UNIVERSITY of York

Discussion Papers in Economics

No. 23/01

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Persuasion in Physician Agency*

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February 21, 2023

Abstract

We revisit the physician-patient agency problem in a model where patients differ in their preferences for treatment and the physician decides whether to recommend a treatment based on the results of a diagnostic test. We show that, in equilibrium, some patients who could benefit from treatment remain untreated, while others receive unnecessary treatment. We explore several policy interventions. A policy that does not authorize tests with high false positives increases health and welfare. Instead, mandatory testing increases health but the effect on welfare is ambiguous. Last, financial incentives increase health by reducing the number of untreated patients but reduce welfare.

JEL codes: D82, D83, I10, I18.

Keywords: Medical tests; Medical Recommendation; Bayesian Persuasion; Health Policy.

*We thank Francesca Barigozzi, Davide Dragone, Calogero Guccio, Huseyin Gurkan, Leonardo Madio, Eduardo Perez-Richet and all participants to the ASSET 2021 meeting in Marseille for their helpful feedbacks, comments and suggestions.

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1 Introduction

Driven by an ageing population and new technologies, healthcare spending continues to rise in OECD countries, reaching 18.8% of the GDP in the US in 2020 and 10.9% in the EU (OECD, 2022). In the wake of the COVID-19 pandemic, there is renewed pressure to contain costs and reduce unnecessary care, while maintaining adequate access to healthcare services. Physicians play a critical role in health systems by advising and recommending appropriate medical treatment to patients. However, the informational advantage that physicians have regarding a patient's health status, which characterises the physician-patient relation, creates a moral hazard problem that may lead to overtreatment or undertreatment (Arrow, 1963). This asymmetry of information can be understood as the extent to which the physician provides or recommends medical services that differ from what the patient would choose if he or she had available the same information and knowledge as the physician (Rice, 1983). Patients need guidance and information to decide whether or not to undergo a treatment. There is an expectation that physicians should use their knowledge and expertise to identify the patient's needs and make a recommendation (Arrow, 1963). However, evidence suggests that up to 20% of healthcare spending is wasteful (OECD, 2017), and that providers respond to financial incentives. For example, Clemens and Gottlieb (2014) show how a 2% increase in physician's payment raises healthcare provision by 3%. Dieperink and Drogemuller (2001) suggest that part of the increase in prescriptions is related to industry-sponsored grandstanding by the pharmaceutical industry.[1] In addition, physicians heavily rely on medical tests and diagnostic procedures to make a diagnosis, and these could also be used inappropriately.

This paper revisits the physician-patient agency problem in a theoretical model where a physician decides whether to recommend a treatment to patients based on the results of a diagnostic test. In our model, a patient visits a physician because she experiences some symptoms but she does not know whether she is ill or not. The physician is paid by a fee-for-service or an activity-based reimbursement and has a financial incentive to recommend treatment creating a conflict of interest. The patient suffers a health loss when she is treated unnecessarily as well as if she is untreated when she is ill. The physician chooses the type of diagnostic test, which improves the accuracy of the diagnosis. However, the choice of test can be used strategically by the physician to induce more treatment. Patients are heterogeneous: some have a strong preference for treatment, while others are reluctant to receive it. A key feature of the model is that the physician has discretion in deciding whether to recommend a test and, if so, in choosing its type and accuracy. In any case, it is ultimately the patient who decides whether or not to go ahead with the treatment.

At equilibrium, we identify three types of patients. Patients with a *low* preference for treatment have no diagnostic test and choose no treatment. Patients with a *high* preference

[1] The leading example they use is the case of anti-psychotic prescriptions in the state of Minnesota.

also have no diagnostic test but decide to have the treatment anyway. Patients with an *intermediate* preference for treatment have a diagnostic test, and receive a treatment based on the results of the test. The diagnostic test is chosen by the physician in equilibrium and features no false negatives (no type-II errors; an ill patient is always detected), but has some false positives (type-I errors; a healthy patient is sometimes classified as ill) leading to some unnecessary treatments. We show that this equilibrium entails a health loss and a welfare loss relative to a first-best solution with no uncertainty about the health condition of the patient. With respect to the health loss, we identify two types of patients: those who would benefit from treatment but remain untreated, and those who receive unnecessary treatment. In terms of welfare, patients who receive unnecessary treatment not only have worse health but also higher treatment costs, thus reducing welfare. Similarly, for patients who remain untreated, the healthcare costs are smaller than the gain in health and utility of being treated, leading to an additional welfare loss.

We analyse the effect of three different policy interventions. First, we consider a policy that imposes minimum standards on the accuracy of the test, i.e., not allowing the use of tests with high false positives or false negatives. We show that a policy limiting false negatives has no bite because physicians always have incentives to choose and recommend tests with low false negatives. Instead, a policy which restricts false positives can be effective in reducing unnecessary treatments, which improves both health and welfare. Second, mandatory testing increases health but the effect on welfare is indeterminate. Provided that the testing cost is sufficiently low, welfare increases for patients with a high preference for treatment because unnecessary care is reduced. Welfare instead decreases for patients with a low preference for treatment, because their utility remains the same although healthcare costs are higher. Third, we consider a policy changing the financial incentives of the physician. We show that the effect on health is positive. Increasing the reimbursement per patient reduces the number of untreated patients, which is beneficial, but at the same time increases the number of unnecessary treatments. Nonetheless, given that tests provide patients with information, the first effect dominates. In contrast, increasing the payment per patient reduces welfare. The additional treatment and testing costs induced by an increase in payment, plus the health and utility loss from unnecessary treatments always exceed the utility and health gain from a reduction in the number of untreated patients.

We make three contributions to the literature. First, we add to the literature on provider incentives in the health sector by explicitly modelling the relationship between physicians and patients. Most of the existing studies assume that patients are passive and accept whichever treatment the physician recommends (see Section 3), and only few allow both the patient and the physician to have a role. Second, building upon the information-design literature (Bergemann and Morris, 2019), we use a Bayesian persuasion framework, such as the one introduced by Kamenica and Gentzkow (2011), to study the physician's incentives to recommend a medical test and its implications for treatment. In our application, the physician provides verifiable information by designing medical tests that persuade patients to make a decision that is more in line with the physician's incentives. This approach has been used recently in the healthcare sector but in the different context of catastrophic events (Alizamir et al., 2020), such as pandemics (de Véricourt et al., 2021). Third, the study highlights the differential impact of policy interventions on health, patient's utility, and ultimately welfare. The typical focus of health system interventions is to improve health, not necessarily patient's utility, which is instead the typical economic focus, and to contain costs, therefore affecting welfare.

The remainder of this paper is organized as follows. Section 2 positions our paper in the literature. We present the model in Section 3, and the equilibrium in Section 4. We derive the health and the welfare loss associated with our equilibrium in section 5 and then discuss how to reduce these losses with some policy interventions in Section 6. Section 7 concludes.

2 Literature

There is an extensive literature that models the supply of healthcare providers. In this literature, the physician typically decides on the treatment or the care provided to the patient, while the patient has a passive role, accepting whichever treatment or intensity of care recommended by the physician. There are few contributions that model the interaction between the physician and the patient. Our study goes in this direction by adopting a Bayesian persuasion framework developed within the literature on information design, and only seldom applied in the context of healthcare markets. We describe these different strands in more detail below.

Ellis and McGuire (1986) show that cost-based reimbursement systems lead to overtreatment, and prospective payment systems can lead to undertreatment. Ellis (1998) shows that prospective payment systems create incentives to providers to compete on quality to cream skim patients with low severity and to skimp on quality for patients with high severity. Malcomson (2005) and Siciliani (2006) examine the optimal payment scheme for hospitals when different treatments are available and patients differ in severity of illness. Hafsteinsdottir and Siciliani (2010) show that a system with a different tariff reimbursed for different treatments within a diagnosis, can lead to overtreatment, while a system which reimburses the same tariff for different treatments can lead to undertreatment. Garcia Mariñoso and Jelovac (2003) study the physician's behaviour in referring patients to specialists in different healthcare systems and derive the socially optimal contracts. Allard et al. (2011) study how different payment mechanisms affect the intensity of the physician referrals. Adida and Dai (2020) study the effect of diagnosis-related payment schemes on the physician's diagnostic effort in assessing patients' health conditions. They show that conditioning the payment on the diagnosis entails higher diagnostic effort but might lead to less accurate recommendations.

The studies reviewed above assume that patients are passive and will accept whichever treatment the physician recommends. Ma and McGuire (1997) provide a model where health outcomes depend on both the physician's effort and the extent of healthcare chosen by the patient, and derive optimal insurance for patients and payment method for physicians. The model is further extended by Alger and Ma (2003) when the insurer is uncertain about the severity of illness (see also Wu et al. 2021).

Our study uses a Bayesian-persuasion framework following the theoretical literature on information design pioneered by Kamenica and Gentzkow (2011) and reviewed in Bergemann and Morris (2019) and Kamenica (2019). We apply this framework to the healthcare context, where neither the physician nor the patient know the health state of the patient with certainty. Recently, some studies have investigated the informative role of medical tests in influencing patient decisions. Schweizer and Szech (2018) propose a theoretical model to investigate cases where a genetic test might deliver information that is particularly frightening for the patient. They show that when the fear of bad information enters patient's utility, the optimal test is partially revealing. In our model, the emergence of a test that is not fully informative is due to physician incentives rather than patient feelings. In Alizamir et al. (2020) and de Véricourt et al. (2021), a public agency designs medical tests in a persuasive way to control unexpected contingencies that affect the whole population as in the case of a pandemic. Unlike these studies, in our model it is the physician – not the public agency – who designs the medical test, and the patient receives health-related information without any fear of contagion. This allows us to highlight a conflict of interest between the physician and the patient and to study the impact of some policy interventions on the informative content of the tests and their uptake among patients.

3 The Model

The patient. Consider a patient who experiences the symptoms of an illness. With probability α, the patient is ill and in a state of disease denoted by $\omega = D$, and with probability $(1-\alpha)$, the patient is in a state of good health denoted by $\omega = H$: $Prob(\omega = D) = \alpha$ and $Prob(\omega = H) = 1 - \alpha$. The true state of illness is not known to the patient, but the probability of falling ill α is common knowledge. The patient seeks advice from a physician on whether to take action $a \in \{0, 1\}$, where 1 indicates that she has the treatment and 0 that she does not. It is therefore ultimately the patient who decides whether or not to be treated.

The patient has four possible states: ill and treated, ill and not treated, healthy and treated, and healthy and not treated. If the patient falls ill (and is not treated), she experiences a health loss equal to $d > 0$. If the patient is ill and receives treatment $a = 1$, then part or all of her health loss is recovered by an amount equal to h with $0 < h \leq d$. If the patient is healthy, she experiences no health loss if she does not receive any treatment. Instead, she experiences a loss equal to $\mu > 0$ if she is healthy but receives an unnecessary treatment. Table 1 summarises the health states in each of the four scenarios.

