the incidence and severity of over- and undertreatment. It is well-understood that the presence of health insurance can induce moral hazard in that a patient who pays only a fraction of his medical bill is likely to obtain more treatment. However, we uncover a countervailing effect in which the presence of insurance increases the appropriateness of treatment by more closely aligning the incentives of the doctor and the patient. In our model this new effect completely dominates the moral hazard effect, so that in equilibrium when the patient purchases more insurance his average treatment remains fixed while its effectiveness increases.

The impact of financial incentives on treatment appropriateness can be expressed in terms of over- and undertreatment. Both of these phenomena persist for alternate model specifications in which some patients are naive while others are rationally skeptical, or in which the patient can obtain a second opinion at a small cost.

In addition to highlighting that the classic PID model understates the effect of the doctor's financial incentives, we also contribute to literature on partial delegation. In a similar setting to ours, Krishna and Morgan (2001) describe an equilibrium which dominates all equilibria in the Crawford and Sobel (1982) framework but leave open whether the equilibrium they find is most informative in their environment. We build on their work by applying the Cho Kreps (1987) intuitive criterion and characterizing the equilibrium set in a more general framework that nests both our and their model. We confirm their equilibrium is in fact the most informative in their parameter space.

Appendix A: Existence and Informativeness Proofs

For the sake of generality and to facilitate comparison with Krishna and Morgan (2001) and Gilligan Krehbiel (1989), we use the following model. Let the utilities of the doctor and the patient be

$$u_d(a|\theta) = -\frac{1}{2}(\theta - a)^2 + b_d a$$
$$u_p(a|\theta) = -\frac{1}{2}(\theta - a)^2 - b_p a$$

The doctor's preferred treatment is $a_d^*(\theta) = \theta + b_d$ and the patient's preferred treatment is $a_p^*(\theta) = \theta - b_p$, in which b_d and b_p are both weakly positive. The patient's outside option treatment is $0 \leq s < 1 - b_d$, so that the outside option is guaranteed to be lower than the doctor's maximal preferred treatment.

Note that our model is a special case in which $b_d = p - c$, $b_p = p$, and $s = 0$ and the Gilligan Kriehbel (1989) and Krishna Morgan (2001) model is also a special case in which $b_d = x_c$, $b_p = 0$, and $3x_c < s < 1 - x_c$.

In what follows we establish several lemmas, characterize the set of equilibria, and then use informativeness to select a particular equilibrium. In doing so we provide a proof of Propositions 1, 2, and 3.

Preliminary Results

Lemma 2 *Equilibrium treatments weakly increase in the health state θ.*

Proof This follows from a single crossing property argument. Toward a contradiction there exist states θ and θ' such that $\theta < \theta'$ and in equilibrium $a(\theta) > a(\theta')$. If the doctor is best responding in state θ, then $u_d(a(\theta), \theta) \geq u_d(a(\theta'), \theta)$ and his ideal treatment is weakly closer to $a(\theta)$ than to $a(\theta')$. However, in state $\theta' > \theta$, the doctor's ideal treatment is even higher which implies $u_d(a(\theta'), \theta') < u_d(a(\theta), \theta')$, and thus leads to a contradiction. ■

Lemma 3 *Suppose treatment a' is pooled on $\left(\underline{\theta}, \overline{\theta}\right)$ and $a_d^*(\bar{\theta}) > a'$. Then there is a discrete jump to the next induced treatment $a'' = 2\left(\overline{\theta} + b_d\right) - a'$ and it is pooled at least out to $\widehat{\theta} \equiv \overline{\theta} + 2\left(b_d + b_p\right) - a' + s$.*

Proof By continuity of the doctor's utility function, the type $\overline{\theta}$ doctor must be indifferent between inducing treatment a' and a''; that is,

$$a'' - a_d^*\left(\overline{\theta}\right) = a_d^*\left(\overline{\theta}\right) - a' \Longleftrightarrow a'' = 2\left(\overline{\theta} + b_d\right) - a'.$$

The treatment a'' is pooled because types $\theta > \overline{\theta}$ in the neighborhood of $\overline{\theta}$ prefer a lower treatment than a'' but treatments $a \in (a', a'')$ are not inducible.

In order for patients to accept a'', their posterior μ must be sufficiently high. That is, the the minimal $\widehat{\theta}$ must satisfy

$$a'' - (\mu - b_p) = \mu - b_p - s \Longleftrightarrow \widehat{\theta} = \overline{\theta} + 2\left(b_d + b_p\right) - a' + s.$$

■

These first two Lemmas demonstrate that all equilibria have some regularities, and we later use these results to classify equilibria into a manageable number of categories. The following two lemmas are intended to reduce later work by performing commonly recurring calculations in the ensuing proof.

