# Classification risk in health insurance: The interaction of prevention and guaranteed renewable insurance

Julia Holzapfel*

August 14, 2021

**Abstract**

We study regulatory regimes toward the use of genetic and behavioral information in the pricing of guaranteed renewable (GR) health insurance. Individuals have access to different prevention technologies to reduce their risk of health losses later in life. Thus, insurance markets may be affected by moral hazard and adverse selection. Our results show that GR contracts which reward investments in prevention but do not use genetic information in pricing can be a good compromise to offer classification risk insurance at an attractive price without disadvantaging individuals with an unfortunate genetic endowment. These contracts guide the insured to reduce expected long-term costs from health losses if prevention is similarly productive for everyone. However, they cannot be geared to each insured's personal abilities. If the productivity of prevention depends strongly on an individual's genetic disposition, there is a need for additional health campaigns targeted at the ones for whom prevention is particularly productive.

*Keywords:* Classification Risk · Prevention · Insurance · Guaranteed Renewability

*JEL Classifications:* D81 · D82 · G22 · G28 · I13 · I18

*LMU Munich School of Management, E-Mail: holzapfel@bwl.lmu.de.

# 1 Introduction

Modifiable risk factors like a high body-mass index or tobacco smoke account for more than a quarter of total healthcare spending in the U.S. (Bolnick et al., 2020). That is, more than USD 700 billion per year are spent on health losses that could have been prevented. Chronic diseases classify individuals as being at high risk for health losses. For example, people with high blood pressure or diabetes are at an increased risk for cardiovascular and renal disease. To cover the treatment costs of health losses, individuals may purchase health insurance. If the price of insurance is adjusted as new information about the insured's risk type is revealed, the diagnosis of a chronic disease may lead to a substantial jump in insurance premiums. In contrast, guaranteed renewable (GR) contracts promise a premium stream that is independent of the insured's future health condition. Therefore, GR contracts may be a means to insure chronic diseases like diabetes or high blood pressure.

If a young person is genetically predisposed or leads an unhealthy lifestyle, it is quite likely that she will develop a chronic disease one day. Over the past years, the technological and scientific progress has significantly extended insurers' possibilities to gather and analyze large amounts of data which can be used to assess a customer's health risk. Genetic tests enable insurers to precisely determine a person's genetic disposition. Wearable devices can be used to track a customer's physical activity. The aim of this paper is to analyze whether genetic and behavioral information should be used in the pricing of GR health insurance. For this purpose, we investigate how restrictions on the use of information affect the insured's behavior and the attractiveness of GR insurance. Our results show that GR contracts which reward investments in prevention but do not use genetic information in pricing can be a good compromise to offer comprehensive health insurance coverage at an attractive price without disadvantaging individuals with an unfortunate genetic endowment. Moreover, these contracts guide the insured to reduce expected long-term costs from health losses if prevention is similarly productive for everyone.

Although chronic diseases mostly appear at an older age, the factors which determine the probability of their onset are at least imperfectly known early in life. When individuals are young, they have an idea about their genetic disposition because they know their family history. Based on this knowledge, they can influence their probability of becoming a high-risk type by investing in a healthy lifestyle or by undertaking preventive medical examinations. To get an initial understanding of the drivers of the prevention decision, we conduct several comparative statics in the absence of insurance and when health insurance is only available as a short-term contract whose price depends on the insured's risk type. In these settings, individuals face a classification risk since high-risk types are worse off than low-risk types. One might conjecture that individuals feel more comfortable and hence exert less effort if they can insure their health risk later in life. However, the effect of insurance on optimal prevention is ambiguous. On the one hand, insurance reduces the size of the potential loss to the difference between the high- and the low-risk premium. On the other hand, prevention becomes more effective because preventing against becoming a high-risk type is equivalent to preventing against a monetary loss if insurance is available. In their seminal paper, Ehrlich and Becker (1972) analyze the interaction of prevention and insurance when both act on the same contemporaneous monetary loss risk. We add to the understanding of this interaction by considering a setting in which the risks affected by prevention and insurance are only indirectly related by the classification of risk types over time.

GR contracts may be offered as a means to insure the classification risk. In such a long-term contract, individuals make a prepayment when they are young which enables them to insure their risk later in life at a premium that does not depend on their risk type. We study regulatory regimes toward the use of genetic and behavioral information in the pricing of GR insurance. The traditional assumption that individuals have an informational advantage compared to their insurer may no longer hold if the insurer collects and evaluates enough health-related data. Hence, symmetric information between insurers and their customers is a realistic assumption if there are no restrictions on the use of information by insurers. In a symmetric information setting, GR insurance is in demand by all individuals and the insured exert the effort in prevention which minimizes their expected lifetime health expenditures. Since large amounts of healthcare spending form an enormous burden for the diseased and also for the health system as a whole, it is desirable that health expenditures are minimized.

However, individuals with an unfortunate genetic endowment face a price disadvantage due to reasons beyond their control under symmetric information. Moreover, the monitoring of prevention activities may be considered an invasion of privacy. Therefore, regulatory restrictions might limit or ban individual underwriting in health insurance, thereby creating information asymmetries between insurers and their customers. If insurance companies must neither use information about the insured's genetic disposition nor about their engagement in prevention in insurance pricing, we find that GR contracts may only attract a small group of purchasers. Better risk types in the pool of insured have to subsidize worse risk types if all customers are offered the same contract. Consequently, only individuals who consider themselves sufficiently likely to become a high-risk type purchase a GR contract. Moreover, GR insurance discourages investments in prevention if its price does not depend on the effort exerted in prevention. Medical studies suggest that prevention against diabetes or high blood pressure is most effective for individuals whose family history indicates that they are likely to come down with these diseases one day. Hence, it is particularly unpleasant that these individuals, who form the group of GR purchasers, do not exert any effort in prevention if individual underwriting is banned.

The issues under a ban of individual underwriting are not present in the symmetric information setting. It is typically believed that when purchasing insurance, individuals should not face a price disadvantage for reasons beyond their control. Consequently, regulation should ban insurance pricing based on genetics. On the other hand, pricing insurance based on one's behavior such as smoking or exercising habits is less of a concern. Therefore, we consider a third informational setting in which the price of insurance depends on the effort exerted in prevention but not on the customer's personal genetic endowment. In this setting, all GR purchasers choose the effort level which minimizes the expected lifetime health expenditures of an average purchaser. This effort in prevention can decrease total expected costs from health losses significantly if prevention is similarly productive for all GR purchasers. If the productivity of prevention differs between individuals, however, the ones with the most productive prevention technologies do not exploit their potential. Since prevention activities reduce the insured's expected health losses, effort-dependent contracts are cheaper than the ones without any individual underwriting. Therefore, GR contracts which reward prevention activities attract a larger group of purchasers than contracts which neglect individuals' effort in prevention. That is, the monitoring of prevention does not only eliminate moral hazard but it also mitigates adverse selection. This results in a Pareto improvement compared to a total ban of individual underwriting.

We add to the literature on GR insurance by introducing prevention activities which allow individuals to improve their future health prospects. Pauly et al. (1995) show that GR insurance fully eliminates premium risk in an ideal setting. However, dropping some of the assumptions for an ideal insurance market results in incomplete premium risk protection. Frick (1998) shows that capital market imperfections may render GR insurance unattractive due to borrowing constraints. Peter et al. (2016) demonstrate that GR insurance is no more in demand by all individuals if they have some private information about their future risk type. Hoy et al. (2021) investigate market inefficiencies when individuals' future demand for insurance is uncertain. All these models assume that the probability of becoming a high-risk type is exogenously given. In real life, however, the probability that someone contracts a chronic disease like diabetes or high blood pressure, which characterizes her as being at high risk for health losses, depends on both her genetic disposition and her lifestyle choices. Therefore, we analyze the market for GR health insurance when individuals can invest in prevention to reduce their probability of becoming a high-risk type. We extend the model of Peter et al. (2016) by disentangling genetic and behavioral factors and analyze how modern technology may help insurers to overcome information asymmetries.

By discussing the pros and cons of the use of genetic and behavioral information in insurance pricing, this paper also contributes to the risk classification literature. The early literature on risk classification focused on easily observable but immutable characteristics like age, race, or gender (Hoy, 1982; Crocker and Snow, 1986). Since genetic tests became more available, there has been an ongoing debate about the use of genetic information in insurance pricing (Hoy and Ruse, 2005). Several papers compare regulatory regimes toward the use of genetic information in pricing when prevention is possible. Barigozzi and Henriet (2011) as well as Crainich (2017) assume that insurers observe preventive activities such as medical checkups whereas Peter et al. (2017) assume that prevention is not observable which would be the case for lifestyle factors. So far, only few contributions explicitly discuss the use of behavioral information in insurance pricing (Bond and Crocker, 1991; Polborn, 2008). In recent years, advances in data science and the ubiquity of mobile devices have improved insurers ability to monitor lifestyle factors like exercising habits. By comparing different informational settings, we provide a foundation to decide whether behavioral information should be used in health insurance pricing from an economic point of view. We focus on the long-term effects of lifestyle choices by considering a market for GR insurance. Most of the risk classification literature is based on models assuming price and quantity competition in which insurers tackle adverse selection by offering self-selecting contract menus.[1] If health insurance is endowed with a GR feature, no underwriting based on the insured's health condition will take place later in life representing full insurance against classification risk. Thus, guaranteed renewability has an all-or-nothing character and insurers only compete over prices in our model, which is more in the spirit of Akerlof (1970) and unlike the well-known environments with self-selecting contract menus. Assuming only price competition in the market for GR insurance is in line with the approaches of Pauly et al. (1995) and Peter et al. (2016) who also limit their analysis to premium schedules providing full insurance against classification risk.

Technological progress may have made effort-dependent contracts technically feasible. Nevertheless, they are not much in demand by now. A possible reason is that there is a lack of acceptance in the population resulting from privacy concerns. Our results show that effort-dependent contracts can be a good compromise not to confront individuals with a price disadvantage due to reasons beyond their control but still to provide premium risk coverage at an attractive price and to reduce long-term health spending due to modifiable risk factors. Therefore, insurance companies and public policy makers should try to find ways to address privacy concerns in order to promote effort-dependent contracts. As insurance contracts whose price only depends on the level of prevention cannot be geared to each individual's personal abilities, additional health campaigns should target the ones for whom prevention is particularly productive. Incorporating our results about the interaction of prevention and insurance in policy making can help to make use of technological progress to increase the accessibility and affordability of health insurance and to reduce the frequency of chronic diseases by promoting a healthy lifestyle.

This paper proceeds as follows. In the next section, we set up our formal model. Afterwards, we analyze optimal prevention under classification risk in section three. In section four, we introduce guaranteed renewable insurance as a means to insure classification risk and study regulatory regimes toward the use of genetic and behavioral information in insurance pricing. The final section concludes.

[1] The underlying models use the equilibrium concepts developed by Rothschild and Stiglitz (1976), Miyazaki (1977), and Spence (1978). For a survey of the risk classification literature based on self-selecting contract menus see e.g. Dionne and Rothschild (2014).

## 2 The model

### 2.1 Individuals' life lottery

We consider risk-averse expected utility maximizers in a two-period setting. They are endowed with a time-additively separable utility function. $u$ and $v$ denote the felicity functions in the first and in the second period, respectively, which are assumed to be twice differentiable.[2] Both felicity functions are increasing and concave ($u' > 0$, $u'' < 0$ and $v' > 0$, $v'' < 0$), i.e. individuals are risk-averse. Initial wealth is given by $w_1$ in the first period and by $w_2$ in the second period.