	$\omega = D$	$\omega = H$
$a = 1$	$h - d$	$-\mu$
$a = 0$	$-d$	0

Table 1: Patient's outcomes conditional on states and actions.

We also assume that patient's preferences play a role in treatment decisions (Say and Thomson 2003 and Ostermann et al. 2020). When the patient is ill and receives treatment, her preference towards a treatment varies with *type* θ, and the benefit from treatment is equal to $h + \theta$. For example, some patients are relatively more inclined to receive medical care, while others are more reluctant and concerned about the side effects or the risks of the treatment. We assume that the idiosyncratic preference parameter θ is randomly drawn from a distribution with cumulative function $F(\theta)$ and density function $f(\theta)$ on the support $[\theta_{min}, \theta_{max}]$, with $\theta_{min} < 0$ and $\theta_{max} > 0$. Therefore, some patients have high valuations of treatments, while others have very low or even negative valuations (e.g., because of fear of side effects).

We assume that the patient is insured, and therefore does not have to pay when visiting the physician. The patient utility in the four possible states is then as follows:

$$U(a|\omega) = \begin{cases} \theta + h - d & \text{if } a = 1 \text{ and } \omega = D, \\ -d & \text{if } a = 0 \text{ and } \omega = D, \\ -\mu & \text{if } a = 1 \text{ and } \omega = H, \\ 0 & \text{if } a = 0 \text{ and } \omega = H. \end{cases} \tag{1}$$

The patient maximises her utility in each state. We assume that $h + \theta_{\text{min}} > 0$, and all patients have higher utility if they are treated when ill. The physician advises the patient whether to be treated or not.

The physician. We assume that each patient who experiences some symptoms will consult a physician who can recommend the treatment or not. The recommendation can be based on the results of one test or a combination of tests (hereafter, the test) chosen by the physician for each type of patient θ. We denote by $t = 1$ the situation in which the physician performs a test and $t = 0$ if he does not. We assume that the test delivers a signal $s \in \{d, h\}$, which is informative about the health state of the patient. The results of the test can be expressed in terms of conditional probabilities: the signal delivered by the test suggests that the patient is ill (healthy) when is actually ill (healthy), Pr $(s = d|\omega = D) = \phi_D \geq 1/2$ and Pr $(s = h|\omega = H) = \phi_H \geq 1/2$. Hence, type-I and type-II errors are: the signal suggests the patient is ill when she is healthy Pr $(s = d|\omega = H) = 1-\phi_H < 1/2$ or that the patient is healthy when she is ill, Pr $(s = h|\omega = D) = 1 - \phi_D < 1/2$.[2]

We assume that the physician can observe the patient preference type θ, and can decide the precision of the test accordingly. The informativeness of the test chosen by the physician for a given patient type θ can be defined by the pair of probabilities $\{\phi_D(\theta), \phi_H(\theta)\}$. As a special case, a test that removes all uncertainty is characterised by $\{1, 1\}$. A test with false positives (type-I errors) but no false negatives is characterised by $\{1, \phi_H(\theta)\}$. Instead, a test with false negatives (type-II errors) but no false positives is characterised by $\{\phi_D(\theta), 1\}$.

If the patient decides to be treated, the physician receives a payment p and incurs a treatment cost equal to k. If the physician performs the test, he incurs a cost equal to c. With respect to physician's payoff, we have three possible scenarios. In the first, the patient is treated, following a test, and the physician's profit is $(p - c - k)$. In the second scenario, the physician performs the test, but the patient decides not to be treated, and the physician's profit is $-k$. In the third scenario, the physician does not recommend the test and the patient is not treated. Physician profit is summarised as follows:

$$\Pi(a|t) = \begin{cases} p - k - c & \text{if } a = 1 \text{ and } t = 1, \\ -c & \text{if } a = 0 \text{ and } t = 1, \\ p - k & \text{if } a = 1 \text{ and } t = 0, \\ 0 & \text{if } a = 0 \text{ and } t = 0. \end{cases} \tag{2}$$

We assume that the physician is profit-oriented and the cost of testing is sufficiently low to make it profitable to offer a test to the patient, i.e. $\alpha(p - k) > c$. Given the above payment and cost structure, the physician has an incentive to maximise the number of treatments, and to minimise the number of tests. This payment system is in line with activity-based reimbursement , fee for service, and commission-based compensations.

Timing. The timing is as follows. At time 0, the patient experiences some symptoms, goes to the physician and her preference type θ becomes common knowledge. At time 1 the physician decides whether to perform a test and which type of test to perform. At time 2 the test, if performed, gives a signal about the state of disease and the patient decides whether or not to receive the treatment.

The solution concept is Perfect Bayesian Equilibrium with sequential rationality. Accordingly, each patient updates beliefs when she observes a signal and all players maximize their

[2]We assume that the test only helps to reveal the health status of the patient and does not affect her level of health or utility.

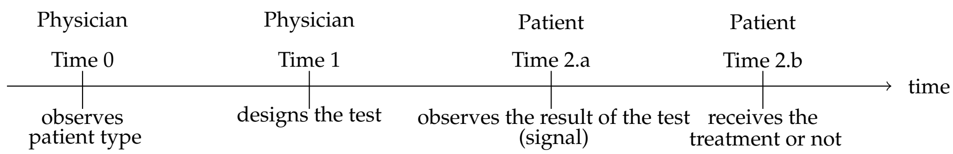

Figure 1: Timing of the game

payoffs given their beliefs at each information set.

4 Equilibrium

We derive the equilibrium by backward induction.

4.1 Time 2: The patient decides whether to be treated

At time 2, the physician has already decided whether to perform a test and the type of test. Each patient has to decide whether to be treated or not, conditional on the physician's action. We examine the two cases separately: i) the physician performs the test; ii) the physician does not perform the test. In each case, we derive the conditions under which the patient is better off with or without treatment.

The physician performs a test. Suppose that the physician performs a test characterised by a level of informativeness equal to $\{\phi_D(\theta), \phi_H(\theta)\}$ and therefore recommends a treatment based on the results of this test. The patient's expected utility from treatment depends on whether the test suggests that she is ill or healthy.

If the test suggests that the patient is ill, her expected utility from treatment is:

$$\begin{aligned} \mathbb{E}U(a=1|s=d,t=1) \quad &= \quad \alpha\,(\theta+h-d)\,\frac{\phi_D(\theta)}{\alpha\phi_D(\theta)+(1-\alpha)(1-\phi_H(\theta))} \\ &\quad -\mu(1-\alpha)\frac{(1-\phi_H(\theta))}{(1-\alpha)(1-\phi_H(\theta))+\alpha\phi_D(\theta)}, \end{aligned} \tag{3}$$

while the expected utility with no treatment is:

$$\mathbb{E}U(a=0|s=d,t=1) = -\alpha d\frac{\phi_D(\theta)}{\alpha\phi_D(\theta)+(1-\alpha)(1-\phi_H(\theta))}. \tag{4}$$

When the test suggests that the patient is ill, she is better off in expected terms if she is treated, whenever $\mathbb{E}U(a=1|s=d,t=1) \geq \mathbb{E}U(a=0|s=d,t=1)$ or, rearranging (3) and (4),

$$\alpha\,(\theta+h)\,\phi_D(\theta) - \mu(1-\alpha)(1-\phi_H\,(\theta)) \geq 0. \tag{5}$$

If, instead, the signal of the test suggests that she is healthy, her expected utility with treatment is:

$$\begin{aligned} \mathbb{E}U(a=1|s=h,t=1) = \quad &\alpha\,(\theta+h-d)\,\tfrac{(1-\phi_D(\theta))}{\alpha(1-\phi_D(\theta))+(1-\alpha)\phi_H(\phi)} \\ &-\mu(1-\alpha)\tfrac{\phi_H(\theta)}{(1-\alpha)\phi_H(\theta)+\alpha(1-\phi_D(\theta))}, \end{aligned}$$

while her expected utility with no treatment is:

$$\mathbb{E}U(a=0|s=h,t=1) = -\alpha d \frac{(1-\phi_D(\theta))}{\alpha(1-\phi_D(\theta))+(1-\alpha)\phi_H(\theta)}.$$

In expected terms, the patient is better off with no treatment when the test suggests that she is healthy whenever $\mathbb{E}U(a=0|s=h,t=1) \geq \mathbb{E}U(a=1|s=h,t=1)$ or

$$\alpha\,(\theta+h)\,(1-\phi_D(\theta)) - \mu(1-\alpha)\phi_H(\theta) \leq 0. \tag{6}$$

In summary, equations (5) and (6) characterise the conditions under which a patient with preference type θ has an incentive to accept the treatment or not when the test suggests that she is ill or healthy, respectively.

The physician does not perform the test. If the physician does not perform a test, the patient has no additional information with respect to her prior belief of being ill α. Therefore, her expected utility from being treated is equal to:

$$\mathbb{E}U(a=1,t=0) = \alpha\,(\theta+h-d) - (1-\alpha)\mu$$

Instead, if the patient is not treated, her expected utility is

$$\mathbb{E}U(a=0,t=0) = -\alpha d.$$

Therefore, the patient is better off with the treatment if $\mathbb{E}U(a=1,t=0) \geq \mathbb{E}U(a=0,t=0)$ or:

$$\theta > \hat{\theta} \equiv \frac{(1-\alpha)\mu - \alpha h}{\alpha}$$

In summary, if the physician does not perform the test, all patient types with a relatively high preference for treatment $\theta \geq \hat{\theta}$ are treated, while those with relative low preference $\theta < \hat{\theta}$ are not.

4.2 Time 1: The physician chooses the test

In this subsection, we analyse the test chosen by the physician, conditional on having decided to perform a test at time 0. For each patient with preference type θ, the physician chooses the type of test that maximises his profit, conditional on the patient being better off following the result of the test rather than ignoring it. This is characterised in equations (5) and (6) for the cases where the test suggests that the patient is ill or healthy, respectively. Formally, the physician solves the following problem:

$$\max_{\phi_D(\theta),\phi_H(\theta)\geq 1/2} \mathbb{E}\Pi(\theta) = (p-k)\left[\alpha\phi_D(\theta) + (1-\alpha)(1-\phi_H(\theta))\right] - c,$$

subject to the two patient rationality constraints (5) and (6), recalling that $\{\phi_D(\theta), \phi_H(\theta)\}$ is the level of informativeness of each test.

The solution is stated in the following lemma, where we use * to denote the optimal informativeness of the test chosen by the physician.