Lemma 4 *The patient accepts $a' > s$ on $\left[\underline{\theta}, \overline{\theta}\right]$ only if $a' + s + 2b_p \leq \underline{\theta} + \overline{\theta}$.*

Proof If the patient's preferred treatment $\mu - b_p$ is above a' then $a' > s$ is accepted. If $a' > \mu - b_p > s$ then, due to the quadratic loss utility, a' is rejected if it is farther away from $\mu - b_p$ than is the outside option s. That is

$$a' - (\mu - b_p) \leq (\mu - b_p) - s \quad \Longleftrightarrow \quad a' + s + 2b_p \leq \underline{\theta} + \overline{\theta}.$$

If $a' > s \geq \mu - b_p$ then a' is rejected. ■

Lemma 5 *Suppose treatments a_x and a_y are accepted in equilibrium and all treatments $a' \in (a_x, a_y)$ are rejected. For any such off-the path treatment a', the lowest beliefs admitted by the intuitive criterion are $\mu = \frac{a'+a_x}{2} - b_d$ and the deviant message is rejected if and only if $a_x \leq 2\,(b_d + b_p) + s$.*

Proof The lowest permissible belief is $\mu = (a_d^*)^{-1}\left(\frac{a'+a_x}{2}\right) = \frac{a'+a_x}{2} - b_d$, as lower types prefer treatment a_x, which gives them at least their equilibrium payoff, to treatment a'. In order to reject a deviant message, conditional on the patient's belief the distance from his preferred treatment to a' must be greater than the distance to the outside option s:

$$a' - (\mu - b_p) \geq (\mu - b_p) - s \Longleftrightarrow a_x \leq 2\,(b_d + b_p) + s.$$

■

Corollary 5 *Let a be the highest treatment induced in equilibrium such that there is a jump to the next highest induced treatment. If $a > 2(b_d + b_p) + s$ then the equilibrium fails the intuitive criterion. Conversely, if $a \leq 2(b_d + b_p) + s$ then beliefs consistent with the intuitive criterion can support the equilibrium.*

Equilibrium Classification

We classify equilibria into two categories: those in which the patient sometimes takes his outside option s and those in which he does not. We will show that depending on parameters the most informative equilibrium can be found in either category. To simplify the presentation of the equilibrium characterization, within each category we focus only on equilibria with the smallest pooling regions. We subsequently show that within a category, an equilibrium with smaller pooling regions is more informative than an equilibrium with larger pooling regions.

Equilibria in which treatment s is not induced

We decompose all equilibria in which s is not induced into subclasses of equilibria, each subclass corresponding to a lowest induced treatment a_1. We demonstrate that once a_1 is chosen, there is little freedom in the remaining construction of the equilibrium.

Proposition 9 *Let a_1 be the lowest induced treatment. In any equilibrium that satisfies the intuitive criterion in which treatment s is not induced, the doctor's message function is of one of the two following forms:*

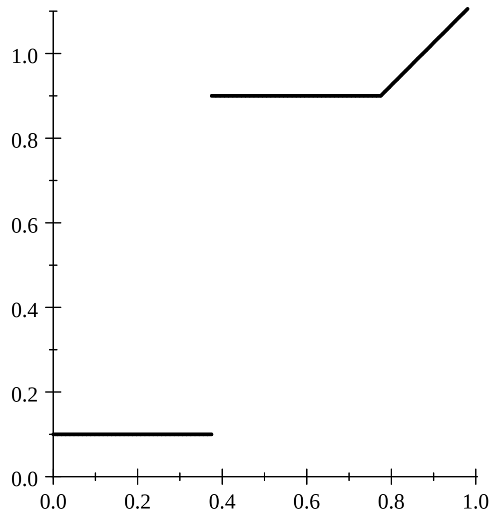


Figure 3: An equilibrium in which $s = \frac{1}{20}$ is not induced; $a_1 = \frac{1}{10} = b_p$, $b_d = \frac{1}{8}$.

i. If $a_1 \in (s, b_d)$ *then the doctor prescribes*

$$m(\theta) = \begin{cases} a_1 & \theta \in [0, b_d + s + 2b_p] \\ 4(b_d + b_p) + 2s - a_1 & \theta \in (b_d + s + 2b_p, 3b_d + 4b_p + 2s - a_1) \\ \theta + b_d & \theta \in [3b_d + 4b_p + 2s - a_1, 1] \end{cases}$$

ii. If $a_1 \in [b_d, 2(b_d + b_p) + s]$ *then the doctor prescribes*

$$m(\theta) = \begin{cases} a_1 & \theta \in [0, a_1 + s + 2b_p] \\ a_1 + 2s + 2b_d + 4b_p & \theta \in (a_1 + s + 2b_p, a_1 + 2s + b_d + 4b_p) \\ \theta + b_d & \theta \in [a_1 + 2s + b_d + 4b_p, 1] \end{cases}$$

and all such messages are accepted.