The first period, $t_1$, describes the situation when individuals are young. Early in life, individuals have an idea about their future risk type but they do not know it perfectly then. For example, they might have some information about their genetic disposition because they know which diseases their family members suffered from in the past. This information is reflected in a personal signal $z_0 \in [0, 1]$, which each agent receives at the beginning of the first period. The signal is always received and it is costless. It can be interpreted as the agent's likelihood of becoming a high-risk type in the second period, $t_2$, if she does not invest in preventive activities. We disentangle risk factors which can be influenced by the agent and those beyond her control. The signal $z_0$ only encodes information about unchangeable characteristics like the agent's genetic disposition. After receiving the signal $z_0$, the agent can invest in prevention in order to reduce her probability of becoming a high-risk type at $t_2$. For example, she may invest in a healthy lifestyle by incorporating a healthy diet or regular exercise in her everyday life, or she may undertake preventive medical examinations. The monetary cost of such preventive activities is reflected in the effort level $e \geq 0$. For reasons of simplicity, we assume that individuals do not face any monetary risk in the first period. Therefore, first-period consumption in the absence of insurance is given by $w_1 - e$ with certainty.

As individuals get older, risk types evolve, and each individual becomes either a high-risk type, $H$, or a low-risk type, $L$, at the beginning of the second period, $t_2$. The prevention technology $z(z_0, e)$ yields the probability of becoming a high-risk type for an agent who receives the signal $z_0$ and makes a monetary investment in prevention of $e$ at $t_1$. As mentioned earlier, the agent expects to become a high-risk type with probability $z_0$ if she does not exert any effort in preventive activities, i.e. $z(z_0, 0) = z_0$ for all $z_0 \in [0, 1]$. Furthermore, we assume $z_{z_0} > 0$, $z_e < 0$, and $z_{ee} > 0$, where subscripts denote partial derivatives.[3] The first assumption implies that $z_0$ can not only be interpreted as the probability of becoming a high risk in the absence of prevention but more generally in the sense that a smaller $z_0$ represents a "better" genetic endowment. If two agents receiving different exogenous signals, $z_0^1 < z_0^2$, exert the same effort in prevention, the one with the better endowment will have a smaller probability of becoming a high-risk type, $z(z_0^1, e) < z(z_0^2, e)$, at any effort level $e \geq 0$. According to the second and third

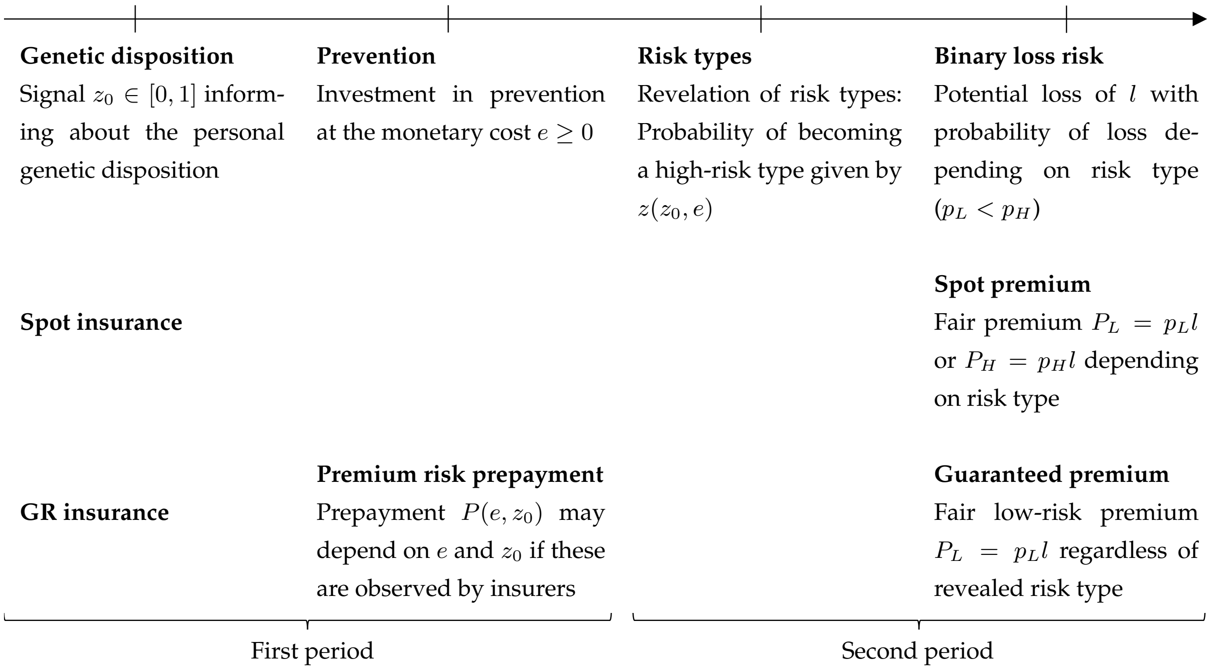
[2]The special case $v = \beta u$ yields the discounted expected utility model with $\beta \in (0, 1]$ being the rate of pure preference for the present.

[3]The assumptions on the partial derivatives with respect to $e$ are relaxed to $z_e \leq 0$ and $z_{ee} \geq 0$ for $z_0 = 0$, which yields $z(0, e) = 0$ for all $e \geq 0$.

assumption, increasing the investment in prevention decreases the probability of becoming a high-risk type, where marginal productivity is decreasing. In the second period, agents face a potential monetary loss of the given amount $l$. Thus, second-period consumption equals $w_2 - l$ in the loss state or $w_2$ in the no-loss state. The probability of loss is given by $p_L$ for low-risk types and by $p_H$ for high-risk types, where $0 < p_L < p_H < 1$. If diabetic patients form the group of high-risk types, for instance, the monetary loss may represent the treatment expenses of regular renal dialysis.

To summarize, individuals' life is represented by a two-stage "life lottery". At the first stage, each agent faces the risk of becoming either a high- or a low-risk type later in life. The distribution of this "risk type lottery" depends on both the exogenous signal which the agent receives at $t_1$ and the effort in prevention which she exerts at $t_1$. At the second stage, the agent faces a binary loss risk at $t_2$, with the probability of loss depending on the outcome of the first stage, i.e. on the agent's risk type. We call the second stage the agent's "loss lottery". The timing of individuals' life lottery is illustrated in Figure 1.

Figure 1: Sequence of play




*Notes:* The figure displays the timing of individuals' life lottery. In the first period, individuals have some information about their genetic disposition and decide about their investment in prevention. GR purchasers also make a premium risk prepayment in the first period to insure the classification risk later in life. In the second period, risk types are revealed. In the absence of insurance, individuals face a binary loss risk. Spot insurance allows them to insure this loss risk at the fair premium depending on their risk type. GR purchasers can insure their loss risk at the fair low-risk premium even if they have become a high-risk type.

## 2.2 Insurance market scenarios

We consider three scenarios for the insurance market. In the first scenario, we assume that insurance markets are absent. This does not only characterize the prevention decision when insurance markets are indeed not existing. It also yields the appropriate setup when individuals do not take into account that they may purchase an insurance contract when deciding about their investment in prevention.[4] Considering the prevention decision in isolation helps us to get an unclouded impression of the factors influencing the optimal level of prevention.

In the second scenario, the health risk of losing $l$ can be insured after the revelation of risk types at the beginning of the second period. We can think of a one-year health insurance contract here whose premium depends on the insured's health condition when entering the contract at the beginning of the year.[5] Insurers are able to distinguish the two risk types. For example, they might check individuals' medical history for pre-existing conditions like diabetes or high blood pressure in their underwriting process to discriminate between high- and low-risk types. We assume that once an agent's risk type has evolved, she can neither hide this characteristic nor influence her probability of loss any more. That is, we abstract from situations in which individuals might not undertake medical examinations in order to avoid being classified as a high risk as well as from problems of moral hazard when insurance is purchased after the revelation of risk types. In a competitive insurance market with symmetric information about risk types, insurance is offered at the fair premium depending on an individual's risk type. Since individuals are risk-averse, they purchase full insurance according to Mossin's (1968) Theorem. Hence, low-risk types pay an insurance premium of $P_L = p_L l$ whereas high-risk types pay $P_H = p_H l$ to obtain full coverage. We call this type of insurance spot insurance because the contract is signed in the same period in which it becomes effective. Spot insurance eliminates the health risk of the loss lottery but individuals are still exposed to a premium risk resulting from the classification of risk types.

Finally, we consider a third scenario with guaranteed renewable (GR) insurance contracts which also eliminate the premium risk. These long-term contracts offer a premium stream that does not depend on any revealed risk type. We assume that insurance companies only engage in price competition. That is, individuals can only choose between purchasing full coverage and not insuring their premium risk.[6] The guaranteed renewability feature comes at the ad-

[4] It is a question of mental accounting (Thaler, 1999) whether individuals decide jointly or separately about the use of different risk management tools. An isolated decision about the optimal level of prevention would be a consequence of narrow bracketing.

[5] Recently, such short-term contracts have gained some attention because they are heavily on the rise in China (Swiss Re, 2021).

[6] In a similar vein, Einav and Finkelstein (2011) analyze possible market outcomes when full coverage insurance contracts are offered in a general one-period setting with adverse selection. Peter et al. (2016) focus on a market for GR insurance in a two-period model. In their models, however, individuals cannot improve their odds by investing in prevention. A real-world example for a health insurance market in which premium risk protection is offered only with full coverage is the German private health insurance market. In Germany, individuals can switch from public to private health insurance if they meet specific income requirements or become a civil servant. If someone expects to switch to private insurance in the future, they can purchase an insurance contract which guarantees them the option to take out private health insurance without any reassessment of their health condition.

ditional cost of a premium risk prepayment. That is, a GR purchaser makes a premium risk prepayment $P(e, z_0)$ in the first period and insures her loss risk in the second period at the low-risk premium $p_L l$ regardless of her risk type. We compare different informational settings for the pricing of GR insurance. If insurers observe the insured's genetic disposition and their investment in prevention, the premium risk prepayment $P(e, z_0)$ may depend on these characteristics. However, regulatory restrictions might prohibit the use of personal genetic and behavioral information in insurance pricing. In a competitive market, GR insurance is offered with the fair premium risk prepayment calculated based on the information available to the insurer. Each individual decides whether she purchases a GR contract or whether she purchases spot insurance without insuring the premium risk.

# 3 Optimal prevention under classification risk

## 3.1 No insurance

To get a sense of the factors influencing prevention decisions, we start our analysis with a setting in which prevention is the only risk management tool available to the agent. The agent cannot avoid the risk of loosing $l$ at $t_2$. However, she can reduce her probability of becoming a high risk at $t_2$ by investing in prevention. Since high risks are more likely to suffer a loss than low risks, this indirectly influences the agent's probability of loss in the loss lottery, and hence her expected utility at $t_2$. An agent receiving the signal $z_0$ chooses the effort level which maximizes her total expected utility given by

$$EU^{\text{No}}(e) = \underbrace{u(w_1 - e)}_{\text{Utility at } t_1} + z(z_0, e) \underbrace{\left[p_H v(w_2 - l) + (1 - p_H) v(w_2)\right]}_{\text{Expected utility at } t_2 \text{ for high-risk types}} + (1 - z(z_0, e)) \underbrace{\left[p_L v(w_2 - l) + (1 - p_L) v(w_2)\right]}_{\text{Expected utility at } t_2 \text{ for low-risk types}}.$$

Since $v$ is increasing and $p_H > p_L$, expected utility at $t_2$ is greater for low-risk types than for high-risk types.