Lemma 1. *The optimal test is as follows:*

(i) If $\theta > \theta' \equiv \mu\frac{(1-\alpha)}{\alpha}\frac{1}{2} - h$*, then* $\phi_D^*(\theta) = 1$ *and* $\phi_H^*(\theta) = 1/2$*.*

(ii) If $\theta \leq \theta'$*, then* $\phi_D^*(\theta) = 1$ *and* $\phi_H^*(\theta) = \min\left\{1 - \frac{\alpha(\theta+h)}{\mu(1-\alpha)}, 1\right\}$*.*

Proof. See Appendix A.1 □

Lemma 3 suggests that, regardless of patient type θ, the physician always has an incentive to recommend a test which is fully informative when the patient is ill. In contrast, the information delivered by the test in the healthy state H depends on the patient type. Patients with a lower preference θ are less willing to undergo the treatment, so the physician chooses a more informative test to encourage them to be treated. Therefore, the informativeness of the test in the healthy state $\phi_H^*(\theta)$ decreases with θ.

Substituting $\phi_D^*(\theta)$ and $\phi_H^*(\theta)$ into $\mathbb{E}\Pi(\theta)$, we obtain the optimised physician's expected profit for each patient type θ when the test is performed. This is equal to:

$$\mathbb{E}\Pi(\theta|t=1) = \begin{cases} (p-k)\frac{1+\alpha}{2} - c & \text{if } \theta > \theta' \\ (p-k)\left[\alpha + (1-\alpha)\frac{\alpha(\theta+h)}{\mu(1-\alpha)}\right] - c & \text{if } \theta \leq \theta' \end{cases}. \tag{7}$$

The physician makes a higher profit for patients with a higher preference for treatment $\theta > \theta'$, rather than those with $\theta \leq \theta'$. These patients have a less informative test, $\phi_H^*(\theta) = 1/2$, and are therefore more likely to be treated.

4.3 Time 0: The physician decides whether to perform the test

At time 0, the physician decides whether or not to perform the test for each θ, anticipating the patient's decision in response to the optimal test reported in Lemma 3. Given that $\hat{\theta} > \theta'$, we can divide patients into two categories.

For patients with a relatively high preference for treatment, i.e., $\theta \geq \hat{\theta}$, the physician's profit is $p-k$ and no test is offered, while the profit is $(p-k)\frac{1+\alpha}{2} - c$ (see equation 7) if a test is provided. Given that all patients with $\theta > \hat{\theta}$ choose treatment even without a test, the optimal choice of the physician is to not to perform the test, as this guarantees higher profits,

$\Pi(\theta|t=0) > \Pi(\theta|t=1)$. This is because the physician saves on testing cost, and has more patients treated when the test is not provided.

For a lower preference for treatment, $\theta < \hat{\theta}$, if the physician does not perform the test, then the patient is never willing to receive treatment and therefore the physician's profit is zero, $\mathbb{E}\Pi(\theta|t=0) = 0$. As a consequence, the physician performs the test if $\Pi(\theta|t=1) \geq 0$, or:[3]

$$\theta \geq \tilde{\theta} \equiv \mu\left(\frac{c}{\alpha(p-k)} - 1\right) - h. \tag{8}$$

Therefore, for low preference for treatment, $\theta < \tilde{\theta}$, the patient chooses no treatment and the physician has zero profits, where $\tilde{\theta} < 0$ under the assumption of profitable testing $\alpha(p-k) > c$. For intermediate preference for treatment, $\tilde{\theta} < \theta < \hat{\theta}$, the patient accepts the treatment and the physician provides a test characterised by $\phi^*_D(\theta) = 1$, and $\phi^*_H(\theta) < 1$ (as described in Lemma 3).

4.4 Equilibrium and payoffs

We summarise the equilibrium in terms of the patient preference for treatment in the following proposition:

Proposition 1. *The equilibrium is as follows:*

1. *patients with low preference $\theta \in [\theta_{min}, \tilde{\theta}]$ do not receive a test and do not take the treatment, $a(\theta) = 0$;*

2. *patients with intermediate preference $\theta \in [\tilde{\theta}, \hat{\theta}]$ receive an informative test characterised by $\phi^*_D(\theta) = 1$, and $\phi^*_H(\theta) = \max\{1 - \frac{\alpha(\theta+h)}{\mu(1-\alpha)}, 1/2\} < 1$. They take the treatment if the test suggests they are ill, $a(\theta) = 1$ if $s = d$, and do not undertake the treatment if the test suggests they are healthy, $a(\theta) = 0$ if $s = h$;*

3. *patients with high preference $\theta \in (\hat{\theta}, \theta_{max}]$ receive no test and take the treatment, $a(\theta) = 1$;*

As illustrated in Figure 2, on the right of $\hat{\theta}$, patients do not receive a test and always accept treatment. On the left of $\tilde{\theta}$, the physician finds it not worth incurring the testing cost as these patients would be hardly persuaded to take the treatment. Patients with intermediate $\theta \in [\tilde{\theta}, \hat{\theta}]$ update their beliefs and opt for the treatment or not based on the test results.

Low types receive no treatment and their expected health and utility is $\mathbb{E}H = \mathbb{E}U = -\alpha d$. With probability α the patient goes untreated and experiences a health loss d. High types always receive treatment. Their expected health is $\mathbb{E}H = \alpha(h-d) - (1-\alpha)\mu$, and their

[3]Note that $\mathbb{E}\Pi(\theta|t=1) > 0$ for all $\theta > \theta'$, therefore we find the following cutoff value by equating $\mathbb{E}\Pi(\theta|t=1)$ to zero when $\theta < \theta'$.

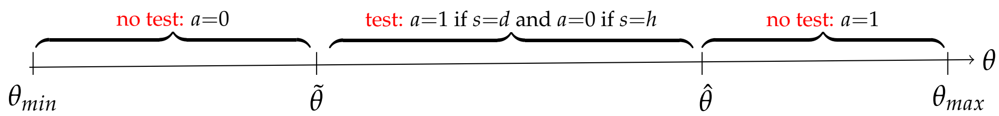

Figure 2: Choice of test and treatment.

expected utility is $\mathbb{E}U = \alpha(\theta + h - d) - (1-\alpha)\mu$. These patients benefit from treatment when they are ill, but lose when they are healthy. Patients with intermediate preference have an expected health equal to $\mathbb{E}H = \alpha(h-d) - \frac{1-\alpha}{2}\mu$ for $\theta \in [\theta', \hat{\theta}]$ and $\mathbb{E}H = -\alpha(d+\theta)$ for $\theta \in [\tilde{\theta}, \theta')$. These patients receive an informative test when they are ill, but not when they are healthy, and thus experience a loss from overtreatment but to a lesser extent compared to patients with high preference for treatment. Similarly, their expected utility is $\mathbb{E}U = \alpha(h + \theta - d) - \frac{1-\alpha}{2}\mu$ for $\theta \in [\theta', \hat{\theta}]$ and $\mathbb{E}U = -\alpha d$ for $\theta \in [\tilde{\theta}, \theta']$.[4] Patients experience a utility loss from overtreatment, but to a lesser extent relative to patients with high preference for treatment.[5]

We can compute the physician's profit for each of the three groups of patients. For patients with low preferences, the physician makes zero profits. For patients with high preferences, profit is equal to the price mark-up of the treatment, $p - k$. For patients with intermediate preferences, the profit is given by $(p-k)\frac{1+\alpha}{2} - c$ for $\theta \in [\theta', \hat{\theta}]$, and $(p-k)\left[\alpha + (1-\alpha)\frac{\alpha(\theta+h)}{\mu(1-\alpha)}\right] - c$ for $\theta \in [\tilde{\theta}, \theta']$, recalling that profit is higher for those with $\theta \in [\theta', \hat{\theta}]$. Indeed, for these patients, the physician chooses a less informative test $\phi^*_H(\theta) = 1/2$ with a higher probability of being treated even if the patient is healthy. Overall, the equilibrium expected profit of the physician is $\Pi^* = \int_{\theta_{min}}^{\theta_{max}} \mathbb{E}\Pi(\theta) f(\theta) d\theta$, or more explicitly:

$$\begin{aligned}
\mathbb{E}\Pi^* &= \int_{\tilde{\theta}}^{\hat{\theta}} (p-k)\left[\alpha\phi^*_D(\theta) + (1-\alpha)(1-\phi^*_H(\theta)) - c\right] f(\theta)d\theta + \int_{\hat{\theta}}^{\theta_{max}} (p-k) f(\theta) d\theta \\
&= (p-k)\left(\alpha(1-F(\tilde{\theta})) + (1-\alpha)\int_{\tilde{\theta}}^{\theta'} \frac{\alpha(\theta+h)}{\mu(1-\alpha)} f(\theta)d\theta\right) \\
&\quad + \left(\frac{p-k}{2} - c\right)(F(\hat{\theta}) - F(\tilde{\theta}))
\end{aligned}$$

Figure 3 illustrates the expected payoff of the physician for each type. Patients with preferences above $\hat{\theta}$ in the gray area are treated but not tested, with a correspondent physician expected payoff equal to $p - k$. Patients in the interval $[\tilde{\theta}, \hat{\theta}]$ are tested and treated according

[4]Recall $\mathbb{E}H = \alpha(h-d) - (1-\alpha)(1-\phi^*_H(\theta))\mu$, where from Lemma 1 $\phi^*_H(\theta) = 1/2$ for $\theta \in [\theta', \hat{\theta}]$ and $\phi^*_H(\theta) = 1 - \frac{\alpha(\theta+h)}{\mu(1-\alpha)}$ for $\theta \in [\tilde{\theta}, \theta')$. By substitution the result is obtained. Similarly, for the expected utility.

[5]The number of treated patients is:

$$N = (1 - F(\hat{\theta})) + \int_{\tilde{\theta}}^{\hat{\theta}} (1 - (1-\alpha)\phi^*_H(\theta)) f(\theta) d\theta,$$

i.e., the sum of patients with intermediate and high preference for treatment in Figure 2.