Proof First, in this type of equilibrium the doctor's preferred treatment is above s for every illness, that is $b_d > s$. Otherwise, there would be at least one θ for which the doctor's preferred treatment is the patient's outside option, and in equilibrium this treatment is induced.

Next, consider the lowest induced treatment a_1 and note that $a_1 > s$. This follows because $a_1 \neq s$ by hypothesis and if $a_1 < s$ then any type that induces a_1 would deviate to inducing treatment s. By Lemma 2, a_1 must be induced on some interval $\theta \in [0, \theta_1)$, and by Lemma 4, $\theta_1 \geq a_1 + s + 2b_p$ in order for the patient to accept. We define $\underline{\theta_1} = a_1 + s + 2b_p$ as the minimal right endpoint necessary to induce acceptance of a_1.

By inspection $a_d^*(\theta_1) > a_1$, meaning that the highest type to induce a_1 strictly prefers a higher treatment. By Lemma 3 this implies at θ_1 there is a jump in treatment up to a specific treatment $a_2 = 2(\theta_1 + b_d) - a_1$, and that treatment at a_2 is also pooled on an interval $(\theta_1, \theta_2]$.

The endpoint θ_2 plays an important role. First, note that the treatment a_2 is higher than the doctor's preferred treatment in the neighborhood of θ_1, in fact the doctor must induce a_2 for all states $\theta > \theta_1$ for which his preferred treatment is lower, i.e. $\theta_2 \geq (a_d^*)^{-1}(a_2)$. The question then is whether $\theta_2 = (a_d^*)^{-1}(a_2)$ is sufficiently large to induce the patient to accept, or whether it must be made larger. We now argue that whenever θ_2 needs to be larger, the equilibrium fails the intuitive criterion.

If $\theta_2 > (a_d^*)^{-1}(a_2)$ then there must be a jump above a_2 to the next highest induced treatment. But by Corollary 5 the intuitive criterion is only satisfied if a_2 is sufficiently small. Note that

$$\begin{aligned} a_2 = 2(\theta_1 + b_d) - a_1 &\geq 2((a_1 + s + 2b_p) + b_d) - a_1 \\ &= a_1 + 2s + 4b_p + 2b_d > 2(b_d + b_p) + s \end{aligned}$$

Thus, since $a_2 > 2(b_d + b_p) + s$, a jump above a_2 means the intuitive criterion is not satisfied. By Lemma 3, $\theta_2 = \theta_1 + 2(b_d + b_p) - a_1 + s$ is the lowest endpoint of this pooling region for which the patient's posterior is sufficiently high to accept. To ensure no jump occurs, it is necessary that

$$\begin{aligned} & \left(a_d^*\right)^{-1}(a_2) \geq \theta_2 \\ \iff\ & 2\theta_1 + b_d - a_1 \geq \theta_1 + 2\left(b_d + b_p\right) - a_1 + s \\ \iff\ & \theta_1 \geq b_d + s + 2b_p \end{aligned} \tag{1}$$

That no jump occurs for any treatment above a_2 also implies that the doctor obtains his preferred treatment for all states greater than θ_2.

We can now classify the equilibria in terms of a_1. If $a_1 > 2\left(b_d + b_p\right) + s$ then by Corollary 5 no equilibrium survives the intuitive criterion. If $a_1 \in [b_d, 2(b_d + b_p) + s]$ then $\underline{\theta}_1 = a_1 + s + 2b_p$ satisfies condition (1) and we obtain equilibrium characterization (ii). If $a_1 \in (s, b_d]$ then $\underline{\theta}_1$ is too small to satisfy condition (1), thus $\theta_1 = b_d + s + 2b_p$ is the smallest endpoint that can be used, and this obtains the characterization (i). ■

Equilibria in which treatment s is induced

This equilibrium set is indexed by the highest state $\theta = \bar{s}$ for which treatment s is induced. Once $\bar{s}$ is fixed, again the way an equilibrium may be constructed is substantially restricted.

Lemma 6 *The lowest state for which treatment s is induced is $\underline{s} = \max\{0, s - b_d\}$.*

Proof First suppose $s > b_d$. If $\underline{s} > s - b_d$ then there exists a type that prefers to induce s and is not doing so, which is a contradiction. If $\underline{s} < s - b_d$, then types $\theta < \underline{s}$ either pool or separate. They cannot separate since there is a type $\theta \in (\underline{s}, s - b_d)$ that would defect from sending message s. If they pool then beliefs that reject off-the-equilibrium-path messages $m < s$ in the neighborhood of s fail the intuitive criterion. When such a message is received the highest permissible belief is the doctor type indifferent between s and m; however, if the doctor is indifferent then the patient strictly prefers the lower treatment and so accepts m.