Interior solutions, $e^{\text{No}} \in (0, w_1)$, are characterized by the first-order condition

$$EU_e^{\text{No}}(e^{\text{No}}) = -u'(w_1 - e^{\text{No}}) - z_e(z_0, e^{\text{No}})(p_H - p_L)\left(v(w_2) - v(w_2 - l)\right) = 0. \quad (1)$$

At the optimal effort level, the agent balances the marginal utility cost caused by the investment in prevention at $t_1$ and its marginal utility benefit, which results from the decrease in the probability of becoming a high-risk type at $t_2$. In Appendix A.1.1, we show that the second-order condition is globally satisfied. A necessary condition for the existence of an interior solution is $EU_e^{\text{No}}(0) > 0$, or equivalently $u'(w_1) < -z_e(z_0, 0)(p_H - p_L)(v(w_2) - v(w_2 - l))$, i.e. the utility cost of an infinitesimal level of effort must be less than its effect on expected utility at $t_2$. In the following, we assume that this holds and an interior solution exists for all $z_0 \in (0, 1]$.[7]

In order to understand the determinants of individuals' risk management decision, we investigate how the outlook for someone's health condition later in life affects her optimal level of prevention. The health outlook is characterized by the parameters of the loss lottery and the properties of the prevention technology. We adapt the terminology introduced by Hoy (1989) and say that the prevention technology exhibits increasing difference (ID) if $z_{ez_0} > 0$, constant difference (CD) if $z_{ez_0} = 0$, and decreasing difference (DD) if $z_{ez_0} < 0$.[8] The three cases are depicted in Figure 2. A comparative statics analysis yields the following proposition.

**Proposition 1.** *In the absence of insurance markets, a risk-averse expected utility maximizer ...*

... *raises her effort in prevention as the probability of loss of high-risk types increases.*

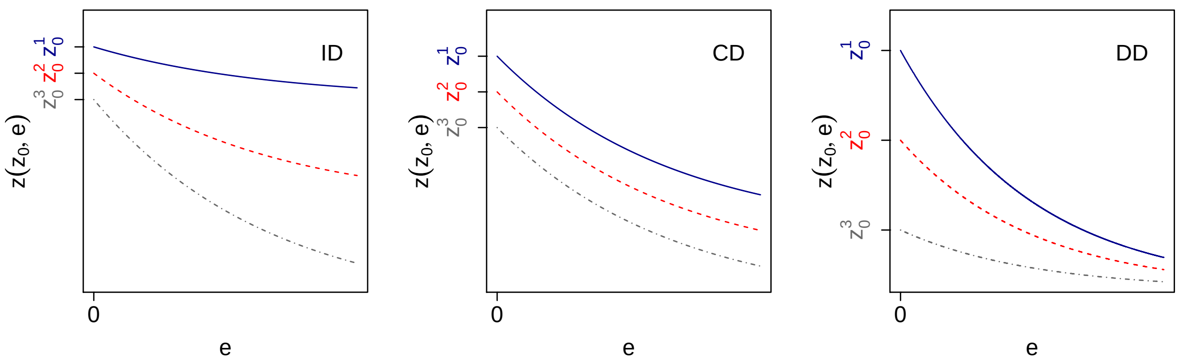
... *reduces her effort in prevention as the probability of loss of low-risk types increases.*

... *raises her effort in prevention as the size of the potential loss in the second period increases.*

... *reduces (does not change, raises) her effort in prevention as her endowed probability of becoming a high-risk type increases if the prevention technology exhibits ID (CD, DD).*

*Proof.* See Appendix A.5.1. □

Figure 2: ID, CD, DD




*Notes:* The figure displays the probability of becoming a high-risk type, $z(z_0, e)$, as a function of the effort in prevention, $e$, for different prevention technologies. The marginal productivity of prevention decreases (stays constant, increases) as the agent's risk type endowment deteriorates if the prevention technology exhibits ID (CD, DD).

[7]Individuals receiving the signal $z_0 = 0$ become low risks for sure even if they do not invest in prevention. Hence, their utility-maximizing effort level equals zero.

[8]This terminology is motivated by the resulting properties of the difference function $\delta(e) = z(z_0^1, e) - z(z_0^2, e) > 0$, for $z_0^1 > z_0^2$. $\delta(e)$ describes the difference between the probabilities of becoming a high-risk type for two agents receiving different signals $z_0^1$ and $z_0^2$. Considering the derivative of the difference function, we find $\delta'(e) = z_e(z_0^1, e) - z_e(z_0^2, e) > (=, <)\ 0$ for all $e \geq 0$ if $z_{ez_0} > (=, <)\ 0$.

The intuition behind these results is as follows. After the revelation of risk types in the second period, the agent faces one of the loss lotteries $l_H = (w_2 - l, p_H, w_2)$ or $l_L = (w_2 - l, p_L, w_2)$, depending on her risk type. $l_L$ yields higher expected utility than $l_H$, and the difference between the two lotteries' expected utility increases as $p_H$ increases, $p_L$ decreases, or $l$ increases. By exerting more effort, the agent reduces her likelihood of ending up with the untoward lottery $l_H$. Thus, she will choose a higher effort level if the high-risk lottery, $l_H$, gets even less attractive compared to the low-risk lottery, $l_L$, which is the case if the difference between their expected utility levels increases.

The comparative statics result concerning the effect of a change in the personal signal $z_0$ informs about how much an individual should invest in prevention depending on her genetic disposition. Since $z_e < 0$, prevention is more productive at the margin if $z_e$ is smaller, i.e. more negative. This implies that the marginal productivity of prevention decreases (stays constant, increases) as the agent's risk type endowment deteriorates if the prevention technology exhibits ID (CD, DD). A higher signal $z_0$, which represents a worse risk type endowment, leads to a lower (unchanged, higher) optimal effort level if the prevention technology exhibits ID (CD, DD). Intuitively, $z_0$ informs the agent not only about her probability of becoming a high-risk type but also about the productivity of her prevention technology. The agent chooses a higher effort level if she perceives her prevention technology as more productive.

The implications of this result can be illustrated by considering the prevention of high blood pressure or diabetes. High blood pressure often occurs in elderly people and it is a key risk factor for cardiovascular diseases. The treatment expenses of such diseases represent the potential monetary loss at $t_2$ in this example. Individuals with normal blood pressure form the group of low risks, and those with high blood pressure are classified as high risks. Although a healthy lifestyle reduces the risk of high blood pressure for all levels of genetic risk, some individuals should exert more effort than others if their prevention technology is more productive. According to the results of Shook et al. (2012), the risk-reducing effect of a higher level of fitness due to regular physical activity is stronger for individuals with a parental history of high blood pressure than for those without. This represents DD in our model, i.e. prevention is particularly effective for individuals who receive a high signal $z_0$. Hence, these individuals should exert more effort than those with a lower signal $z_0$ according to Proposition 1. Concerning the prevention of diabetes, the findings of Said et al. (2018) also suggest DD. In contrast, if individuals whose parents were diagnosed with high blood pressure or diabetes believe that they will become a high-risk type anyway and only individuals with a "better" genetic endowment are able to avoid becoming a high-risk type, this represents ID. Therefore, individuals' perception of their personal prevention technology plays a crucial rule in their choice of effort, and health education can help individuals to include scientific knowledge in their decision-making.

### 3.2 Spot insurance

We modify the previous setting by introducing insurance in the second period, which can be purchased after the revelation of risk types. For example, individuals may purchase one-year health insurance contracts later in life whose price depends on their health condition when entering a contract. A competitive insurance market allows individuals to insure the potential loss of $l$ at the fair price depending on their risk type. Since individuals are risk-averse and insurance is offered at the fair premium, they purchase full insurance according to Mossin's (1968) Theorem. By doing so, they eliminate the risk of the loss lottery, and only a premium risk due to the evolution of risk types at the beginning of the second period remains. Hence, expected utility of an agent receiving the signal $z_0$ is given by

$$EU^{\text{Sp}}(e) = u(w_1 - e) + z(z_0, e)v(w_2 - p_H l) + (1 - z(z_0, e))v(w_2 - p_L l). \tag{2}$$

Interior solutions for the optimal effort level, $e^{\text{Sp}} \in (0, w_1)$, are characterized by the first-order condition

$$EU_e^{\text{Sp}}(e^{\text{Sp}}) = -u'(w_1 - e^{\text{Sp}}) - z_e(z_0, e^{\text{Sp}})\left(v(w_2 - p_L l) - v(w_2 - p_H l)\right) = 0. \tag{3}$$

At the optimal effort level, the marginal utility cost of prevention and its expected marginal utility benefit are equalized. The second-order condition is globally satisfied, see Appendix A.1.2. Again, we assume that an interior solution exists for all $z_0 \in (0, 1]$.

Like in the scenario without insurance markets, we conduct a comparative statics analysis to understand how someone's perception of her health outlook influences her prevention decision. The results are summarized in the following proposition.

**Proposition 2.** *If spot insurance at the fair premium is offered after the revelation of risk types, a risk-averse expected utility maximizer ...*

- *... raises her effort in prevention as the probability of loss of high-risk types increases.*
- *... reduces her effort in prevention as the probability of loss of low-risk types increases.*
- *... raises her effort in prevention as the size of the potential loss in the second period increases.*
- *... reduces (does not change, raises) her effort in prevention as her endowed probability of becoming a high-risk type increases if the prevention technology exhibits ID (CD, DD)*

*Proof.* See Appendix A.5.2. □

The effects are qualitatively the same as in the setting without insurance. The underlying rationale is slightly different, however. Since the agent fully insures her risk of loosing $l$, a change in the parameters of the loss lottery reduces to one in the fair premiums, $P_H = p_H l$ and $P_L = p_L l$. The difference between the two premiums, and thus between the utility at $t_2$ of a low-and a high-risk type, increases (decreases, increases) as $p_H$ ($p_L$, $l$) increases. As the perspective of becoming a high-risk type will be more deterrent if the difference between a high risk's and a low risk's utility is greater, the agent will exert more effort in these cases. An increase in the size of the loss, $l$, affects the utility of both a high- and a low-risk type at $t_2$. Both premiums increase, and thus the wealth of both risk types decreases. The effect on high risks' wealth is stronger since $p_H > p_L$. Moreover, it follows from decreasing marginal utility that a change in wealth at $t_2$ has a larger impact on the utility of high-risk types because their wealth level lies below that of low-risk types. Both effects are heading in the same direction such that high-risk types suffer more from an increase in $l$, and the optimal effort level increases as $l$ increases. The effects resulting from the interaction of genetics and prevention follow the same rationale as in the setting without insurance. That is, the agent exerts more effort if her prevention technology is more productive.

### 3.3 The effect of the introduction of spot insurance

When insurance becomes available, individuals have another tool of risk management in addition to prevention at their disposal. The availability of spot insurance changes the risky situation that individuals face later in life, which will likely affect their prevention decision when they are young. One might expect that individuals reduce their investment in prevention if they can insure their loss risk in the second period because the difference between the high- and the low-risk premium is smaller than the size of the original loss. This is not always true, however. Instead, the following proposition holds.