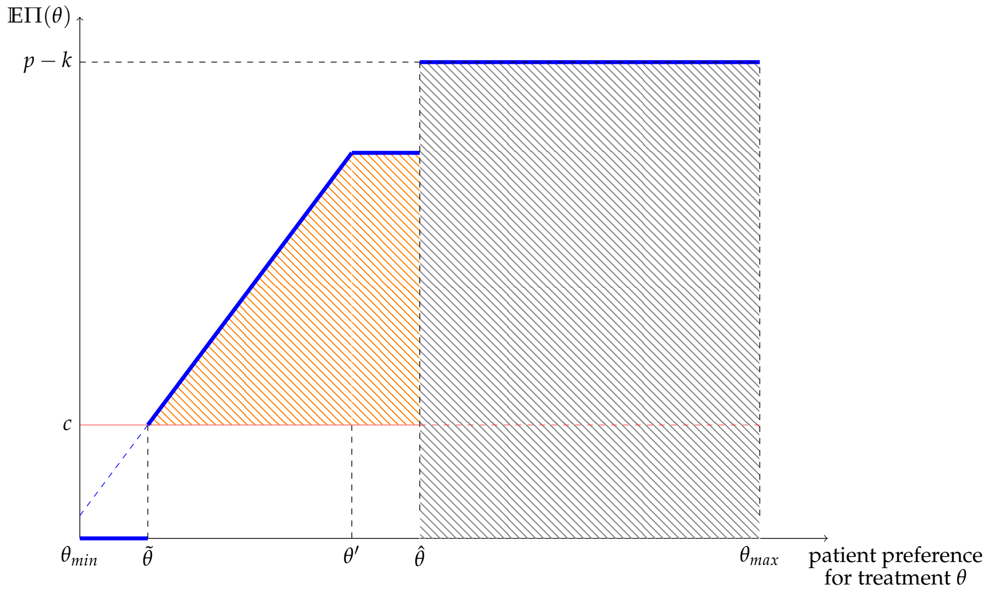

Figure 3: The physician's expected payoff for each θ.

to the signals reported in Lemma 3. For these patients, the physician's expected payoff is given by $(p-k)(\alpha + (1-\alpha)(1-\phi_H^*(\theta))$. As observed in the orange region, the higher the preference for treatment θ, the higher the payoff of the physician due to a lower informativeness of tests (lower ϕ_H^*). Finally, the payoff is zero for patients who are neither tested nor treated, i.e., $\theta < \tilde{\theta}$.

Lemma 2 investigates how the interval of patients' types who are tested, $\hat{\theta} - \tilde{\theta}$, is influenced by the parameters α, μ and h.

Lemma 2. *Consider the equilibrium described in Proposition 1. The following holds:*

(i) Increasing the probability of illness α reduces the range of patients who are tested;

(ii) increasing the loss from unnecessary treatment μ increases the range of patients who are tested;

(iii) increasing the health benefit h does not change the range of patients who are tested.

Proof. See Appendix A.2 □

Figure 4 illustrates these findings. An increase in the probability of illness α makes a test unnecessary for some patients, while increasing the physician's incentives to inform some other patients. While both $\hat{\theta}$ and $\tilde{\theta}$ move left, the impact of α on $\hat{\theta}$ is stronger. An increase in the loss from unnecessary treatment μ instead shifts both $\hat{\theta}$ and $\tilde{\theta}$ to the right, but the first effect is stronger. Finally, increasing the health benefit h reduces both thresholds by the same amount.

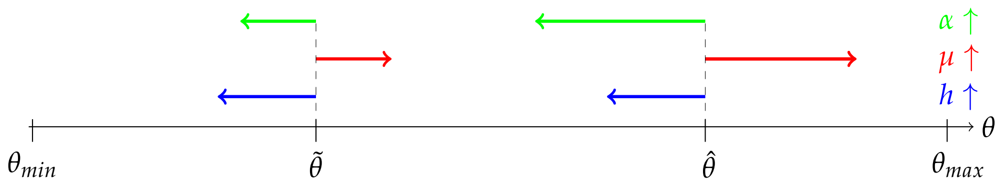

Figure 4: Informed and uninformed patients in response to changes of α, μ, and h.

5 Health and welfare loss

We have assumed that the patient does not know her state of illness, and therefore seeks advice to a physician to decide whether to be treated. This lack of knowledge generates a health loss, which we characterise in more detail below. We then take a utilitarian welfare perspective. We define welfare as the difference between patient's utility and provider costs, and characterise the loss arising from uncertainty.

5.1 Health loss

If there is no uncertainty about the state of illness, the patient's health when ill and treated is $(h-d)$, and zero when not ill. The expected health, defined with H^f (where f denotes 'first best'), is $H^f = \alpha(h-d)$. In contrast, with uncertainty there are $F(\tilde{\theta})$ patients who receive no treatment, and their expected health is $-\alpha d$. There are $1-F(\hat{\theta})$ who always receive the treatment and have an expected health equal to $\alpha(h-d)-(1-\alpha)\mu$. There are $F(\hat{\theta})-F(\tilde{\theta})$ patients who take the test and receive the treatment if the signal from the test suggests that the patient is ill, while receiving no treatment if the test suggests that the patient is healthy. For this group, the test is such that $\phi_D^*(\theta)^* = 1$, and $\phi_H^*(\theta) \geq \frac{1}{2}$, and is therefore characterised by false positives.

Define H^s as the expected health under uncertainty (where s denotes the 'second best'). This is lower than the expected health H^f due to the inability of the patient to assess the state of disease. The health loss is reported below:

$$H^f - H^s = F(\tilde{\theta})\alpha h + (1-\alpha)\mu\left[\left(1-F(\hat{\theta})\right) + \int_{\tilde{\theta}}^{\hat{\theta}} (1-\phi_H^*(\theta)) f(\theta) d\theta\right]. \tag{9}$$

We can identify two groups of patients who are worse off with uncertainty. The first group is worse off because they would benefit from treatment, but they remain untreated (first term in equation (9)). The second group is worse off because they receive unnecessary treatment (second term in equation (9)).

Figure 5 illustrates the equilibrium probability of treatment across patients with different preferences.

In the first best, it is optimal to treat the patient only if she falls ill. Therefore, in expecta-

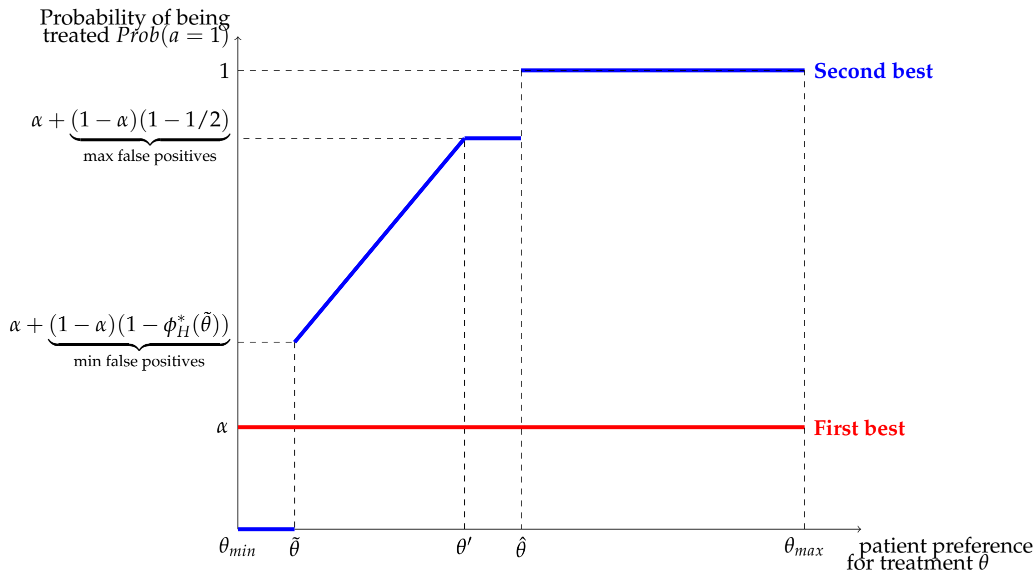

Figure 5: Probability of treatment in the first best and at equilibrium (second best).

tion, patients should be treated with probability α (red line). In the second best, we distinguish between different types of patients (blue line). Each of the three groups of patients suffers a different health loss. Patients with a low preference for treatment, $\theta < \tilde{\theta}$, decide not to be treated (horizontal line at zero), while patients with a high preference for treatment, $\theta > \hat{\theta}$, always receive treatment with probability 1. As a result, the former group experiences undertreatment and the latter overtreatment. Patients with intermediate preference for treatment, $\tilde{\theta} < \theta < \hat{\theta}$, receive a test and thus experience overtreatment due to the false positives of the test. The expected health loss for this group increases with the probability of treatment due to the higher incidence of false positives.

5.2 Welfare loss

In this subsection, we adopt a utilitarian welfare function, and define welfare as the difference between -the patient's utility and the provider's costs. In the absence of uncertainty, the patient's expected utility under the first best is:

$$V^f = \int_{\theta_{\min}}^{\theta_{\max}} \alpha(\theta + h - d) f(\theta) d\theta.$$

Given there is no uncertainty, there is no need of a test, but the physician incurs the treatment cost k for each patient. Therefore, welfare under the first best, defined by W^f, is equal to $W^f = V^f - \alpha k$.

Instead, with uncertainty, there are $F(\tilde{\theta})$ patients who receive no treatment, whose expected utility is $-\alpha d$. There are $F(\hat{\theta}) - F(\tilde{\theta})$ patients who take the test. Among these, some will receive the treatment if the signal suggests they are ill, and no treatment is the signal suggests they are healthy. For this group, the expected utility is: $\alpha(h+\theta-d)-(1-\alpha)(1-\phi_H^*(\theta))\mu$. Finally, there are $1-F(\hat{\theta})$ who always receive the treatment, and have an expected utility of $\alpha(h+\theta-d)-(1-\alpha)\mu$. Overall, the expected utility across the three groups is:

$$\begin{aligned} V^s &= -F(\tilde{\theta})\alpha d + \int_{\tilde{\theta}}^{\hat{\theta}} \left(\alpha(\theta+h-d)-(1-\alpha)(1-\phi_H^*(\theta))\mu\right) f(\theta)d\theta \\ &\quad + \int_{\hat{\theta}}^{\theta_{max}} \left(\alpha(\theta+h-d)-(1-\alpha)\mu\right) f(\theta)d\theta \\ &= V^f - \int_{\theta_{\min}}^{\tilde{\theta}} \alpha(\theta+h)f(\theta)d\theta - (1-\alpha)\mu\left(\int_{\tilde{\theta}}^{\hat{\theta}}(1-\phi_H^*)f(\theta)d\theta + 1 - F(\hat{\theta})\right) \end{aligned}$$

The provider incurs the testing cost c performed to a number of patients equal to $F(\hat{\theta}) - F(\tilde{\theta})$, and the treatment cost k for all patients treated. The latter includes two groups. For $1-F(\hat{\theta})$, the cost is faced with certainty, whereas for those with $\theta \in (\tilde{\theta},\hat{\theta})$ the cost is incurred only in case of signal d, i.e., with probability $\alpha+(1-\alpha)(1-\phi_H^*(\theta))$. Therefore, the utilitarian welfare under the second best is defined as:

$$W^s = V^s - c\left(F(\hat{\theta})-F(\tilde{\theta})\right) - k\left[1-F(\hat{\theta})+\alpha(F(\hat{\theta})-F(\tilde{\theta}))+(1-\alpha)\int_{\tilde{\theta}}^{\hat{\theta}}\left(1-\phi_H^*(\theta)\right)f(\theta)d\theta\right].$$

The welfare loss due to patient uncertainty on the state of disease is given by:

$$\begin{aligned} W^f - W^s &= \alpha\int_{\theta_{\min}}^{\tilde{\theta}}(h+\theta-k)f(\theta)d\theta \\ &\quad +(1-\alpha)\,(\mu+k)\left[\int_{\tilde{\theta}}^{\hat{\theta}}(1-\phi_H^*(\theta))f(\theta)d\theta + 1 - F(\hat{\theta})\right] \\ &\quad + c\left(F(\hat{\theta})-F(\tilde{\theta})\right) \end{aligned} \tag{10}$$

The first term is the utilitarian welfare loss of untreated patients. This arises as the benefit overcomes the cost of the treatment. The second term represents the welfare loss from unnecessary treatment, and includes both the patient health loss and the treatment costs. The third term relates to the costs of the test, which are absent in the first best.