If $s < b_d$ then the doctor's preferred treatment is above s for every state, and given that s is induced for any state θ, by Lemma 2 it must be induced for all states from 0 to θ. ■

Lemma 7 *In any equilibrium that satisfies the intuitive criterion, the doctor induces his preferred treatment for* $\theta < \underline{s}$.

Proof First, it is an equilibrium for $m(\theta) = \theta + b_s$ for $\theta < s - b_s$ because it is a best response for the doctor if the patient accepts and a best response for the patient since he infers the true state and prefers a treatment even lower than what the doctor prescribes. It is also the case that any treatment $a \in [b_d, b_d + s]$ cannot be off the equilibrium path, since that would imply the treatment is rejected but no beliefs satisfying the intuitive criterion could support this. ■

Lemma 8 *The treatment* s *is induced on a set of positive measure, that is there exists* $\bar{s} > \underline{s}$ *so that* s *is induced on* $[\underline{s}, \bar{s}]$.

Proof Suppose not. There are two cases. First, the separating region may continue locally for $\theta > \underline{s}$. But this is impossible as the message $s + \varepsilon$ allows the patient to deduce the state is $s + \varepsilon - b_d$ to which s is the patient's best response. The second case is that a next inducible treatment a_1 is discretely higher than s. But this fails as there would exist types $s+\varepsilon_2$ that would defect to the inducible message s. ■

We have thus established that $\underline{s} = \max\{0, s - b_d\}$ in every equilibrium, and the choice in equilibrium construction begins with the choice $\bar{s}$.

Proposition 10 *Let $[\underline{s}, \bar{s}]$ denote the set of illnesses for which treatment s is induced. In any equilibrium $\underline{s} = \max\{0, s - b_d\}$. Furthermore, any equilibrium in which treatment s is induced has one of the following two forms:*

i. If $\overline{s} \in (\underline{s}, s + b_d + 2b_p]$ then the doctor prescribes

$$m(\theta) = \begin{cases} \theta + b_d & \theta \in [0, \underline{s}] \\ s & \theta \in [\underline{s}, \overline{s}] \\ 2\overline{s} + 2b_d - s & \theta \in (\overline{s}, \overline{s} + 2b_d + 2b_p) \\ s + 4(b_d + b_p) & \theta \in [\overline{s} + 2b_d + 2b_p, s + 3b_d + 4b_p] \\ \theta + b_d & \theta \in [s + 3b_d + 4b_p, 1] \end{cases}$$

ii. If $\overline{s} \in \left[s + b_d + 2b_p, \frac{1+s-b_d}{2}\right]$ then the doctor prescribes

$$m(\theta) = \begin{cases} \theta + b_d & \theta \in [0, \underline{s}] \\ s & \theta \in [\underline{s}, \overline{s}] \\ 2\overline{s} + 2b_d - s & \theta \in (\overline{s}, 2\overline{s} + b_d - s) \\ \theta + b_d & \theta \in [2\overline{s} + b_d - s, 1] \end{cases}$$

If $\bar{s} \in (s + b_p, s + b_d + 2b_p)$ then no equilibrium survives the intuitive criterion.

Proof The type (i) equilibrium occurs for smaller values of $\bar{s}$ and has three pooling regions while the type (ii) equilibrium occurs for larger values of $\bar{s}$ and has two pooling

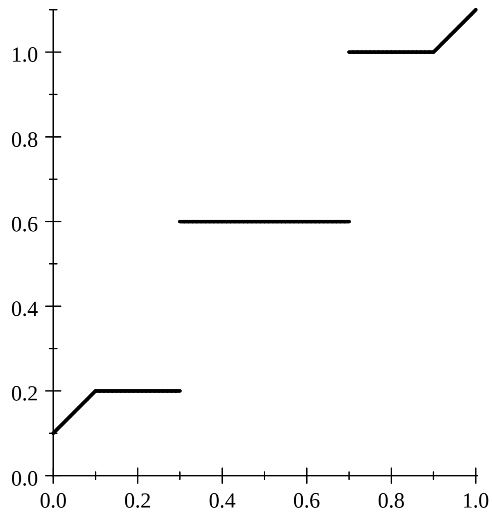


Figure 4: An equilibrium in which $s = \frac{2}{10}$ is induced; $\overline{s} = \frac{3}{10}$, $b_p = b_d = \frac{1}{10}$.