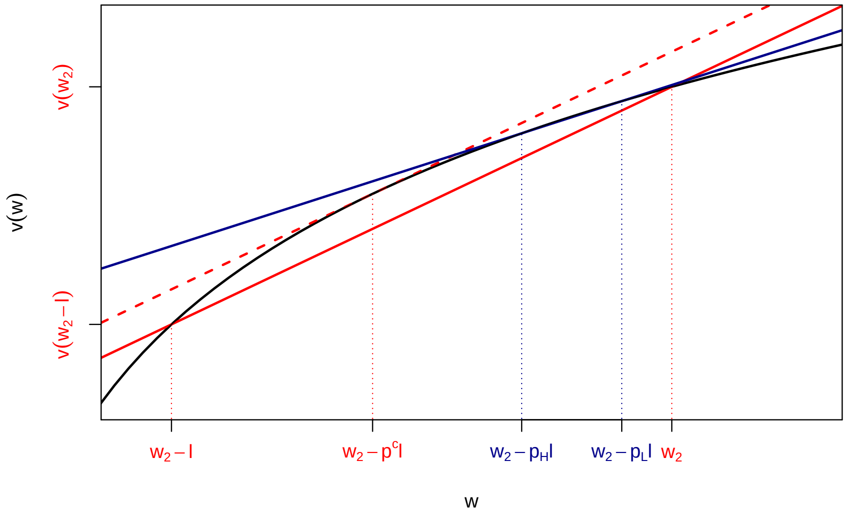
**Proposition 3.** *The introduction of spot insurance in the second period raises the optimal effort level if the low-risk probability of loss, $p_L$, lies above an endogenously determined threshold, $p^c$. It reduces the optimal effort level if the high-risk probability of loss, $p_H$, lies below $p^c$.*

*Proof.* See Appendix A.5.3. □

Intuitively, paying the more expensive high-risk premium instead of the low-risk premium hurts the more, the steeper the felicity function $v$ between the resulting second-period wealth levels is. The steepness of $v$ in the setting with spot insurance is captured by the slope of the secant line between $w_2 - p_H l$ and $w_2 - p_L l$, which increases in $p_H$ and $p_L$ (see Figure 3). To sign the effect of insurance on prevention, this slope has to be compared to the slope of the secant line between the possible second-period wealth levels in the absence of insurance, $w_2 - l$ and $w_2$. The mean value theorem yields the critical probability $p^c$ at which the sign of the difference between the two slopes switches.

The reason why the introduction of insurance may raise the optimal effort level is that in addition to the "loss size effect" in form of the reduction of the monetary loss to the premium difference, there is also a "productivity effect" which must not be neglected. Low risks' second-period consumption exceeds that of high risks with certainty when spot insurance is purchased

Figure 3: The effect of the introduction of spot insurance




*Notes:* The figure displays the secant lines whose slopes determine the effect of the introduction of insurance as well as the tangent line at $w_2 - p^c l$ whose slope equals that of the secant line over $[w_2 - l, w_2]$. We use the specification $v(w) = \ln(w)$, $w_2 = 5$, $l = 3.5$, $p_H = 0.3$, and $p_L = 0.1$. This yields the critical probability $p^c \approx 0.6 > p_H$. Thus, the secant line over $[w_2 - p_H l, w_2 - p_L l]$ is flatter than that over $[w_2 - l, w_2]$, and the introduction of insurance lowers the optimal effort level.

whereas both risk types may or may not suffer a loss in the scenario without insurance. Hence, the introduction of insurance may make prevention against becoming a high-risk type more attractive.

The trade-off between the two effects can be illustrated by reconsidering expected utility in the two insurance market scenarios. To this end, we reduce the compound life lottery to the corresponding simple loss lottery with the same distribution of wealth outcomes. From a perspective where risk types have not yet evolved, individuals suffer a monetary loss at $t_2$ with probability $\hat{z}(z_0, e) := z(z_0, e)p_H + (1 - z(z_0, e))p_L$. Therefore, we can rewrite

$$EU^{\text{No}}(e) = u(w_1 - e) + \hat{z}(z_0, e)v(w_2 - l) + (1 - \hat{z}(z_0, e))v(w_2).$$

The corresponding first-order condition is given by

$$EU_e^{\text{No}}(e^{\text{No}}) = -u'(w_1 - e^{\text{No}}) - \hat{z}_e(z_0, e^{\text{No}})(v(w_2) - v(w_2 - l)) = 0. \tag{4}$$

Thus, the risk management decision in the absence of insurance is formally equivalent to the choice of the optimal level of effort in a simple loss lottery with the probability of loss given by $\hat{z}(z_0, e)$.[9] That is, exerting effort to reduce the probability of becoming a high risk with prevention technology $z(z_0, e)$ is equivalent to exerting effort to reduce the probability of a monetary loss of $l$ with prevention technology $\hat{z}(z_0, e)$ in the absence of risk type uncertainty.

[9] More precisely, initial wealth is given by $w_1$ in the first and by $w_2$ in the second period, and the agent faces a potential monetary loss of $l$ at $t_2$. She may invest in prevention at a monetary cost of $e$ at $t_1$ in order to reduce her probability of loss at $t_2$ given by $\hat{z}(z_0, e)$. As $\hat{z}_e = (p_H - p_L)z_e < 0$, $\hat{z}$ defines indeed a prevention technology in the sense that an increase in $e$ decreases the probability of loss. Moreover, $\hat{z}_{ee} = (p_H - p_L)z_{ee} > 0$, i.e. $\hat{z}$ fulfills the usual assumption of decreasing marginal productivity.

Furthermore, we rewrite expected utility in the scenario with spot insurance by setting $\hat{w}_2 := w_2 - p_L l$ and $\hat{l} := (p_H - p_L)l$, which yields

$$EU^{\text{Sp}}(e) = u(w_1 - e) + z(z_0, e)v(\hat{w}_2 - \hat{l}) + (1 - z(z_0, e))v(\hat{w}_2).$$

The associated first-order condition is given by

$$EU_e^{\text{Sp}}(e^{\text{Sp}}) = -u'(w_1 - e^{\text{Sp}}) - z_e(z_0, e^{\text{Sp}})(v(\hat{w}_2) - v(\hat{w}_2 - \hat{l})) = 0. \quad (5)$$

Again, the risk management decision is formally equivalent to the choice of the optimal level of effort in a simple loss lottery. This time initial wealth at $t_2$ is given by $\hat{w}_2$, the size of the loss by $\hat{l}$, and the probability of loss by $z(z_0, e)$.

Comparing the respective first terms above, we observe that the utility cost of prevention is the same with and without insurance. Hence, it is sufficient to compare the marginal utility benefit to determine the effect of the introduction of spot insurance.[10] The second summands in the first-order conditions (4) and (5) represent the respective marginal utility benefit of prevention. On the one hand, $w_2 - l < \hat{w}_2 - \hat{l} < \hat{w}_2 < w_2$, i.e. the monetary loss in the setting with insurance is less severe. This represents the "loss size effect" through which insurance has a negative effect on optimal prevention. On the other hand, $\hat{z}_e(z_0, e) = (p_H - p_L)z_e(z_0, e)$. That is, the decrease in the probability of loss resulting from a marginal increase in effort is smaller without insurance. In both settings, investments in prevention reduce the probability of becoming a high-risk type. When insurance is purchased, becoming a high risk coincides with the monetary loss state in the associated simple loss lottery since it implies a higher insurance premium. Without insurance, a monetary loss may occur for both risk types, and only the probability of loss depends on the risk type. Therefore, the monetary loss in the simple loss lottery can be prevented more effectively when insurance is purchased after the revelation of risk types. This "productivity effect" of insurance represents a positive effect on optimal prevention. Due to decreasing marginal utility of $v$, the effect of the transition from $l$ to $\hat{l}$ on expected utility depends not only on the relationship between $l$ and $\hat{l}$ but also on the respective initial wealth levels $w_2$ and $\hat{w}_2$. The agent suffers the less from losing $\hat{l}$, the wealthier she is. Smaller probabilities of loss lead to lower insurance premiums, and thus higher second-period wealth in the scenario with insurance. Hence, if the probabilities of loss are sufficiently small (large), the loss size effect dominates (is dominated by) the productivity effect, and the introduction of insurance reduces (raises) the optimal investment in prevention.

Interestingly, the direction of the effect of insurance on prevention only depends on the parameters of the loss lottery and on the shape of the felicity function in the second period. In particular, it is independent of the personal signal $z_0$, which characterizes the agent's prevention technology. This holds because the relative change in the productivity of prevention from $\hat{z}_e$ to $z_e$ when comparing the simple loss lotteries without and with insurance is independent

[10]Given equal marginal utility costs, uniformly greater marginal utility benefit directly translates into a higher level of optimal prevention because the marginal productivity of prevention is decreasing.

of the personal signal $z_0$. Therefore, all individuals raise or reduce their effort in prevention unanimously when insurance is introduced.

## 4 The interaction of prevention and guaranteed renewable insurance

When purchasing short-term contracts whose price depends on the insured's risk type at the beginning of the term, individuals face a premium risk due to uncertain future insurance premiums. In particular, the diagnosis of a chronic disease may result in a surge of insurance premiums. Guaranteed renewable (GR) insurance contracts which can be purchased early in life solve this issue. In such a long-term contract, individuals make a prepayment when they are young which allows them to insure their health risk later in life at a premium that is independent of their risk type. Hence, GR contracts do not only cover potential health losses later in life but also the premium risk resulting from the classification of high-risk types. Following Pauly et al. (1995), the premium risk prepayment in the first period equals the expected losses in excess of the low-risk premium of everyone who becomes a high risk in the second period such that all GR purchasers can insure their health risk in the second period at the fair premium for low risks. We assume that insurance companies only engage in price competition. That is, individuals can only choose between purchasing full coverage and not insuring their premium risk. In our setting, an individual is characterized by the exogenously given signal $z_0$ representing her genetic disposition and the endogenously chosen effort level $e$. The premium risk prepayment $P(e, z_0)$ may depend on these characteristics if they are observed by insurers and may be used in insurance pricing. In the following, we discuss several informational settings to investigate how the use of individuals' genetic disposition and their effort in prevention in insurance pricing affects the market outcome and individuals' decision-making process. The table in Appendix A.6 summarizes our main results.

In contrast to the previous settings, we allow individuals to transfer wealth between the two periods using a risk-free savings account. Which model is best-suited to describe reality, the one with or the one without saving, is an empirical question of mental accounting (Thaler, 1999). Most of the following results would also hold if we continued without saving. The main difference is that without saving people who only have little income when they are young but a lot of income later in life might prefer not to purchase GR insurance even if it is offered at or below their personal fair premium. When we analyze whether an individual prefers a spot or a GR contract in the following, we need to ensure the comparability of the two settings. Therefore, we calculate the optimal effort level in a setting with spot insurance and saving in Appendix A.2.

**Optimal prevention**

The total expected utility of a GR purchaser receiving the signal $z_0$ and exerting the effort $e$ is given by

$$EU^{\mathrm{GR}}(e, s; z_0) = u(w_1 - e - P(e, z_0) - s) + v(w_2 - p_L l + s). \tag{6}$$

In the first period, the agent receives the income $w_1$, invests in prevention at a cost of $e$, and makes the premium risk prepayment $P(e, z_0)$. This prepayment may depend on $z_0$ and $e$ if insurers can distinguish individuals based on these characteristics. If a characteristic is unobservable to insurers, $P(e, z_0)$ is a constant function in the corresponding variable. Savings $s$ transfer wealth between the two periods, where we assume a risk-free interest rate equal to zero for reasons of simplicity. In the second period, the GR purchaser receives the income $w_2$ and pays the low-risk health premium $p_L l$. When purchasing GR insurance, the agent's consumption in both periods is given with certainty. That is, her consumption does neither depend on the realization of her risk type nor on the occurrence of a health loss. The functional form of $P(e, z_0)$ depends on how insurers incorporate information about individuals' genetic disposition and their effort in prevention in insurance pricing. We first keep the general expression $P(e, z_0)$ to analyze individuals' decision-making. Later we specify the explicit form of the actuarially fair prepayment $P(e, z_0)$ in each informational setting.