6 Policy interventions

We focus on the impact of three interventions on health and welfare: i) introducing policies that increases the accuracy of the tests; ii) making tests mandatory, and iii) changing financial incentives.

6.1 Improving the accuracy of the test

In our model, improving the accuracy of the test is equivalent to reducing the frequency of false negatives or of false positives.

Do not authorize tests with high false negatives. The first policy involves regulation which does not authorise tests with high false negatives. The probability that the test delivers a false negative, when the patient is ill but the test suggests that she is healthy, is $(1-\phi_D)$. Our model shows that in equilibrium the physician always chooses a test with no false negatives as $\phi_D^* = 1$ for all $\theta \in [\tilde{\theta}, \hat{\theta}]$. Therefore, any additional regulation has no effect on the expected health and welfare loss in (9) and (10).

Do not authorize tests with high false positives. The second policy involves regulation which does not authorize tests with high false positives. The probability that the test suggests that the patient is healthy when she is ill is given by $1 - \phi_H$. Suppose that the regulator only allows tests with a maximum rate of false positives equal to $(1 - \underline{\phi}_H)$. Given this constraint, the physician could respond to this policy by not prescribing the test for some types of patients. We show below that this is not the case. indeed, whenever the constraint is binding, the physician's profit when the patient takes the test is:

$$\mathbb{E}\Pi(t = 1) = (p - k)[\alpha + (1 - \alpha)(1 - \underline{\phi}_H)] - c.$$

If the patient has high preference for treatment, with $\theta > \hat{\theta}$, the physician treats the patient without a test, obtaining $\mathbb{E}\Pi(\theta > \hat{\theta}|t = 0) = p - k$. These patients are never tested because the physician always has a higher profit regardless of the accuracy of the test, i.e. $\mathbb{E}\Pi(t = 1) < p - k$ for any $\underline{\phi}_H$.

Patients with $\theta < \hat{\theta}$ never accept to be treated without a test, so that $\mathbb{E}\Pi(\theta < \hat{\theta}|t = 0) = 0$. Therefore, the physician delivers a test under this policy only if $\mathbb{E}\Pi(t = 1) \geq 0$, implying that the degree of informativeness imposed by the new regulation should be not too high:

$$\underline{\phi}_H \leq \frac{p - k - c}{(1 - \alpha)(p - k)}. \tag{11}$$

This condition is always satisfied given our assumption that the testing cost is sufficiently low, $\alpha(p - k) > c$ (see Subsection 3.2).[6] Hence, the composition of the patients who are tested and receive treatment remain the same. Patients with an intermediate preference for treatment $\theta \in [\tilde{\theta}, \hat{\theta}]$ are still tested, while patients with a low preference for treatment $\theta < \tilde{\theta}$ are neither tested nor treated.

[6]When the lower bound is at its maximum, i.e., $\underline{\phi}_H = 1$, the condition becomes $(1 - \alpha)(p - k) \leq p - k - c$, which is always satisfied.

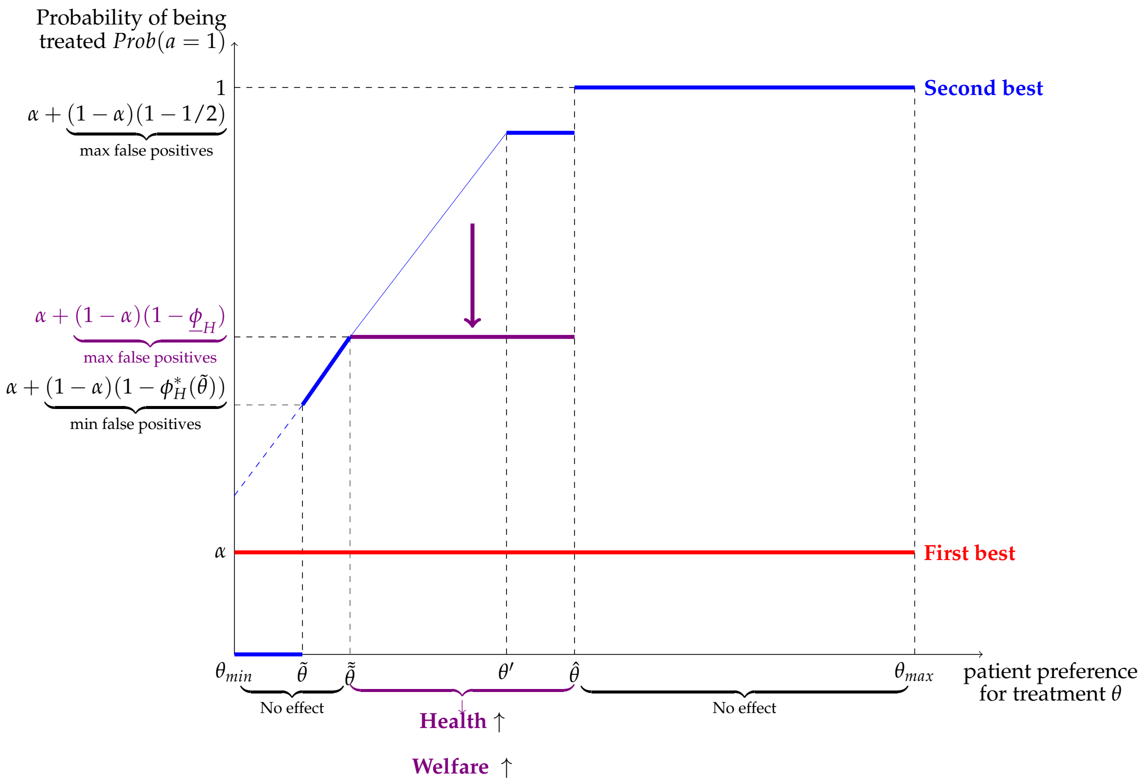

Figure 6: Effect of a policy that does not authorize tests with high false positives.

Even if the composition of tested patients remains the same as in its absence, a policy that does not authorise tests with high false positives still has some health effects because there are patients who receive tests with fewer false positives. In more detail, the policy is binding whenever $\underline{\phi}_H > \phi_H^*(\theta)$, which gives the cutoff point $\tilde{\tilde{\theta}} \equiv \frac{(1-\alpha)\mu(1-\underline{\phi}_H)-\alpha h}{\alpha}$ such that $\phi_H^*(\tilde{\tilde{\theta}}) = \underline{\phi}_H$. This implies that the policy reduces false positives for patients with preference types in the interval $[\tilde{\tilde{\theta}}, \hat{\theta}]$, who experience a lower probability of treatment, and has no effect on patients with preference types in the interval $[\tilde{\theta}, \tilde{\tilde{\theta}}]$. Given that $\tilde{\tilde{\theta}}$ decreases with $\underline{\phi}_H$, the impact of the policy is maximised by setting $\underline{\phi}_H = \phi_H^*(\tilde{\theta})$. This is depicted in Figure 6, where the differences with respect to Figure 5 are drawn in violet. The probability of treatment is reduced for patients with preferences in the interval $[\tilde{\tilde{\theta}}, \hat{\theta}]$, while the other patients with preferences above $\hat{\theta}$ or below $\tilde{\tilde{\theta}}$ are not affected.

The effect of the policy on health is equal to:

$$H(\underline{\phi}_H) - H^s = (1-\alpha)\mu \int_{\tilde{\tilde{\theta}}}^{\hat{\theta}} (\underline{\phi}_H - \phi_H^*(\theta)) f(\theta) d\theta. \tag{12}$$

Patients with preferences in the interval $[\tilde{\theta}, \tilde{\tilde{\theta}}]$ have fewer false positives, and are less likely to receive unnecessary treatment, which increases expected health.

The effect on welfare is:

$$W(\underline{\phi}_H) - W^s = (1-\alpha)\,(\mu + k) \int_{\tilde{\tilde{\theta}}}^{\hat{\theta}} (\underline{\phi}_H - \phi_H^*(\theta)) f(\theta) d\theta.$$

Reducing unnecessary treatments not only improves health, but also reduces treatment costs, thereby increasing welfare. We summarise these results with the following proposition:

Proposition 2. *A policy that does not authorize tests with high false positives increases both health and welfare.*

6.2 Make the test mandatory

We now consider the effects of a policy which makes the test mandatory when a patient experiences some symptoms and therefore visits a physician. One rationale for this policy is to ensure that the patient is informed before deciding whether or not to accept a treatment. However, although the test is mandatory for treatment, the physician could still respond to this policy by choosing a type of test that is potentially less informative. We investigate whether this is the case below.

Define $\tilde{\phi}_D(\theta)$ and $\tilde{\phi}_H(\theta)$ as the informativeness of the test optimally chosen by the physician for a patient with preference type θ under this policy. The new equilibrium is as follows:

Lemma 3. *Under a mandatory test, at equilibrium, all patients take the treatment if the test suggests they are ill, $a(\theta) = 1$ if $s = d$, and do not take the treatment if the test suggests they are healthy, $a(\theta) = 0$ if $s = h$. In particular:*

1. *patients with low and intermediate preferences for treatment, $\theta \in [\theta_{min}, \hat{\theta}]$, receive a test characterised by a degree of informativeness $\tilde{\phi}_D(\theta) = 1$, and $\tilde{\phi}_H(\theta) = \phi_H^*(\theta)$;*
2. *patients with a high preference for treatment $\theta \in (\hat{\theta}, \theta_{max}]$ receive a test characterised by a degree of informativeness equal to $\tilde{\phi}_D(\theta) = 1$, and $\tilde{\phi}_H(\theta) = 1/2$.*

Proof. See Appendix A.3. □

Lemma 3 suggests that patients with low preference for treatment now take the test and also receive the treatment if the tests suggests they are ill. The test, and its degree of informativeness, is the same as the one used for patients with intermediate preferences for treatment. Patients with a high preference for treatment also receive the test but the test chosen by the physician is not informative if the patient is healthy, while it is informative if the patient is ill.