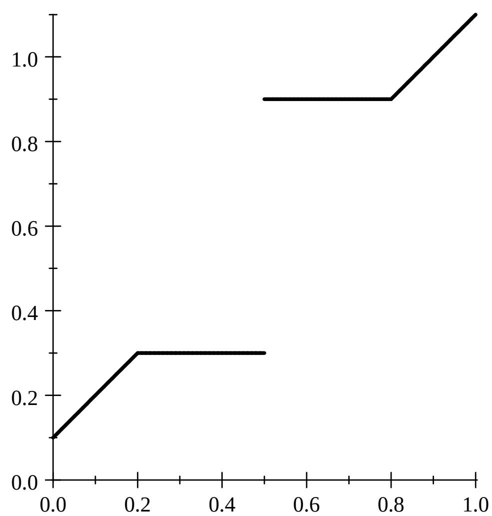


Figure 5: An equilibrium in which $s = \frac{3}{10}$ is induced; $\overline{s} = \frac{1}{2}$, $b_p = \frac{1}{20}$, $b_d = \frac{1}{10}$.

regions. When $\bar{s} = s + b_d + 2b_p$, which is on the border between the two equilibrium regions, the equilibrium looks the same when evaluated by either the type (i) or type (ii) characterization. This is because in the type (i) characterization the top pooling region shrinks to nothing.

First we consider $\bar{s} \in (\underline{s}, s+b_d+2b_p]$. Since at $\theta = \bar{s}$ the doctor's preferred treatment is strictly larger than s, there is a jump to the next highest treatment which by Lemma 3 is $a_1 = 2(\bar{s} + b_d) - s$. In order for treatment a_1 to be accepted, again by Lemma 3 it must pool at least out to $\theta_1 = \bar{s} + 2b_d + 2b_p$. By inspection, the doctor's preferred treatment at θ_1 is above a_1 and thus there is a jump to $a_2 = s + 4(b_d + b_p)$. The treatment a_2 is computed again using Lemma 3, and surprisingly is not a function of $\bar{s}$. This observation is used in our later discussion of informativeness.

The pooling region at a_2 must extend out to at least the state for which a_2 is the doctor's preferred treatment, namely $\theta_2 = s + 3b_d + 4b_p$. By inspection, this makes the patient's posterior strictly greater than what is necessary to induce him to accept. For states $\theta > \theta_2$, the doctor's preferred treatments $a(\theta) = \theta + b_d$ are induced.

The previous construction is well-defined up to $\bar{s} = s + b_d + 2b_p$, at which point $\theta_2 - \theta_1 = 0$. For $\bar{s} > s+b_d+2b_p$, only two pooling regions can be supported and we find ourselves in a type (ii) equilibrium. Treatment $a_1 = 2\bar{s} + 2b_d - s$ is constructed in the same manner as before. Previously, in order to induce acceptance it was necessary for the pooling region to extend beyond $(a_d^*)^{-1}(a_1)$, thus creating another jump. However, now at $(a_d^*)^{-1}(a_1)$ the patient's posterior is larger than what is necessary for acceptance, hence the pooling region ends at $\theta_1 = 2\bar{s} + b_d - s$, beyond which the doctor induces his preferred treatments for every state.

Lastly, when $\bar{s}$ is sufficiently large the separating region disappears. This happens at $\bar{s} = \frac{1}{2}(1 + s - b_d)$. Equilibria in this range are comprised of two pooling regions, one at s and one at a much higher treatment. It can be shown that these are easily ruled out on the basis of informativeness and we omit their characterization here. ■

Corollary 6 *An equilibrium in Proposition* 10 *survives the intuitive criterion unless* $s \in (s + b_p, s + b_d + 2b_p)$.

Proof By Corollary 5, no jumps may be supported above $a = 2(b_d + b_p) + s$. This rules out type (i) equilibria in which $a_1 > 2(b_d + b_p) + s$ but leaves in tact all type (ii) equilibria. ■

Equilibrium Selection Using Informativeness

Recall that previously we characterized equilibria using the smallest allowable pooling regions. For instance, in the class of equilibria in which treatment s is not induced, the smallest treatment a_1 was induced out to θ_1 so that the patient's posterior is sufficiently high to accept and the and doctor's preferred treatment at θ_1 was at least as large as a_1. Specifically, at least one of these constraints was required to bind. However, an equilibrium could also be supported in which this pooling region was extended and similar such decisions could have been made in other equilibrium classes. It seems unlikely that increasing pooling beyond the constraints improves informativeness, and we demonstrate that doing so results in a mean-preserving spread in treatment. The following lemmas will apply to both classes of equilibrium discussed above.