In each setting, the agent chooses her effort in prevention and her level of savings to maximize expected utility and interior solutions $(e^{\mathrm{GR}}, s^{\mathrm{GR}})$ are characterized by the first-order conditions

$$EU_e^{\mathrm{GR}} = u'\left(w_1 - e^{\mathrm{GR}} - P\left(e^{\mathrm{GR}}, z_0\right) - s^{\mathrm{GR}}\right)\left(-1 - P_e\left(e^{\mathrm{GR}}, z_0\right)\right) = 0, \tag{7}$$

$$EU_s^{\mathrm{GR}} = -u'\left(w_1 - e^{\mathrm{GR}} - P\left(e^{\mathrm{GR}}, z_0\right) - s^{\mathrm{GR}}\right) + v'\left(w_2 - p_L l + s^{\mathrm{GR}}\right) = 0. \tag{8}$$

In Appendix A.1.3, we show that the second-order conditions are globally fulfilled if $P_{ee} > 0$. When purchasing GR insurance, a change in the effort in prevention only affects the agent's first-period wealth – namely through the monetary cost of effort and the potentially effort-dependent premium risk prepayment. Since $u' > 0$, the first-order condition with respect to $e$ is equivalent to

$$P_e\left(e^{\mathrm{GR}}, z_0\right) = -1. \tag{9}$$

At the optimal effort level the decrease in the prepayment resulting from a marginal increase in effort equals the marginal cost of effort which is constantly equal to 1. Since GR insurance removes all the risk from an agent's consumption stream, she only takes into account how investments in prevention impact her first-period wealth. She no more worries about the effect on her personal probability of a health loss later in life and the optimal effort level becomes independent of the agent's risk preferences. Therefore, a GR purchaser chooses the effort level which maximizes her wealth according to (9). She then smooths her consumption across the two periods by choosing the optimal level of saving according to (8).

In the following, we investigate the market outcome and the effect of GR insurance on individuals' prevention decision depending on how insurers incorporate information about individuals' genetic disposition and their effort in prevention in insurance pricing.

## 4.1 Symmetric information

First, we analyze individuals' behavior in a market for GR insurance when customers and insurers are equally informed about the customers' genetic disposition and their effort in prevention. Over the past years, the technological and scientific progress has significantly extended insurers' possibilities to gather and analyze large amounts of data which can be used to assess a customer's health risk. The increasing availability of genetic tests enables insurers to precisely determine a person's genetic disposition already at an early stage in life. The ubiquity of smartphones and the increasing popularity of wearable devices has significantly improved insurers' ability to monitor prevention activities, e.g. by tracking a customer's physical activity. Digital stamp cards can be used to evaluate whether preventive examinations are undertaken regularly. In addition, insurers might collect and evaluate data about a customer's and her parents' medical history to determine her personal risk type prospects. Consequently, the traditional assumption that individuals have an informational advantage compared to their insurer may no more hold if the insurer collects and evaluates enough health-related data. Therefore, we start our analysis of the interaction of GR insurance and prevention with a symmetric information setting.

**Optimal prevention**

Under symmetric information, insurers know that an individual received the signal $z_0$ and exerts the effort $e$ and hence becomes a high-risk type with probability $z(z_0, e)$. Since a high risk's expected loss is given by $p_H l$ and all GR purchasers pay the low risk premium $p_L l$ in the second period, the expected excess loss of a high risk equals $(p_H - p_L)l$. Thus, GR insurance is offered with an actuarially fair premium risk prepayment equal to

$$P(e, z_0) = z(z_0, e)(p_H - p_L)l. \tag{10}$$

As insurers incorporate individuals' genetic disposition and their effort in prevention into insurance pricing, the prepayment depends on both $z_0$ and $e$. Inserting the explicit form of $P(e, z_0)$ into the general first-order condition (9), we see that the optimal effort level is characterized by

$$z_e(z_0, e^{\text{GR}})(p_H - p_L)l = -1. \tag{11}$$

We assume that an interior solution exists for all $z_0 \in (0, 1]$, which holds if $-z_e(z_0, 0) > \frac{1}{(p_H - p_L)l}$, i.e. if an infinitesimal investment in prevention has a sufficiently large effect on the probability of becoming a high-risk type for all individuals.

The agent's health-related expenditures consist of the potential health loss later in life and the expenditures on prevention, i.e. expected lifetime health expenditures are given by

$$EH(e) = [z(z_0, e)p_H + (1 - z(z_0, e))p_L]\, l + e.$$

Since the costs resulting from chronic diseases like diabetes or high blood pressure form an enormous burden for healthcare systems, it is desirable from a social planner point of view to minimize them. One can easily see that the effort level minimizing expected health expenditures is also characterized by the first-order condition (11). This yields the following proposition.

**Proposition 4.** *If an expected utility maximizer purchases GR insurance under symmetric information, she chooses the effort level which minimizes her expected lifetime health expenditures.*

### The decision which type of insurance to purchase

If both spot and GR insurance are offered, individuals can either only insure their health risk later in life by purchasing spot insurance or also insure the premium risk resulting from risk classification by purchasing GR insurance. Under symmetric information, everyone can insure their premium risk at their personal fair premium, which is desirable for a risk-averse agent. Therefore, we obtain the following proposition.[11]

**Proposition 5.** *If GR insurance is offered at an actuarially fair price under symmetric information, it is in demand by all individuals.*

*Proof.* See Appendix A.5.4. □

The market outcome that all individuals purchase GR insurance is the same as the one obtained by Pauly et al. (1995) in the absence of prevention and genetic heterogeneity. The reason is that the GR contract characterized by a particular prepayment $P(e, z_0)$ is only offered to individuals who received the signal $z_0$ about their genetic disposition and exert the effort $e$ in prevention, i.e. to a homogeneous group of customers.

### The effect of the introduction of GR insurance on optimal prevention

Intuitively, one might expect that the introduction of GR insurance decreases the optimal investment in prevention because both GR insurance and prevention are means to reduce the premium risk which an individual faces. However, our results concerning the introduction of spot insurance as well as the well-known one-period results of Ehrlich and Becker (1972) show

[11] We use the tiebreaker rule that individuals who are indifferent between spot and GR insurance purchase the GR contract. In fact, everyone strictly prefers GR insurance over spot insurance except for certain low risks receiving the signal $z_0 = 0$ who are indifferent.

that intuition might be misleading when thinking about the interaction of market insurance and prevention. Indeed, the following holds:

**Proposition 6.** *Under symmetric information, the introduction of GR insurance raises (does not change, reduces) the optimal effort level compared to the setting with spot insurance if the probability of becoming a high-risk type under spot insurance,* $z(z_0, e^{\text{Sp}})$*, is greater than (equal to, less than) an endogenously determined threshold* $z^c$*.*

*Proof.* See Appendix A.5.5. □

Once more, the introduction of insurance may increase or decrease the optimal effort level and the probability of the bad state of the world is the crucial factor determining which case occurs.

### The effect of genetics on optimal prevention

To analyze the effect of an individual's genetic endowment on her prevention decision, we apply the implicit function theorem on (11) which yields

$$\frac{de^{\text{GR}}}{dz_0} = -\frac{z_{ez_0}(z_0, e^{\text{GR}})}{z_{ee}(z_0, e^{\text{GR}})}.$$

Since $z_{ee} > 0$, the sign of this expression solely depends on the sign of the cross-derivative $z_{ez_0}$, and we obtain the following proposition.

**Proposition 7.** *If an expected utility maximizer purchases GR insurance under symmetric information, she reduces (does not change, raises) her effort in prevention as her endowed probability of becoming a high-risk type increases if the prevention technology exhibits ID (CD, DD).*

Similar to the situation in the absence of insurance and with spot insurance only, the optimal effort level is the higher, the more productive an individual's prevention technology is. However, there is a significant difference in how the information about the productivity of prevention enters the decision-making process. In the two previous settings, individuals have to know the productivity of their prevention technology themselves in order to decide about the optimal level of effort. Scientific studies suggest that preventing against high blood pressure and diabetes is particularly productive for those who are likely to suffer from these diseases later in life. However, individuals who know that their family members suffered from chronic diseases might erroneously think that they will come down with the same diseases anyway because of their "bad" genetic endowment. Hence, these individuals might exert less effort in prevention than optimal. If individuals purchase GR insurance in the symmetric information setting, they no more have to acquire the scientific knowledge about prevention themselves. Instead, the dependence structure of the premium risk prepayment on the effort level automatically informs them about how investments in prevention affect their expected health costs.

Since it is much easier for a large insurance company than for a single individual to collect current scientific knowledge about the productivity of prevention, GR insurance can thus guide individuals to base their choice of effort on the current state of scientific research.

## 4.2 Asymmetric information

Individual underwriting in health insurance is rather unpopular and often banned or limited by regulation. Premium discrimination based on someone's genetics is criticized for disadvantaging individuals for characteristics beyond their control. The monitoring of prevention activities is often considered an invasion of privacy. If the informational advantage of the insured is not an immutable fact but a man-made consequence of a lack of acceptance of individual underwriting in the population, it is important to understand the consequences of restrictions on the use of information by insurers in order to decide whether regulatory restrictions are desirable or whether individually underwritten contracts should be promoted. We therefore analyze three different settings of asymmetric information to reveal how restrictions on the use of genetic information and the monitoring of prevention affect the insured's behavior and the market outcome.

### 4.2.1 No individual underwriting of GR insurance

**Optimal prevention**

In our first asymmetric information setting, we assume that no individual underwriting of GR insurance takes place. To assess a young customer's health risk, insurers need rather sophisticated underwriting methods because diseases have typically not yet materialized early in life. Privacy concerns may be much larger when insurers require access to genetic test results or activity data tracked by wearable devices for the pricing of GR insurance than when they include information about chronic diseases in the pricing of spot insurance. Therefore, regulatory restrictions may ban individual underwriting of GR insurance. In this case, insurers can neither use information about an agent's genetic disposition nor about her effort in prevention in insurance pricing, i.e. $z_0$ and $e$ are unobservable for insurers. Hence, everyone is offered the same GR contract with the same premium risk prepayment and every GR purchaser's expected utility is given by

$$EU^{\mathrm{GR}}(e,s) = u(w_1 - e - P - s) + v(w_2 - p_L l + s), \tag{12}$$

where $P$ denotes the premium risk prepayment. Since the price of insurance does neither depend on the effort level nor on the revealed risk types, the agent is not rewarded for exerting effort in prevention. Therefore, the optimal effort level is given by $e^{\mathrm{GR}} = 0$ and prevention activities are completely discouraged if GR insurance is purchased without any individual underwriting. This yields the following proposition.

**Proposition 8.** *If individual underwriting of GR insurance is banned, GR purchasers do not exert any effort in prevention.*

**The decision which type of insurance to purchase**

Individuals choose between purchasing GR insurance in the first period or leaving the premium risk uninsured and purchasing spot insurance in the second period. Obviously, a GR purchaser's utility is independent of her personal genetic endowment since all GR purchasers face the same premium stream in (12). In contrast, expected utility without GR insurance strongly depends on one's personal probability of becoming a high-risk type. If prevention is particularly effective for individuals with a genetic predisposition towards becoming a high-risk type, they can partly offset their genetic disadvantage by investing in prevention. Nevertheless, individuals who receive a high signal $z_0$ are more likely to become a high-risk type and pay the more expensive high-risk premium than those receiving a low signal $z_0$ at any given effort level. By applying the envelope theorem, we obtain

$$\frac{dEU^{\text{Sp}}(e^{\text{Sp}}, s^{\text{Sp}})}{dz_0} = z_{z_0}(z_0, e^{\text{Sp}}) \Big( v(w_2 - p_H l + s^{\text{Sp}}) - v(w_2 - p_L l + s^{\text{Sp}}) \Big) < 0, \tag{13}$$

i.e. expected utility with spot insurance is decreasing in $z_0$.