Figure 7 illustrates the impact of a mandatory test on the probability of being treated for different types of patients. The test increases the probability of treatment for patients with low preferences, while reducing it for patients with high preferences (violet line).

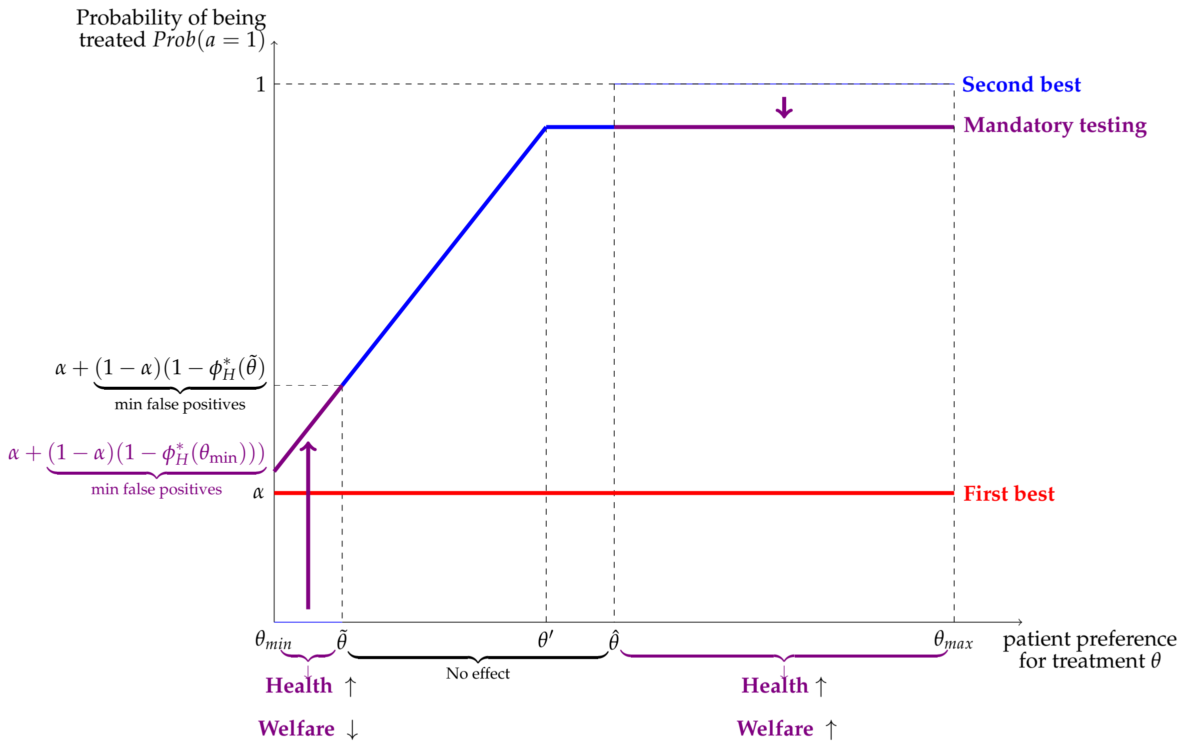

Figure 7: Effects of mandatory testing.

The effect of introducing a mandatory test on expected health is:

$$\widetilde{H} - H^s = F(\tilde{\theta})\alpha h + (1-\alpha)\mu \left[\frac{1-F(\hat{\theta})}{2} - \int_{\theta_{min}}^{\tilde{\theta}} (1-\tilde{\phi}_H(\theta)) f(\theta) d\theta \right] \tag{13}$$

There are three effects. The first term captures the health gain from treatment for patients with a low preference who would have remained untreated if the test were not mandatory. The second term relates to the health gain for patients with a high preference: some of these patients are healthy and therefore the test reduces the number of unnecessary treatments. The third term gives the health loss arising from the false positives for patients with a low preference who would have been untreated if the test were not mandatory. We can show that this third effect is of second order importance relative to the benefits brought about the policy. Substituting the equilibrium $\tilde{\phi}_H(\theta)$ into (13), in Appendix A.4 we show:

$$\widetilde{H} - H^s = (1-\alpha)\mu \frac{1-F(\hat{\theta})}{2} - \alpha \int_{\theta_{min}}^{\tilde{\theta}} \theta f(\theta) d\theta, \tag{14}$$

which is always positive given that $\theta_{min} < \tilde{\theta} < 0$ from equation (8). Therefore, the policy always improves expected health.

The effect of the policy on welfare is instead equal to:

$$\begin{aligned}\widetilde{W}-W^{s} &= \tilde{H}-H^{s}+\alpha\int_{\theta_{\min}}^{\tilde{\theta}}(\theta-k)f(\theta)d\theta \\ &\quad -(1-\alpha)k\int_{\theta_{min}}^{\tilde{\theta}}(1-\tilde{\phi}_{H}(\theta))f(\theta)d\theta-c\left(1-F(\hat{\theta})+F(\tilde{\theta})\right) \\ &\quad +k(1-\alpha)\frac{1-F(\hat{\theta})}{2} \end{aligned} \tag{15}$$

In comparison with the effect of the policy on health, we have three additional effects. The integral in the first line in (15) is negative and it is equal to the difference between the preference for treatment θ and the treatment cost k for patients with low preferences (with $\theta - k < 0$ in all elements in the integral). The terms in the second line are also negative and express the increase in costs for all people who now receive both a test and a treatment. The term in the third line is instead positive, as people with a high preference ($\theta > \hat{\theta}$) now receive a test, with consequent cost savings from a reduction in treatments when the test suggests the patient is healthy.

Substituting the health expression, we obtain:

$$\begin{aligned}\widetilde{W}-W^{s} &= (1-\alpha)\left(\mu+k\right)\frac{1-F(\hat{\theta})}{2} \\ &\quad -k\int_{\theta_{min}}^{\tilde{\theta}}\left[1-(1-\alpha)\tilde{\phi}_{H}(\theta)\right]f(\theta)d\theta \\ &\quad -c\left(1-F(\hat{\theta})+F(\tilde{\theta})\right)\end{aligned}$$

The first term is positive and gives the health benefit plus cost savings from unnecessary treatment for patients with high preferences. The second term is negative and represents the additional cost of treating patients with low preferences. Note that low-preference patients have better health as a result of the policy, but this is completely offset by their negative preferences. The third term is also negative and gives the additional testing cost for patients with low and high preferences for treatment.

We summarise the effect of the mandatory test in the following proposition:

Proposition 3. *Mandatory testing increases expected health, whereas its effect on welfare is ambiguous. In more detail, the policy reduces welfare for low-preference types* $\theta \in [\theta_{\min}, \tilde{\theta}]$*, whereas it increases welfare for high preference types* $\theta \in [\hat{\theta}, \theta_{\max}]$ *only if* $c < \frac{(1-\alpha)(\mu-k)}{2}$*. The policy is neutral for patient types in the range* $\theta \in [\tilde{\theta}, \hat{\theta}]$*.*

Proof. See Appendix A.5. □

In the proof, we show that a patient with a low preference obtains the same utility with and without the mandatory tests. As a result, mandatory testing leads to additional healthcare costs to treat patients whose positive effect on health is exactly offset by the negative utility from treatment. Instead, there is no welfare effect for patients with intermediate preferences because they receive the same test with or without the policy. Finally, patients with a high preference for treatment experience a utility gain, but the overall welfare effect is positive only if the cost of the test is sufficiently low.

6.3 Financial incentives

Last, we investigate a policy that changes financial incentives by increasing the payment per patient treated. This policy affects the composition of the tested patients by reducing the lower threshold $\tilde{\theta}$, as $\frac{\partial \tilde{\theta}}{\partial p} = -\frac{c\mu}{\alpha(p-k)^2} < 0$. A higher price provides the physician with a stronger incentive to choose an informative test to patients with a relatively low preference for treatment. More tests increase the number of patients who are subsequently treated, if the test suggests that they are ill, and physician's revenues. Figure 8 illustrates the effect of the increase in the payment on the probability of being treated.

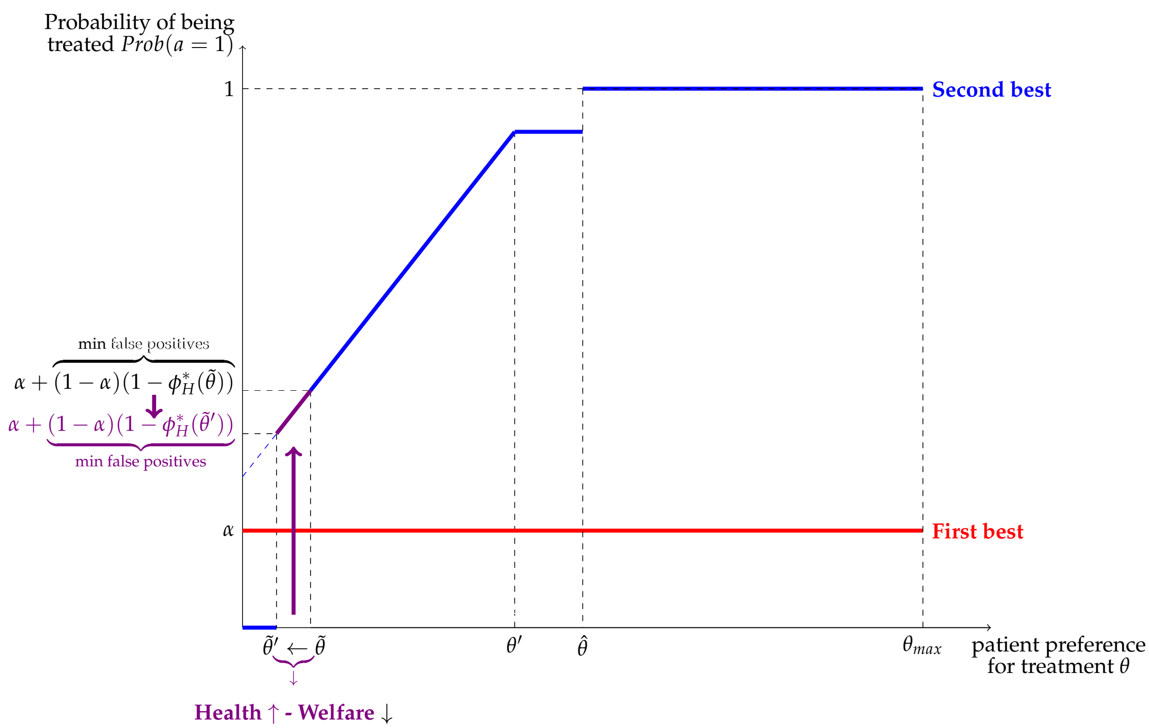

Figure 8: Effects of an increase of the payment received by the physician.