Lemma 9 *Let* a_1 *be a pooled treatment ending at* θ_1 *so that* $a_d^*(\theta_1) > 1$. *Let there also be only one pooling treatment* $a_2 > a_1$ *ending at* θ_2 *at which* $a_d^*(\theta_2) = a_2$. *Then* *constructing an equilibrium with a higher* a_1 *creates a mean preserving spread in* $a(\theta)-\theta$*. Similarly, if any pooled treatment* a' *can stop at* $(a_d^*)^{-1}(a')$ *but instead is extended beyond it such that another pooled treatment* $a''>a'$ *exists, then increasing the* θ'*, the endpoint of* a'*, is a mean preserving spread.*

Proof We first show $E[\theta-a]$ is constant. Let $\varepsilon>0$ be given and compare any θ_1 to $\theta_1+\varepsilon$. It suffices to show the unconditional expected treatment on $[\theta_1, 2\theta_1+2\varepsilon+b_d-a_1]$ is constant. This follows since

$$\begin{aligned} & (\theta_1+b_d-a_1)(2\theta_1+2b_d-a_1)+\int_{2\theta_1+b_d-a_1}^{2\theta_1+b_d-a_1+2\varepsilon}(\theta+b_d)\,d\theta \\ = \; & \varepsilon a_1+(\theta_1+\varepsilon+b_d-a_1)(2\theta_1+2\varepsilon+2b_d-a_1) \end{aligned}$$

We now show $Var[\theta-a]$ increases. By construction, a_1 and a_2 are equidistant from θ_1+b_d and thus $E\left[(\theta+b_d-a)^2\right]$ is higher for larger θ_1 while $E[(\theta+b_d-a)]^2$ is invariant. The results follows since $Var[\theta-a]=Var[\theta+b_d-a]$. By a similar calculation, extending a pooled treatment a' beyond $(a_d^*)^{-1}(a')$ is also a mean preserving spread.

■

The previous lemma applies to equilibria in Proposition 9 for the selection of θ_1 and θ_2, to type (i) equilibria in Proposition 10 for the selection of θ_1 and θ_2, and to type (ii) equilibria in Proposition 10 for the selection of θ_1.

Proposition 11 *Suppose* $b_d\le s$*. Then the equilibrium in Proposition* 10 *in which* $\overline{s}=s+b_p$ *is the most informative equilibrium that survives the intuitive criterion.*

Proof Recall that when $b_d\le s$ an equilibrium in which s is not induced cannot be supported. Thus we only examine equilibria in which s is induced. First suppose the equilibrium is of type (i), so that $\bar{s} \in (\underline{s}, s+b_d+2b_p)$. An explicit calculation reveals that the unconditional mean of $a(\theta)$ is invariant to $\bar{s}$, while the variance of $\theta - a$ is minimized at $\bar{s} = s + b_p$. For later comparison, we note here that $Var[\theta - a] = \frac{4}{3}(b_d + b_p)^3$. Now consider an equilibrium of type (ii), in which $s + b_d + 2b_p \leq \bar{s} \leq \frac{1}{2}(1 + s - b_d)$. By Lemma 9, increasing $\bar{s}$ in this region corresponds to a mean preserving spread. ■

Corollary 7 *The equilibrium in Proposition 8 of Krishna and Morgan* (2001) *(in which $b_p = 0$ and $\bar{s} = s$) is most informative.*

Proposition 12 *Let $b_d > s$. Then, restricting attention to equilibria that survive the intuitive criterion, either the equilibrium in Proposition 9 in which $a_1 = b_d$ is most informative or the equilibrium in Proposition 10 in which $\bar{s} = s+b_p$ is most informative.*

Proof In this parameter range both equilibria in which treatment s is induced and equilibria in which treatment s is not induced may be supported. Our strategy is to identify the most informative equilibrium, i.e. the one with the lowest $Var(\theta - a(\theta))$, in both classes and then compare the informativeness of the two winning equilibria. The results come form an explicit computation but we provide some intuition below.