Consequently, individuals receiving a high signal $z_0$ are more interested in GR insurance than those receiving a low signal $z_0$. For any given prepayment $P$, this implies that either no one purchases GR insurance or there exists a cutoff signal $z_0^* \in [0, 1]$ such that individuals receiving a signal $z_0 \geq z_0^*$ purchase GR insurance whereas individuals receiving a signal $z_0 < z_0^*$ prefer not to insure their premium risk. Insurers anticipate this market outcome and the discouraging effect of GR insurance on prevention and price insurance accordingly. They know that a fraction $\mathbb{E}[z_0 \mid z_0 \geq z_0^*]$ of the pool of insured becomes a high-risk type later in life if the cutoff signal is given by $z_0^*$. Hence, the actuarially fair premium risk prepayment aiming at the cutoff $z_0^*$ is given by

$$P(z_0^*) = \mathbb{E}[z_0 \mid z_0 \geq z_0^*] \, (p_H - p_L) \, l. \tag{14}$$

In the following we denote expected utility under the GR contract with the prepayment $P(z_0^*)$ by $EU^{\text{GR}}(e, s; z_0^*)$ in order to clarify on which cutoff signal the prepayment calculation is based.

In equilibrium, only informationally consistent contracts can exist. That is, the cutoff which forms under the GR contract with the prepayment $P(z_0^*)$ indeed has to be equal to $z_0^*$. In order to analyze whether such an informationally consistent contract exists, we follow the approach of Peter et al. (2016) who study the market outcome when GR insurance is offered in the absence of prevention. We first consider the two extreme cases $z_0^* = 0$ and $z_0^* = 1$. The corresponding calculations can be found in Appendix A.3. An individual receiving the signal $z_0 = 0$ does not face a premium risk but would have to subsidize worse risk types if she purchased GR insurance. She therefore prefers to purchase only spot insurance. Hence, $z_0^* = 0$ cannot be an informationally consistent cutoff and, in contrast to the symmetric information setting, GR insurance is not in demand by all individuals when individual underwriting is banned.

Concerning the case $z_0^* = 1$, Peter et al. (2016) show that the worst possible signal always represents a potential cutoff in the absence of prevention. An individual who becomes a high risk for sure does not face an actual premium risk but she does not have to subsidize other GR purchasers either. Therefore, she is indifferent whether to purchase GR insurance based on the cutoff signal $z_0^* = 1$ or not. In our setting, prevention allows an individual to improve her risk type prospects such that someone receiving the signal $z_0 = 1$ has at least a small change to become a low-risk type later in life. However, if insurers cannot monitor prevention activities, the prepayment of a GR contract with the cutoff $z_0^* = 1$ would be based on the assumption that all purchasers become a high-risk type with certainty. Therefore, someone receiving the signal $z_0 = 1$ prefers not to purchase such a GR contract and $z_0^* = 1$ cannot be an informationally consistent cutoff when prevention is possible but not observed by insurers.

An individual receiving an intermediate signal $z_0 \in (0, 1)$ faces the following trade-off when deciding whether to purchase GR insurance or not. On the one hand, GR insurance is attractive because it removes the premium risk resulting from risk classification. On the other hand, investments in prevention do not pay off if GR insurance is purchased and insurers cannot monitor preventive activities. Moreover, the prepayment is calculated based on the average probability of becoming a high-risk type among the pool of insured if insurers cannot observe each individual's personal genetic disposition. Consequently, better risks in the pool have to subsidize worse risks.

We know that $EU^{\text{Sp}}(e^{\text{Sp}}, s^{\text{Sp}}; z_0 = z_0^*) > EU^{\text{GR}}(e^{\text{GR}}, s^{\text{GR}}; z_0^*)$ for $z_0^* \in \{0, 1\}$. If it holds that $EU^{\text{Sp}}(e^{\text{Sp}}, s^{\text{Sp}}; z_0 = z_0^*) > EU^{\text{GR}}(e^{\text{GR}}, s^{\text{GR}}; z_0^*)$ for all potential cutoffs $z_0^* \in [0, 1]$, GR insurance is not in demand. If there exists at least one informationally consistent cutoff $z_0^* \in (0, 1)$ such that $EU^{\text{Sp}}(e^{\text{Sp}}, s^{\text{Sp}}; z_0 = z_0^*) = EU^{\text{GR}}(e^{\text{GR}}, s^{\text{GR}}; z_0^*)$, the GR contract with the premium risk prepayment $P(z_0^*)$ is preferred over spot insurance by all individuals receiving a signal $z_0 \geq z_0^*$ and GR insurance is in demand.

**Several informationally consistent cutoffs**

In general, there may be several informationally consistent cutoffs $z_0^* \in (0, 1)$ fulfilling $EU^{\text{Sp}}(e^{\text{Sp}}, s^{\text{Sp}}; z_0 = z_0^*) = EU^{\text{GR}}(e^{\text{GR}}, s^{\text{GR}}; z_0^*)$. In the following, we compare individuals' welfare when they purchase the respective GR contracts and discuss what the market equilibrium will be.

Concerning the welfare of a GR purchaser, the envelope theorem yields

$$\frac{d}{dz_0^*} EU^{\text{GR}}(e^{\text{GR}}, s^{\text{GR}}; z_0^*) = u' \left( w_1 - P\left(z_0^*\right) - s^{\text{GR}} \right) \left( -P_{z_0^*}\left(z_0^*\right) \right) < 0, \tag{15}$$

where we used the calculations in Appendix A.4 with $e^{\mathrm{GR}} = 0$ to see $P_{z_0^*}(z_0^*) > 0$. A lower cutoff signal implies a pool of insured with better risk type odds on average. Hence, GR insurance is cheaper and a GR purchaser's welfare is higher under a lower cutoff signal. We can therefore Pareto-rank different cutoff signals.

**Proposition 9.** *If individual underwriting of GR insurance is banned and $z_0^{*,1} < z_0^{*,2}$ are two informationally consistent cutoffs, $z_0^{*,1}$ Pareto-dominates $z_0^{*,2}$.*

*Proof.* In order to compare each individual's welfare under the two cutoffs, we divide the population into three groups. The first group consists of individuals who are not interested in GR insurance under both cutoffs. The members of this group stay equally well off as the cutoff changes since expected utility under sport insurance is independent of the GR cutoff. Secondly, the individuals who switch from spot insurance to GR insurance as the cutoff decreases from $z_0^{*,2}$ to $z_0^{*,1}$ must be better off under the lower cutoff $z_0^{*,1}$ because they could have stayed with the same spot insurance contract which they chose under $z_0^{*,2}$. Finally, individuals who purchase GR insurance under both cutoffs are better off under $z_0^{*,1}$ because their expected utility decreases in the cutoff signal according to (15). In conclusion, no one is worse off but some are better off under the lower cutoff signal $z_0^{*,1}$. □

Having above welfare considerations in mind, we discuss which contracts are in demand in equilibrium. We use the criteria of Rothschild and Stiglitz (1976) for a Nash equilibrium in a competitive insurance market under asymmetric information to show the following proposition.

**Proposition 10.** *Assume that individual underwriting of GR insurance is banned. If no informationally consistent cutoff exists, GR insurance is not in demand. If at least one informationally consistent cutoff exists, the uniquely determined Nash equilibrium in the market is characterized by the lowest informationally consistent cutoff signal $z_0^* \in (0,1)$, i.e. individuals receiving a signal $z_0 \geq z_0^*$ purchase GR insurance whereas individuals receiving a signal $z_0 < z_0^*$ purchase spot insurance.*

*Proof.* We first show that the lowest cutoff is the only candidate for a Nash equilibrium. GR contracts which are priced based on an informationally consistent cutoff are the only GR contracts which make zero profit. Hence, no other GR contract can be in the equilibrium set. If several informationally consistent cutoffs exist and the corresponding GR contracts are offered simultaneously in the market, all GR purchasers choose the contract with the lowest cutoff because it yields the highest expected utility according to (15). Consequently, the GR contract based on the lowest cutoff signal is the only contract in demand. We now have to check that this contract indeed constitutes a Nash equilibrium in the sense of Rothschild and Stiglitz (1976). That is, it fulfills the following two criteria.

1. The contract makes non-negative expected profits. This holds true since $z_0^*$ is an informationally consistent contract with an actuarially fair premium stream.

2. There is no contract outside the equilibrium set that, if offered, will make a non-negative profit. Any GR contract aiming at a higher cutoff yields lower expected utility and is therefore not in demand. If a GR contract aims at a lower cutoff, the intended cutoff individuals (and some individuals receiving a slightly higher signal) prefer to purchase spot insurance. Consequently, the actual pool of insured in this contract consists of worse risk types than the pool used in pricing and the contract makes negative profits.

□

In conclusion, two types of market outcome are possible if GR contracts are not individually underwritten. Either all individuals prefer to purchase spot insurance which leads to a complete unraveling of the market for GR insurance. Or individuals receiving a sufficiently high signal $z_0 \geq z_0^*$ purchase GR insurance and do not exert any effort in prevention whereas individuals receiving a lower signal $z_0 < z_0^*$ prefer not to insure their premium risk and choose the effort level which maximizes their expected utility under spot insurance. In addition, all individuals use savings to smooth their consumption over time.

**Discussion**

Compared to the symmetric information case, two disadvantages occur if the premium risk prepayment is independent of individuals' genetic disposition and their effort in prevention. Firstly, investments in prevention are discouraged if individuals purchase GR insurance whose prepayment does not depend on the exerted effort level. Under DD, prevention is particularly productive for individuals whose family history indicates that they are likely to become a high-risk type. These individuals also form the group of GR purchasers if GR insurance is in demand. Thus, GR contracts discourage preventive activities of those individuals who should actually invest the most in prevention which is particularly unfortunate. Secondly, individuals who consider themselves not very likely to become a high-risk type do not purchase GR insurance and the premium risk of these individuals is not insured despite their risk aversion. Therefore, these individuals are worse off than in the symmetric information setting. In the extreme case of complete market unraveling, all individuals purchase only spot insurance and everyone, except for the definite low risks, is strictly worse off than in the symmetric information setting with individual underwriting. Prohibiting the use of genetic and behavioral information without further regulatory interventions would create an environment similar to the health insurance market in the U.S. before the Affordable Care Act came into force in 2014. In those days, the use of genetic information in insurance pricing was prohibited by the Health Insurance Portability and Accountability Act of 1996 and the Genetic Information and Nondiscrimination Act of 2008. Since mobile devices were not as ubiquitous as today, the monitoring of prevention was technically not feasible in the past. Indeed, markets failed to provide comprehensive health insurance coverage and many people who became severely sick were not able to renew their health insurance contracts in this setting.

#### 4.2.2 Monitoring of prevention only

The issues that arise when individual underwriting of GR insurance is banned are not present in the symmetric information setting. However, it is typically believed that when purchasing insurance, individuals should not face a price disadvantage for reasons beyond their control. Consequently, regulation should ban insurance pricing based on genetics. On the other hand, pricing insurance based on one's behavior such as smoking or exercising habits, is less of a concern. Recent advances in data science and the ubiquity of mobile phones have increased insurers' ability to monitor prevention activities. For example, insurers may make the premium risk prepayment dependent on a customer's physical activity tracked by wearable devices or use a digital stamp card to evaluate whether preventive examinations are undertaken regularly. Such technological progress has made effort-dependent contracts feasible. Therefore, we consider a third informational setting in which the prepayment depends on the effort exerted by an individual but not on her genetic endowment in order to investigate whether effort-dependent contracts should be promoted.

Of course, some prevention activities are easier to monitor than others. Individuals can easily provide proof of regular preventive medical examinations. In contrast, it is quite difficult to monitor their nutritional habits but some individuals may simply like healthy food more than others. Even if insurers are not perfectly informed about prevention activities, our model can be used to assess the impact of the monitoring of some prevention activities. In this case, $z_0$ represents characteristics which are not observed by insurers and exogenous to our model and $e$ represents characteristics which are observed by insurers and endogenously determined depending on the monetary incentives resulting from insurance contract design. Consequently, the different nutritional habits would also be encoded in the signal $z_0$ in the example above.