In Appendix A.6 we show that the effect of a marginal increase in the payment on the expected health is:

$$\frac{\partial H^s}{\partial p} = -\alpha h f(\tilde{\theta}) \frac{\partial \tilde{\theta}}{\partial p} + (1-\alpha)\mu \left[1 - \phi^*_H(\tilde{\theta})) f(\tilde{\theta})\right] \frac{\partial \tilde{\theta}}{\partial p} = \alpha \tilde{\theta} \frac{\partial \tilde{\theta}}{\partial p} f(\tilde{\theta}) > 0, \tag{16}$$

where recall that $\tilde{\theta} < 0$. A higher number of tests increases health for ill patients but also increases unnecessary treatment for healthy patients due to false positives. However, the latter is a second-order effect, and overall expected health increases across patients.

Oppositely, the effect on welfare is:

$$\frac{\partial W^s}{\partial p} = f(\tilde{\theta})\frac{\partial \tilde{\theta}}{\partial p}\left[-\alpha(h+\tilde{\theta}-k)+(1-\alpha)(\mu+k)\left(1-\phi_H^*(\tilde{\theta})\right)+c\right] = f(\tilde{\theta})\frac{\partial \tilde{\theta}}{\partial p}\frac{pc}{p-k} < 0 \quad (17)$$

Even though the higher payment increases expected health, the patients affected by the policy have relatively low preference for treatment. Given that the higher payment also increases treatment and test costs, the overall effect on welfare is negative. Similar to the case of mandatory testing, Appendix A.7 shows that a patient with a low preference obtains the same utility with or without the policy, leading to additional healthcare costs without utility benefits for patients.[7]

We summarise with the following proposition.

Proposition 4. *An increase in the payment per treatment increases expected health but reduces welfare.*

7 Conclusion

In this study, we have provided a model which revisits the physician-patient agency relationship. We used a general framework where both the physician and the patient take decisions and both are uncertain about the patient's health state. The physician decides whether to recommend a diagnostic test to the patient and the type of test, while the patient has to decide whether to accept the treatment based on the test results. As the physician is paid by fee for service, the diagnostic test can be used by the physician to persuade the patient to accept the treatment. The patients differ in their preference for treatment and, in equilibrium, are divided into three groups. Patients with a low preference for treatment have no diagnostic test and choose no treatment. Patients with an intermediate preference have a diagnostic test, and receive a treatment based on the results of the test. Patients with a high preference also have no diagnostic test but choose the treatment anyway.

The equilibrium outcome of our model is characterised by both health and welfare losses for two groups of patients. The first group involves patients who would benefit from treatment but remain untreated because their reluctance leads them to receive no diagnostic test and no treatment. If they had known their illness, they would have opted for treatment. Therefore, they experience a health loss and utility loss that are never compensated by savings

[7] Appendix A.8 shows that the effect of a marginal increase in treatment and test costs is qualitatively similar to the effect of a marginal reduction in payment.

in treatment costs, thus reducing welfare. The second group includes patients who receive unnecessary treatment, which reduces health and utility as well as increases treatment costs. Our model therefore captures two distinct policy concerns at health system level across OECD countries in terms of access and inefficiency: some individuals have poor access to health care leading to worse health (EXPH, 2016), while others receive unnecessary health care with no health benefits and in some cases harmful, which generates waste in health spending (OECD, 2017).

We have therefore explored three policy interventions that could alleviate such concerns. We show that a policy that imposes minimum standards on the accuracy of tests can improve both health and welfare.[8] This is the case when fewer false positives translate in fewer unnecessary treatments. In contrast, policies that are stricter on false negatives are ineffective. This is a direct consequence of physician incentives. As the physician aims at encouraging treatment, then there is no incentive to recommend tests that suggest the patient is healthy when ill.

Rather than acting on the accuracy of the test, an alternative policy is to introduce mandatory testing. We show that this policy improves health by reducing the number of ill patients that remain untreated as well as the unnecessary treatments. For patients with a high preference for treatment, welfare also increases due to higher utility and lower costs, as long as the cost of the test is sufficiently low. In contrast, the utility of patients with a low preference (the untreated) remains the same but the healthcare costs are higher, which reduces welfare. This shows that policy reforms can have different effects on health, which is a primary objective of health system mandates, and on utility, which also encompasses patients' preferences.

Last, we consider the effect of financial incentives, which has been the typical focus of previous literature. Stronger financial incentives increase both the treatments of ill patients and unnecessary treatments. We show that the first effect dominates and health improves. In contrast, welfare declines and this is driven by the additional treatment and testing costs induced by an increase in payment. Overall, our analysis highlights the importance of decomposing the welfare effects of policy interventions into health, utility and costs. While some policies can address both access and waste, others create a stark trade-off between health and costs when a policy can reduce welfare despite improving health.

A Technical Appendix

A.1 Proof of Lemma 3

Unconstrained problem. Given that the profit function is decreasing in $\phi_H(\theta)$ and increasing in $\phi_D(\theta)$, it is optimal for the physician to set $\phi^*_D(\theta) = 1$, $\phi^*_H(\theta) = 1/2$ as long as the patient

[8]There are examples of international research networks that assess how much each test is close to a reference standard. See https://www.eunethta.eu/wp-content/2018/01.

constraints are not binding, or more explicitly:

$$\begin{aligned} \alpha\,(\theta + h) - \mu(1-\alpha)\frac{1}{2} &\geq 0, \\ -\mu(1-\alpha)\frac{1}{2} &\leq 0. \end{aligned}$$

This is the case only if

$$\theta \geq \theta' \equiv \mu\frac{(1-\alpha)}{\alpha}\frac{1}{2} - h$$

Constrained problem. If this condition does not hold, and $\theta < \theta'$, we start by considering the case in which the constraint in (5) is binding, while (6) is slack. Given that the payoff is increasing in $\phi_D(\theta)$, we set $\phi_D^*(\theta) = 1$. Plugging into (6), we obtain $-\mu(1-\alpha)\phi_H(\theta) < 0$ for any positive $\phi_H(\theta)$. Therefore, we only need a $\phi_H^*(\theta)$ such that:

$$\alpha\,(\theta + h) - \mu(1-\alpha)(1 - \phi_H^*(\theta)) = 0 \Leftrightarrow \phi_H^*(\theta) = \min\left\{1 - \frac{\alpha\,(\theta+h)}{\mu(1-\alpha)}, 1\right\}.$$

A.2 Proof of Lemma 2

$$\frac{\partial\hat{\theta}}{\partial\alpha} = -\frac{\mu}{\alpha^2} < 0, \qquad \frac{\partial\tilde{\theta}}{\partial\alpha} = \left(\frac{c}{p-k}\right)\frac{\partial\hat{\theta}}{\partial\alpha} < 0$$

$$\frac{\partial\tilde{\theta}}{\partial\mu} = -\frac{\alpha(p-k)-c}{\alpha(p-k)} > 0, \qquad \frac{\partial\hat{\theta}}{\partial\mu} = \frac{1-\alpha}{\alpha} > 0.$$

Given that $p - k > c$, we have $\frac{\partial\hat{\theta}}{\partial\alpha} > \frac{\partial\tilde{\theta}}{\partial\alpha}$. Moreover, we observe that

$$\frac{\partial\hat{\theta}}{\partial\mu} - \frac{\partial\tilde{\theta}}{\partial\mu} = \frac{1-\alpha}{\alpha} - \left(-\frac{\alpha(p-k)-c}{\alpha(p-k)}\right) = \frac{p-k-c}{\alpha(p-k)} > 0.$$

Finally, we have $\frac{\partial\tilde{\theta}}{\partial h} = \frac{\partial\hat{\theta}}{\partial h} = -1$.

A.3 Proof of Lemma 3

The physician decides on the accuracy of the test by solving the maximisation problem in equation (5). Being the test compulsory, the physician's decisions at time 0 in section 4.3 are no longer part of the game. As a consequence, replicating the analysis made in the proof of Lemma 3, we can observe the following:

- for patients with low types $\theta \in [\theta_{min}, \tilde{\theta}]$, the optimal test is stated in point (ii) of Lemma 3, so that $\tilde{\phi}_D(\theta) = 1$, and $\tilde{\phi}_H(\theta) = \phi_H^*(\theta)$. Note that, given the constraint in (5), provided that $\theta_{min} \geq -h$, all patients will undertake the treatment if the test suggests they are ill, $a(\theta) = 1$ if $s = d$, and do not undertake the treatment if the tests suggests they are healthy, $a(\theta) = 0$ if $s = h$.

- Patients with intermediate types $\theta \in [\tilde{\theta}, \hat{\theta}]$ receive the same test they would have received in the absence of the policy (points (i) and (ii) of Lemma 3).

- For patients with high types $\theta \in (\hat{\theta}, \theta_{max}]$, the optimal test is stated in point (ii) of Lemma 3, so that $\tilde{\phi}_D(\theta) = 1$, and $\tilde{\phi}_H(\theta) = 1/2$. Since the constraint in (5) is always satisfied, these patients will undertake the treatment if the test suggests they are ill, $a(\theta) = 1$ if $s = d$, and do not undertake the treatment if the tests suggests they are healthy, $a(\theta) = 0$ if $s = h$.

A.4 Derivation of equation (14)

Plugging the equilibrium $\tilde{\phi}_H$ into (13), we obtain:

$$
\begin{aligned}
\widetilde{H} - H^s &= F(\tilde{\theta})\alpha h + (1-\alpha)\mu \left[\frac{1 - F(\hat{\theta})}{2} - \int_{\theta_{min}}^{\tilde{\theta}} \frac{\alpha\,(\theta + h)}{\mu(1-\alpha)} f(\theta) d\theta \right] \\
&= F(\tilde{\theta})\alpha h + (1-\alpha)\mu \left[\frac{1 - F(\hat{\theta})}{2} - \frac{\alpha h}{\mu(1-\alpha)} F(\tilde{\theta}) - \frac{\alpha}{\mu(1-\alpha)} \int_{\theta_{min}}^{\tilde{\theta}} \theta f(\theta) d\theta \right] \\
&= (1-\alpha)\mu \left[\frac{1 - F(\hat{\theta})}{2} - \frac{\alpha}{\mu(1-\alpha)} \int_{\theta_{min}}^{\tilde{\theta}} \theta f(\theta) d\theta \right] \\
&= \mu(1-\alpha)\frac{1 - F(\hat{\theta})}{2} - \alpha \int_{\theta_{min}}^{\tilde{\theta}} \theta f(\theta) d\theta.
\end{aligned}
$$

A.5 Proof of Proposition 3

In order to understand welfare effects, we need to look at each group of patient types.