First, for equilibria in which s is not induced, as in Proposition 9, the most informative equilibrium is the one in which $a_1 = b_d$. Here, a higher value for a_1 increases the interval $[0, \theta_1]$ and keeps the interval $[\theta_1, \theta_2]$ constant, which ends up resulting in higher variance. For a lower value of a_1, the interval $[0, \theta_1]$ remains the same and the interval $[\theta_1, \theta_2]$ increases. An explicit computation confirms that $a_1 = b_d$ is the most informative and yields

$$Var(\theta - a(\theta)) = \frac{2}{3}(b_d + 2b_p + s)^3 \tag{2}$$

Next, for equilibria in which s is induced, as in Proposition 10, the most informative equilibrium is the one in which $\bar{s} = s + b_p$. Here, it can be seen using Lemma 9 that any move above or below $\bar{s} = s + b_p$ is a mean preserving spread. Again, an explicit computation reveals that

$$
\begin{aligned}
&Var(\theta - a(\theta)) \\
&= -\frac{1}{4}s^4 + s^3 b_d + \frac{1}{3}s^3 - \frac{3}{2}s^2 b_d^2 - s^2 b_d + s b_d^3 + s b_d^2 - \frac{1}{4}b_d^4 + b_d^3 + 4b_d^2 b_p + 4b_d b_p^2 + \frac{4}{3}b_p^3
\end{aligned}
\tag{3}
$$

Lastly, comparing these two expressions we find that either can dominate the other depending on bias parameters b_d and b_p. ■

Corollary 8 *If $b_p > b_d > s$ then the most informative equilibrium that survives the intuitive criterion is the equilibrium from Proposition 9 in which $a_1 = b_d$.*

The proof follows from comparing expressions 2 to 3 when $b_d = b_p$ and then taking a derivative with respect to b_p.

Appendix B: Other Proofs

Proof of Corollary 4 We demonstrate the existence of p and c such that $U_p(a_p^*) + U_p(a_{eqm}) < 2U_p(a_d^*)$. Let $p = c = \frac{1}{4}$ so that $3p - c = \frac{1}{2}$. A calculation shows

$$2U_p(a_d^*) = -\frac{1}{4} > -\frac{25}{96} = -\frac{3}{32} - \frac{1}{6} = U_p(a_p^*) + U_p(a_{eqm}).$$

Because the payoff functions are continuous, the parameter space for which the inequality holds has positive measure. ■

Proof of Proposition 4 In our model the difference in actions grows with the interval of over- and undertreatment and expected utility declines in it. Thus it suffices to track increases in the interval on which over- and undertreatment occur. Expected undertreatment is $(3p-c)-(2p-c)=p$, which increases in p, is constant with respect to c, and increases for an equal increase in p and c (fixed markup). Expected overtreatment is $(6p-2c)-(3p-c)=3p-c$, which increases in p, decreases in c, and increases for an equal increase in p and c (fixed markup).

$$\begin{aligned} U_d(a(\theta)) &= -\frac{1}{2}E\left[(a(\theta)-\theta)^2\right]+(p-c)E[a(\theta)] \\ U_p(a(\theta)) &= -\frac{1}{2}E\left[(a(\theta)-\theta)^2\right]-pE[a(\theta)] \end{aligned}$$

These functions share the quadratic loss term and so their derivatives will share the terms $\frac{d}{dc}E\left[(a(\theta)-\theta)^2\right]=-2(3p-c)^2$ and $\frac{d}{dp}E\left[(a(\theta)-\theta)^2\right]=6(3p-c)^2$. A calculation shows

$$\begin{aligned} \frac{dU_p}{dc} &= (3p-c)^2+(p-c)+p>0 \\ \frac{dU_p}{dp} &= -3(3p-c)^2-p-\frac{1}{2}<0 \\ \frac{dU_d}{dc} &= (3p-c)^2-(p-c)-\frac{1}{2}<0 \\ \frac{dU_d}{dp} &= -3(3p-c)^2+(p-c)+\frac{1}{2}\gtreqless 0 \end{aligned}$$

where this last term is ambiguous since, for example, letting $p=c$ it is positive when $p<\frac{1}{2\sqrt{6}}$ but negative when $p>\frac{1}{2\sqrt{6}}$. It follows from above that $\frac{dU_d}{dc}+\frac{dU_d}{dp}<0$ and $\frac{dU_p}{dc}+\frac{dU_p}{dp}<0$. ■

Proof of Proposition 6 First note that total expected treatment is constant in γ,

$$\begin{aligned} &= \int_0^{(1+2\gamma)p-c} (p-c)\, d\theta + \int_{(1+2\gamma)p-c}^{(2+4\gamma)p-2c} ((3+4\gamma)\, p - 3c)\, d\theta + \int_{(2+4\gamma)p-2c}^{1} (\theta + p - c)\, d\theta \\ &= p - c + \frac{1}{2} \end{aligned}$$

and thus $\frac{\partial E[a]}{\partial \gamma} = 0$. It therefore suffices to show that the treatment is more accurate, i.e., that $\int_0^1 -(\theta - a)^2 d\theta$ is decreasing in γ. This follows from differentiating

$$\int_0^{(1+2\gamma)p-c} -\frac{1}{2}\left(\theta - (p-c)\right)^2 d\theta + \int_{(1+2\gamma)p-c}^{(2+4\gamma)p-2c} -\frac{1}{2}\left(\theta - ((3+4\gamma)\, p - 3c)\right)^2 d\theta$$
$$+ \int_{(2+4\gamma)p-2c}^{1} -\frac{1}{2}\left(\theta - (\theta + p - c)\right)^2 d\theta$$

with respect to γ to find $-2p\left(p - c + 2p\gamma\right)^2 < 0$ since $p \geq c$. Thus $\gamma = 0$ is optimal for the patient. ■