**Optimal prevention**

Insurers demand a premium prepayment which depends on a purchaser's investment in prevention, $e$, but not on her personal genetic endowment, $z_0$. Hence, all GR purchasers face the same optimization problem when deciding about their investments in prevention and saving. This implies that all GR purchasers exert the same level of effort in prevention and their utility does not depend on $z_0$. As expected utility under spot insurance decreases in $z_0$ according to (13), the market outcome is again characterized by a cutoff signal. The actuarially fair prepayment aiming at the cutoff signal $z_0^*$ at which GR insurance is offered to individuals exerting effort $e$ is given by

$$P\left(e, z_0^*\right) = \mathbb{E}\left[z\left(z_0, e\right) \mid z_0 \geq z_0^*\right]\left(p_H - p_L\right) l.$$ [12]

The general first-order condition (9), which characterizes the utility-maximizing effort level, therefore translates to

[12] Please note the slight abuse of notation. Here the second argument $z_0^*$ refers to the cutoff signal characterizing the market outcome. In contrast, the second argument in $P(e, z_0)$ in (6) refers to the personal signal of a particular GR purchaser.

$$\mathbb{E}\left[z_e\left(z_0, e^{\mathrm{GR}}\right) \;\middle|\; z_0 \geq z_0^*\right](p_H - p_L)\, l = -1. \tag{16}$$

In contrast to the symmetric information setting, the optimal effort level no more depends on someone's personal genetic endowment but it is the same for all GR purchasers. In the symmetric information setting, a GR purchaser minimizes her personal expected health expenditures. Comparing (16) to (11), we see that the optimal effort level in the current setting minimizes the expected health expenditures of an average GR purchaser. That is:

**Proposition 11.** *If insurers condition the GR premium stream on an individual's effort in prevention but not on her genetic disposition, all GR purchasers choose the effort level which minimizes the expected lifetime health expenditures of an agent with the average prevention technology* $z^{\mathrm{avg}}(e) = \mathbb{E}\left[z\left(z_0, e\right) \mid z_0 \geq z_0^*\right]$.

Under CD, prevention is equally productive for all individuals and $z_e(z_0, e)$ does actually not depend on $z_0$. Therefore, both first-order conditions (11) and (16) yield the same optimal effort level which minimizes each individual's personal expected health expenditures. If individuals have differently productive prevention technologies, however, GR purchasers whose prevention technology is more (less) productive than the average prevention technology $z^{\mathrm{avg}}(e)$ invest less (more) in prevention when the premium risk prepayment is independent of their genetic endowment than under symmetric information. In consequence, individuals with a particularly productive prevention technology do not fully exploit their potential in reducing health costs whereas those with not so productive prevention technologies waste money on prevention activities whose costs exceed their expected benefits. This inefficiency results from the fact that GR contracts can be designed to incentivize prevention activities when these can be monitored but the contract design cannot be geared to each individual's personal abilities when insurers cannot observe their customers' genetic disposition.

#### The decision which type of insurance to purchase

As in the setting with no individual underwriting of GR insurance, only informationally consistent cutoffs can be present in equilibrium. In order to analyze whether such cutoffs exist, we again start with the extreme cases $z_0^* = 0$ and $z_0^* = 1$. For $z_0^* = 0$, both the formal argument and the underlying rationale are the same as in the case where both $e$ and $z_0$ are not observed by insurers. Since $P(e, 0) = \mathbb{E}\left[z\left(z_0, e\right)\right](p_H - p_L)\, l > 0$ for all $e \geq 0$, individuals who become a low risk for sure would have to subsidize others although they do not benefit from insuring the premium risk. Hence, definite low risks prefer to purchase spot insurance only and $z_0^* = 0$ cannot be an informationally consistent cutoff. For $z_0^* = 1$, the premium risk prepayment is given by $P(e, 1) = \mathbb{E}\left[z\left(z_0, e\right) \mid z_0 \geq 1\right](p_H - p_L)\, l = z\left(1, e\right)(p_H - p_L)\, l$ and thus equal to the prepayment which individuals receiving the signal $z_0 = 1$ face under symmetric information. Therefore, individuals receiving the signal $z_0 = 1$ strictly prefer GR insurance over spot insurance according to the calculation in the proof of Proposition 5 and $z_0^* = 1$ cannot be an informationally consistent cutoff either.

Above considerations have shown that $EU^{\text{Sp}}(e^{\text{Sp}}, s^{\text{Sp}}; z_0 = 0) > EU^{\text{GR}}(e^{\text{GR}}, s^{\text{GR}}; z_0^* = 0)$ whereas $EU^{\text{Sp}}(e^{\text{Sp}}, s^{\text{Sp}}; z_0 = 1) < EU^{\text{GR}}(e^{\text{GR}}, s^{\text{GR}}; z_0^* = 1)$. Therefore, there must be at least one informationally consistent interior cutoff $z_0^* \in (0,1)$ such that $EU^{\text{Sp}}(e^{\text{Sp}}, s^{\text{Sp}}; z_0 = z_0^*) = EU^{\text{GR}}(e^{\text{GR}}, s^{\text{GR}}; z_0^*)$, i.e. such that an individual receiving the signal $z_0^*$ is indifferent between spot insurance and GR insurance with a prepayment aiming at the cutoff $z_0^*$.

**Several informationally consistent cutoffs**

As in the previous informational setting, there may be several informationally consistent cutoffs $z_0^* \in (0,1)$ fulfilling $EU^{\text{Sp}}(e^{\text{Sp}}, s^{\text{Sp}}; z_0 = z_0^*) = EU^{\text{GR}}(e^{\text{GR}}, s^{\text{GR}}; z_0^*)$ in general. In the following, we compare individuals' behavior, the fair premium prepayments and individuals' welfare when they purchase the respective GR contracts and discuss the market equilibrium.

First, we apply the implicit function theorem to compare the optimal levels of effort and saving under different informationally consistent GR contracts.

**Proposition 12.** *If insurers condition the GR premium stream on an individual's effort in prevention but not on her genetic disposition and $z_0^{*,1} < z_0^{*,2}$ are two informationally consistent cutoffs, it holds that*

- $e^{\text{GR}}(z_0^{*,1}) > (=, <)\ e^{\text{GR}}(z_0^{*,2})$ *if the prevention technology exhibits ID (CD, DD),*
- $s^{\text{GR}}(z_0^{*,1}) > s^{\text{GR}}(z_0^{*,2})$.

*Proof.* See Appendix A.5.6. □

The decision about the optimal level of effort and the optimal level of saving are decoupled since both the monetary cost of prevention and its beneficial effect on the premium risk prepayment occur in the first period whereas second period wealth is independent of the chosen level of effort. Therefore, indirect effects are absent. This finding is closely related with the extended separation result of Menegatti and Rebessi (2011). The pool of insured under the smaller cutoff consists of the pool under the larger cutoff plus the individuals receiving a signal $z_0 \in [z_0^{*,1}, z_0^{*,2})$. To gain an intuitive understanding of the effect on the optimal effort level, we focus on the DD case. The other cases follow analogously. Under DD, the newly joining individuals possess a less productive prevention technology than those who opt for GR insurance under both cutoffs. Since insurers anticipate the composition of the pool of insured under each cutoff, they know that a marginal increase in prevention results in a weaker reduction of the average expected health losses within the larger pool than within the smaller pool. Therefore, insurers grant a smaller reduction in the premium risk prepayment to the GR purchasers if these increase their investment in prevention when the pool of insured is larger. Consequently, investments in prevention pay less off and GR purchasers reduce their effort level as the pool of insured increases. Concerning the effect on optimal saving, it holds that the newly joining individuals are less likely to become a high-risk type later in life than the GR purchasers under both cutoffs. Hence, GR insurance is cheaper under the smaller cutoff. Since the premium risk prepayment is made early in life, this would increase individuals' first-period consumption whilst leaving their second-period consumption unchanged. As individuals prefer a smooth consumption stream over time, they transfer some of their increased first-period wealth to the second period, i.e. they increase their savings, as the cutoff decreases.

Knowing how GR purchasers behave under different informationally consistent cutoffs, we now investigate how this affects the actuarially fair premium risk prepayment. It holds that

$$\frac{d}{dz_0^*}P(e^{\mathrm{GR}}, z_0^*) = P_{z_0^*}(e^{\mathrm{GR}}, z_0^*) + P_e(e^{\mathrm{GR}}, z_0^*)\frac{de^{\mathrm{GR}}}{dz_0^*}.$$

The calculations in Appendix A.4 show that $P_{z_0^*} > 0$ and $P_e < 0$. The direct effect resulting from an increase in the cutoff signal is always positive. A higher cutoff implies a pool of insured with worse risk type prospects, and hence, yields a higher premium risk prepayment at any given effort level. The indirect effect on the prepayment resulting from adaptions of individuals' prevention behavior, however, depends on the properties of their prevention technology. We have shown in Proposition 12 that individuals invest less (the same amount, more) in prevention as the cutoff signal increases if the prevention technology exhibits ID (CD, DD). Therefore, the indirect effect on the premium risk prepayment resulting from an increased cutoff signal is positive (equal to zero, negative) if the prevention technology exhibits ID (CD, DD). Hence, the direct and the indirect effect are aligned under ID and CD and opposite to each other under DD, and we obtain the following proposition.

**Proposition 13.** *If insurers condition the GR premium stream on an individual's effort in prevention but not on her genetic disposition and $z_0^{*,1} < z_0^{*,2}$ are two informationally consistent cutoffs, it holds that*

- $P(e^{\mathrm{GR}}, z_0^{*,1}) < P(e^{\mathrm{GR}}, z_0^{*,2})$ *if the prevention technology exhibits ID or CD,*
- $P(e^{\mathrm{GR}}, z_0^{*,1})$ *may be smaller or larger than* $P(e^{\mathrm{GR}}, z_0^{*,2})$ *depending on whether the direct or the indirect effect prevails if the prevention technology exhibits DD.*

Concerning the DD case, the direct effect prevails and $P(e^{\mathrm{GR}}, z_0^{*,1}) < P(e^{\mathrm{GR}}, z_0^{*,2})$ if the difference in the productivity of individuals' prevention technologies is not too large, which is what we would expect intuitively. However, the indirect effect resulting from adaptions in prevention behavior may also outweigh the direct effects implying $P(e^{\mathrm{GR}}, z_0^{*,1}) > P(e^{\mathrm{GR}}, z_0^{*,2})$ under DD.

Having above ambiguous effect of the cutoff signal on the premium risk prepayment in mind, one might think that it is hard to determine under which GR contract individuals are better off. However, one must not forget that if the prepayment under $z_0^{*,2}$ is smaller than the prepayment under $z_0^{*,1}$ in the DD case, this does not come for free. Instead, individuals have to spend more money on prevention to be eligible for the smaller prepayment. Since individuals adapt their effort in prevention such that its marginal cost always equals its marginal benefit, only the direct effect of a change in the cutoff signal affects their welfare and the envelope theorem yields

$$\frac{d}{dz_0^*}EU^{\text{GR}}(e^{\text{GR}}, s^{\text{GR}}; z_0^*) = u'\left(w_1 - e^{\text{GR}} - P\left(e^{\text{GR}}, z_0^*\right) - s^{\text{GR}}\right)\left(-P_{z_0^*}\left(e^{\text{GR}}, z_0^*\right)\right) < 0. \tag{17}$$

The more individuals join the pool, the better their risk type odds become on average. Hence, GR purchaser's welfare is higher under a lower cutoff signal with a larger pool of insured. We can therefore Pareto-rank different cutoff signals.