- There is no welfare effect of the policy for people in the interval $\theta \in [\tilde{\theta}, \hat{\theta}]$, as they are tested and treated with same probability with and without the policy.

- A patient with a low type $\theta \in [\theta_{\min}, \tilde{\theta}]$ receives a utility of $-\alpha d$ in the absence of the policy, while the utility is $\alpha(\theta + h - d) - (1-\alpha)(1 - \tilde{\phi}_H)\mu$ under the policy. Comparing the two, we obtain $\alpha(\theta + h) - (1-\alpha)(1 - \tilde{\phi}_H)\mu = 0$, so that the policy is neutral for the utility of these patients. As a consequence, mandatory testing decreases welfare because it imposes c and k with no utility gain.

- A patient with a high type $\theta \in [\hat{\theta}, \theta_{\max}]$ obtains $\alpha(\theta + h - d) - (1-\alpha)\mu$ without the policy, whereas the utility received with the introduction of the policy is $\alpha(\theta + h - d) - (1-\alpha)(1-\tilde{\phi}_H)\mu$. The net effect of the policy on this utility is $(1-\alpha)\tilde{\phi}_H\mu = \frac{(1-\alpha)\mu}{2}$. Recalling that under the policy the probability of treatment is $\alpha + (1-\tilde{\phi}_H)(1-\alpha) = \frac{1+\alpha}{2}$, the overall expected cost faced for a patient is $c + \frac{k}{2}(1+\alpha)$, whereas in the absence of the policy the cost is k. Hence, the welfare for high-preference types increases if $\frac{(1-\alpha)\mu}{2} - c > \frac{k(1-\alpha)}{2}$.

A.6 Derivation of equations (16) and (17)

After substituting $\phi^*_H(\tilde{\theta})$ in equation (16), we obtain $\frac{\partial H^s}{\partial p} = \frac{\partial \tilde{\theta}}{\partial p} f(\tilde{\theta}) \left[-\alpha h + (1-\alpha)\mu \frac{\alpha(\tilde{\theta}+h)}{(1-\alpha)\mu}\right]$. Substituting for $\phi^*_H(\theta)$ and for $\tilde{\theta} \equiv \mu\left(\frac{c}{\alpha(p-k)} - 1\right) - h$ in equation (17), we obtain:

$$\begin{aligned}
\frac{\partial W^s}{\partial p} &= f(\tilde{\theta})\frac{\partial \tilde{\theta}}{\partial p}\left[-\alpha(h+\tilde{\theta}-k) + (1-\alpha)(\mu+k)\left(1-\phi^*_H(\tilde{\theta})\right) + c\right] \\
&= f(\tilde{\theta})\frac{\partial \tilde{\theta}}{\partial p}\left[-\alpha(h+\tilde{\theta}-k) + (1-\alpha)(\mu+k)\left(1-\left(1-\frac{\alpha(\tilde{\theta}+h)}{(1-\alpha)\mu}\right)\right) + c\right] \\
&= f(\tilde{\theta})\frac{\partial \tilde{\theta}}{\partial p}\left[-\alpha(h+\tilde{\theta}-k) + (1-\alpha)(\mu+k)\frac{\alpha(\tilde{\theta}+h)}{(1-\alpha)\mu} + c\right] \\
&= f(\tilde{\theta})\frac{\partial \tilde{\theta}}{\partial p}\left[\alpha k + \frac{k}{\mu}\alpha(\tilde{\theta}+h) + c\right] \\
&= f(\tilde{\theta})\frac{\partial \tilde{\theta}}{\partial p}\frac{pc}{p-k} < 0
\end{aligned}$$

A.7 Utility neutrality of an increase in the payment p

A patient with a low preference $\theta \in [\theta_{\min}, \tilde{\theta}]$ receives a utility of $-\alpha d$ in the absence of the policy, while the utility is $\alpha(\theta + h - d) - (1-\alpha)(1-\phi^*_H(\theta)\mu$ under the policy. Comparing the two terms, we obtain $\alpha(\theta + h) - (1-\alpha)(1-\phi^*_H(\theta))\mu = 0$, so that the policy is neutral for the utility of these patients. As a consequence, an increase in the payment reduces welfare because it entails c and k with no utility gain.

A.8 Effects of increasing testing cost and treatment cost

The analysis provided in Proposition 4 focuses on the incentives of a higher payment. Given that the physician is profit-oriented, a reduction in treatment costs k or test costs c also increases the number of patients who are tested, $\frac{\partial \tilde{\theta}}{\partial c} = \frac{\mu}{\alpha(p-k)} > 0$ and $\frac{\partial \tilde{\theta}}{\partial k} = -\frac{\partial \tilde{\theta}}{\partial p} > 0$, and subsequently treated. The effect of a marginal reduction in treatment and testing costs on the expected health is:

$$\frac{\partial H^s}{\partial \chi} = -\alpha h f(\tilde{\theta})\frac{\partial \tilde{\theta}}{\partial \chi} + (1-\alpha)\mu\left[(1-\phi_H^*(\tilde{\theta}))f(\tilde{\theta})\frac{\partial \tilde{\theta}}{\partial \chi}\right]$$

with $\chi \in \{c, k\}$. First, using the result of Proposition 4, we can conclude that a higher k or c reduce health.

Concerning the treatment cost, we can rewrite (18) as follows.

$$\begin{aligned}\frac{\partial W^s}{\partial k} &= -\frac{\partial W^s}{\partial p} + \alpha\left(1+\frac{h}{\mu}\right)F(\tilde{\theta}) + \frac{\alpha}{\mu}\int_{\tilde{\theta}}^{\hat{\theta}} \theta f(\theta)d\theta - (1-\alpha)(1-F(\hat{\theta})) \\ &= -\frac{\partial W^s}{\partial p} + \frac{\alpha}{\mu}\left[(1-\alpha)F(\hat{\theta})\mu + F(\tilde{\theta})h + \alpha\left(\int_{\tilde{\theta}}^{\hat{\theta}} \theta f(\theta)d\theta + \mu\right)\right] \qquad (18)\end{aligned}$$

Finally, exploiting that $\frac{\partial \tilde{\theta}}{\partial p} = -\frac{c\mu}{\alpha(p-k)^2}$ and that $\frac{\partial \tilde{\theta}}{\partial c} = \frac{\mu}{\alpha(p-k)}$, we can write $\frac{\partial \tilde{\theta}}{\partial c} = -\frac{p-k}{c}\frac{\partial \tilde{\theta}}{\partial p}$, so that:

$$\frac{\partial W^s}{\partial c} = -\frac{p-k}{c}\frac{\partial W^s}{\partial p} - \left[F(\hat{\theta}) - F(\tilde{\theta})\right].$$

The sign of the derivative above depends on the relative size of two terms.

References

Adida, E. and Dai, T. (2020). Payment for diagnosis under limited outcome visibility. Available at SSRN.

Alger, I. and Ma, C.-t. A. (2003). Moral hazard, insurance, and some collusion. Journal of economic behavior & organization, 50(2):225–247.

Alizamir, S., de Véricourt, F., and Wang, S. (2020). Warning against recurring risks: An information design approach. Management Science, 66(10):4612–4629.

Allard, M., Jelovac, I., and Léger, P. T. (2011). Treatment and referral decisions under different physician payment mechanisms. Journal of Health Economics, 30(5):880–893.

Arrow, K. J. (1963). Uncertainty and the welfare economics of medical care. The American Economic Review, 53(5):941–973.

Bergemann, D. and Morris, S. (2019). Information design: a unified perspective. Journal of Economic Literature, 57(1):44–95.

Clemens, J. and Gottlieb, J. D. (2014). Do physicians' financial incentives affect medical treatment and patient health? American Economic Review, 104(4):1320–49.

de Véricourt, F., Gurkan, H., and Wang, S. (2021). Informing the public about a pandemic. Management Science, 67(10):6350–6357.

Dieperink, M. E. and Drogemuller, L. (2001). Industry-Sponsored Grand Rounds and Prescribing Behavior. JAMA, 285(11):1443–1444.

Ellis, R. P. (1998). Creaming, skimping and dumping: provider competition on the intensive and extensive margins. Journal of Health Economics, 17(5):537–555.

Ellis, R. P. and McGuire, T. G. (1986). Provider behavior under prospective reimbursement: Cost sharing and supply. Journal of Health Economics, 5(2):129–151.

EXPH (2016). Expert panel on effective ways in investing in health (2016). Access to health services in the European Union. European Commission.

Garcia Mariñoso, B. n. and Jelovac, I. (2003). Gps' payment contracts and their referral practice. Journal of Health Economics, 22(4):617–635.

Hafsteinsdottir, E. J. G. and Siciliani, L. (2010). Drg prospective payment systems: refine or not refine? Health Economics, 19(10):1226–1239.

Kamenica, E. (2019). Bayesian persuasion and information design. Annual Review of Economics, 11(1):249–272.

Kamenica, E. and Gentzkow, M. (2011). Bayesian persuasion. The American Economic Review, 101(6):2590–2615.

Ma, C.-T. A. and McGuire, T. G. (1997). Optimal health insurance and provider payment. The American Economic Review, 87(4):685–704.

Malcomson, J. M. (2005). Supplier discretion over provision: Theory and an application to medical care. The RAND Journal of Economics, 36(2):412–432.

OECD (2017). Tackling wasteful spending on health. OECD Publishing, Paris, France.

OECD (2022). Health at a glance: Europe 2022: State of health in the eu cycle. OECD Publishing, Paris, France.

Ostermann, J., Muhlbacher, A., Brown, D. S., Regier, D. A., Hobbie, A., Weinhold, A., Alshareef, N., Derrick, C., and Thielman, N. M. (2020). Heterogeneous patient preferences for modern antiretroviral therapy: Results of a discrete choice experiment. Value in Health, 23(7):851–861.

Rice, T. H. (1983). The impact of changing medicare reimbursement rates on physician-induced demand. Medical care, 21(8):803–815.

Say, R. E. and Thomson, R. (2003). The importance of patient preferences in treatment decisions: challenges for doctors. Bmj, 327(7414):542–545.

Schweizer, N. and Szech, N. (2018). Optimal revelation of life-changing information. Management Science, 64(11):5250–5262.

Siciliani, L. (2006). Selection of treatment under prospective payment systems in the hospital sector. Journal of Health Economics, 25(3):479–499.

Wu, Y., Bardey, D., Chen, Y., and Li, S. (2021). Health care insurance policies when the provider and patient may collude. Health Economics, 30(3):525–543.