Proof of Proposition 7 Type $\theta_1 = 3p - c$ has most incentive to defect from any equilibrium as his equilibrium action is farthest from his preferred. It suffices to find α such that this type is indifferent between his equilibrium payoff and the payoff obtained from defecting and having α consumers take action $a_d^*(\theta_1)$ and the remaining $(1-\alpha)$ take action zero:

$$u_d(\theta_1, a = p - c) = \alpha u_d\left(\theta_1, a = \theta + p - c\right) + (1-\alpha) u_d(\theta_1, a = 0)$$

A solution $\alpha^* \in (0,1)$ exists as $U_d(\theta_1, a = 0) < U_d(\theta_1, a = p{-}c) < u_d\left(\theta_1, a = \theta + p - c\right)$. Thus whenever $\alpha \leq \alpha^*$ our equilibrium survives unchanged. ■

Conclusion

This dissertation has examined two common and economically significant market settings in which asymmetric information has potentially large welfare effects: the introduction of new products versions and the communication between doctor and patient and resulting treatment decision. In each case matters are not as straightforward as they might seem. Given that firms mostly introduce improved new versions of their products, consumers rationally expect new versions to be better, which in turn effects the incentive to introduce new versions and thus consumer beliefs. I show that new product versions are improved on average, but trivial or even harmful new versions may occasionally be introduced. Also, the desire to show off quality by introducing a new version serves to offset an existing market inefficiency– Arrow's underinvestment problem– so that welfare may actually be higher when consumers are initially uninformed of product quality.

In contrast to the introduction of new product versions, asymmetric information and differing incentives will always cause a welfare loss in the doctor-patient communication setting. What is most interesting here is the manner in which this welfare loss arises. While the classic physician-induced demand hypothesis holds in the aggregate so that the patient receives more treatment than he would like on average, the interaction of patient skepticism and the doctor's incentives further exacerbates the welfare loss. The doctor severely exaggerates his diagnosis for some illnesses in order to induce the patient to accept treatment, while for other illnesses the doctor recommends a light treatment to prevent the patient from selecting his outside option of no treatment. This leads to over- and undertreated, respectively. Thus the strategic communication effect causes treatment to be less medically appropriate on average and therefore lowers welfare. Interestingly, insurance can alleviate the communication problem and increase welfare notwithstanding the traditional moral hazard problem by better aligning the financial incentives of doctors and patients.

While the chapters of this dissertation have uncovered many insights, there remain fruitful avenues for future research. Investigating the competitive effects between firms to introduce a new product version would prove useful. Might a competitor's new version spur other firms in the market to introduce their own new versions, even if their quality is lacking? How would the ability to sell the old and new versions of the product simultaneously affect the new product signal? And how would the welfare analysis change if firms with endogenous R&D investment sell a durable good for many periods? Regarding doctor and patient communication, modeling a strategic insurer that attempts to gain information about the patient's health condition and demands justification from the doctor when seeking reimbursement would add realistic institutional details that may affect equilibrium communication.

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PAPERS

- "New and Improved?"
- "Physician Overtreatment and Undertreatment with Partial Delegation" (with Dmitry Lubensky)

CONFERENCE PRESENTATIONS

"New and improved?"

- International Industrial Organization Conference, *Rising Star Session*, Chicago, IL, (April, 2014)
- 5th ZEW / MaCCI Conference on the Economics of Innovation and Patenting, Mannheim, Germany (June, 2013)
- INFORMS Marketing Science Conference, Boston, MA (June, 2012)
- Midwest Economic Theory Conference, Bloomington, IN (May, 2012)
- Jordan River Conference, Bloomington, IN (April 2012)

"Physician Overtreatment and Undertreatment with Partial Delegation"

- Midwest Decision Sciences Institute Annual Meeting, Chicago, IL (April, 2014). *Recipient: Best Theoretical Research Paper Award*.
- International Industrial Organization Conference, Chicago, IL, (April, 2014)
- INFORMS Marketing Science Conference, Istanbul, Turkey (July, 2013)
- INFORMS Healthcare Conference, Chicago, IL (June, 2013)
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Research Assistant, Cooper Union, New York, NY	2007 - 2009
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