**Proposition 14.** *If insurers condition the GR premium stream on an individual's effort in prevention but not on her genetic disposition and $z_0^{*,1} < z_0^{*,2}$ are two informationally consistent cutoffs, $z_0^{*,1}$ Pareto-dominates $z_0^{*,2}$.*

*Proof.* Analogously to the proof of Proposition 9. □

This result helps us to identify the Nash equilibrium according to the criteria of Rothschild and Stiglitz (1976).

**Proposition 15.** *Assume that insurance pricing is based on an individual's effort in prevention but not on her genetic disposition. The uniquely determined Nash equilibrium in the market is characterized by the lowest informationally consistent cutoff signal $z_0^* \in (0,1)$, i.e. individuals receiving a signal $z_0 \geq z_0^*$ purchase GR insurance whereas individuals receiving a signal $z_0 < z_0^*$ purchase spot insurance.*

*Proof.* Analogously to the proof of Proposition 10. □

The result is similar to the equilibrium obtained when individual underwriting of GR insurance is completely banned but there are two decisive differences which must not be overlooked. Firstly, if individuals' effort in prevention is monitored by insurers, the existence of an informationally consistent cutoff is guaranteed. Hence, there are always some individuals who purchase GR insurance which is not the case when the effort in prevention is unobservable. Secondly, in equilibrium, all individuals receiving a signal $z_0 \geq z_0^*$ purchase GR insurance and choose the effort level which minimizes the health expenditures of an average purchaser. In contrast, GR purchasers do not exert any effort in prevention if insurers cannot observe prevention activities. Comparing individuals' welfare under the two types of contracts, we find

**Proposition 16.** *GR contracts monitoring individuals' effort in prevention Pareto-dominate GR contracts without any individual underwriting.*

*Proof.* First, note that if the equilibrium without any individual underwriting of GR insurance is characterized by the lowest informationally consistent cutoff $z_0^{*,\text{ban}}$, it holds that when the effort in prevention is monitored,

$$\begin{aligned} EU^{\text{GR,mon}}(e^{\text{GR,mon}}, s^{\text{GR,mon}}; z_0^{*,\text{ban}}) &= \max_{e,s} u(w_1 - e - P(e, z_0^{*,\text{ban}}) - s) + v(w_2 - p_L l + s) \\ &> \max_{s} u(w_1 - P(z_0^{*,\text{ban}}) - s) + v(w_2 - p_L l + s) \\ &= EU^{\text{GR,ban}}(e^{\text{GR,ban}}, s^{\text{GR,ban}}; z_0^{*,\text{ban}}), \end{aligned} \tag{18}$$

where the superscript $^{\text{GR,mon}}$ refers to GR contracts with a monitoring of effort, the superscript $^{\text{GR,ban}}$ refers to GR contracts without any individual underwriting, and we used $e^{\text{GR,mon}} > 0$ as well as $e^{\text{GR,ban}} = 0$. Since a cutoff individual receiving the signal $z_0^{*,\text{ban}}$ is indifferent between purchasing GR insurance without any individual underwriting and not insuring her premium risk, above inequality implies that this individual strictly prefers GR insurance monitoring prevention and aiming at the cutoff $z_0^{*,\text{ban}}$ over spot insurance. Hence, the lowest informationally consistent cutoff in the monitoring setting, $z_0^{*,\text{mon}}$, must be smaller than $z_0^{*,\text{ban}}$. Since the GR purchasers' utility decreases in the cutoff signal, $z_0^{*,\text{mon}} < z_0^{*,\text{ban}}$ together with (18) implies that the GR purchasers of the effort-dependent contract are better off than the GR purchasers in the setting in which the effort is not monitored.

We can now distinguish three groups of individuals. We have just shown that the purchasers of both types of GR contracts are better of when the effort in prevention is monitored. Since $z_0^{*,\text{mon}} < z_0^{*,\text{ban}}$, there are some individuals who switch from spot insurance to GR insurance when insurers start to monitor prevention activities. Since these switchers could have stayed with the same spot contract, they must also be better off when prevention is monitored. Finally, the utility of those who purchase spot insurance anyway does not change as the GR contract changes. In conclusion, some individuals are better off and nobody is worse off when prevention activities are monitored. □

**Discussion**

By now, contracts monitoring the insured's effort in prevention are not much in demand. There are some cautious approaches to include lifestyle factors in insurance pricing. In the U.S., the Affordable Care Act allows to impose a surcharge on tobacco users' premiums. Bonus programs in German statutory health insurance reward health-promoting activities, such as joining a fitness class or attending medical checkups, by subsidizing course fees or paying out a cash bonus at the end of the year. However, there seems to be a lack of acceptance in the population if insurers collect "too much" lifestyle data often resulting from privacy concerns.[13] We show that from an economic point of view contracts monitoring prevention activities are welfare improving. If young customers can prove their engagement in prevention, they will receive cheaper long-term health insurance coverage if they live a healthy lifestyle. As a consequence, GR contracts are offered at a price that is attractive to a larger group of individuals. An increasing pool of insured makes GR insurance even cheaper since the newly joining in-

[13]Such a lack of acceptance does not only play a role in health insurance but also in other lines of insurance. For example, take-up rates of telematics tariffs in car insurance are quite low although risk-based premium discrimination in car insurance is widely accepted in general.

dividuals have better risk type prospects than the purchasers of the more expensive contract which does not monitor prevention activities. Thus, both the individuals who only purchase the cheaper effort-dependent contract and the ones who purchase GR insurance anyway benefit from the monitoring of prevention in a GR contract because they receive affordable coverage for the undesirable premium risk resulting from risk classification. Moreover, effort-dependent GR contracts support effective prevention activities which reduce long-term health losses. In contrast, effort-independent GR contracts discourage such prevention activities. Several experimental studies suggest that modern technology indeed has the potential to create favorable behavioral patterns if incentives for healthy behavior are provided (The Geneva Association, 2020). Since the treatment costs of health losses related to chronic diseases like diabetes or high blood pressure represent an enormous burden for healthcare systems, it is desirable to motivate prevention activities. Therefore, insurance companies and public policy makers should try to find ways to address the insured's privacy concerns in order to promote effort-dependent GR contracts.

Nevertheless, one must not forget the potential downsides which occur if insurers are not perfectly informed about each customer's personal prevention technology. If insurers cannot distinguish individuals based on their genetic disposition, they must offer a one-size-fits-all GR contract to all individuals. Such a contract forces individuals with promising risk type prospects to subsidize those with worse prospects. As a consequence, the individuals with the best risk type prospects might prefer to abstain from purchasing GR insurance and bear the premium risk on their own which is inefficient as individuals are risk-averse. Moreover, all GR purchasers are incentivized to make the same investments in prevention regardless of their private knowledge of their genetic disposition. If prevention activities are differently effective for different individuals, this means that some people do not exploit the potential of prevention while others knowingly waste money on inefficient prevention activities. If prevention activities are similarly beneficial for all individuals, this is not much of a problem. If there are large differences in the effectiveness of prevention across the population, however, other ways of targeting different risk groups to promote sensible prevention activities need to be found.

#### 4.2.3 Use of genetic information only

If insurers include behavioral information in pricing, they must constantly monitor people's prevention activities throughout the contract term. In contrast, genetic information only needs to be collected once when the insurance contract is concluded. Therefore, individuals might have more privacy concerns when their insurer constantly collects activity data tracked by a wearable device than when they once fill out a questionnaire about their family's medical history when entering the GR contract. To understand the resulting effects on the GR insurance market, we consider the case that regulation bans the monitoring of prevention but does not limit the use of genetic information. That is, we assume that the premium risk prepayment depends on the personal signal $z_0$ but not on the effort in prevention $e$.

**Optimal prevention**

Similarly to the setting without any individual underwriting, the price of GR insurance does neither depend on the effort exerted in prevention nor on the insured's risk type later in life. Hence, GR insurance with a prepayment depending only on the purchaser's genetic disposition discourages prevention activities yielding the following proposition.

**Proposition 17.** *If insurers condition the GR premium stream on an individual's genetic disposition but not on her effort in prevention, GR purchasers do not exert any effort in prevention.*

As in the setting without any individual underwriting, a lack of engagement in prevention implies that expected long-term health costs are high which can be a huge burden for the health-care system.

**The decision which type of insurance to purchase**

To decide who purchases the GR contract, we once more compare expected utility with GR insurance and with spot insurance only. If someone receives the signal $z_0$ about her genetic disposition, her fair premium risk prepayment is given by

$$P(z_0) = z_0\,(p_H - p_L)\,l.^{14} \tag{19}$$

Insurers anticipate that GR insured do not exert any effort in prevention and price the contract accordingly. The prepayment is higher, if an insured's genetic disposition suggests that she is rather likely to become a high-risk type. Such premium discrimination based on genetics is often considered ethically undesirable. However, we have seen in the previous sections that the use of genetic information may be beneficial for market efficiency because individuals with favorable genes might not purchase GR insurance otherwise.

We once more start our analysis of the market outcome by considering the extreme cases $z_0 \in \{0, 1\}$. For a definite low risk receiving the signal $z_0 = 0$, we have $P(0) = 0$. A definite low risk could obtain the GR feature for free. However, she does not face a premium risk because she would get the low-risk spot contract in the second period with certainty. Hence, there is no need for her to enter the GR contract and she is indifferent between the spot and the GR contract. For an individual receiving the worst possible signal $z_0 = 1$, it holds that $P(1) = (p_H - p_L)l$. If such an individual purchased the GR contract, she would be treated as a definite high risk. If she only purchases the spot contract and invests in prevention, however, there is a small chance that she gets the cheaper low-risk contract later in life. Therefore, someone receiving the signal $z_0 = 1$ prefers not to purchase the GR feature. The formal argument is

[14] Again note the slight abuse of notation. Here the argument $z_0$ refers to the personal signal of a particular GR purchaser. In contrast, the argument in $P(z_0^*)$ in (14) refers to the cutoff signal characterizing the market outcome.

again the one provided in Appendix A.3. By continuity, individuals receiving a signal $z_0$ close to but not equal to 1 also prefer the spot over the GR contract.[15]

Individuals receiving an intermediate signal $z_0 \in (0, 1)$ face the following trade-off when deciding which type of insurance to purchase. On the one hand, the GR contract enables them to get rid of the undesirable premium risk. On the other hand, it does not reward prevention activities. In contrast, to the asymmetric information settings in which genetic information was not used in pricing, GR insurance is now the more expensive the higher someone's personal signal $z_0$ is. Therefore, the market outcome is not necessarily described by a cutoff signal. Instead, we even saw that the ones who are particularly likely to become a high-risk type ($z_0$ close to 1) never purchase a GR contract. Therefore, the possible market outcomes can be described as follows.

**Proposition 18.** *Assume that insurance pricing is based on an individual's genetic disposition but not on her effort in prevention. Either GR insurance is not in demand or some individuals purchase GR insurance and some purchase spot insurance. Individuals receiving a signal $z_0$ close to 1 never purchase GR insurance.*

Similar to the setting without any individual underwriting, there will always be some individuals who bear the premium risk themselves and even complete market unraveling is possible.

Compared to the symmetric information setting, the set of available GR contracts represents a subset defined by the restriction $e^{\text{GR}} = 0$. Therefore, individuals are worse off if prevention activities are not monitored. Either they have to make a higher prepayment or they bear the premium risk themselves because the GR contract would be too expensive. This implies:

**Proposition 19.** *GR contracts using only genetic information in pricing are Pareto-dominated by contracts which additionally monitor individuals' effort in prevention.*

**Discussion**

It may be tempting to restrict underwriting to the seemingly less invasive collection of genetic information and to forgo the opportunity to classify risks based on their behavior. From an economic standpoint, however, additionally including behavioral information in insurance pricing yields unambiguously positive welfare implications because a larger group of insured obtains affordable protection against the undesirable premium risk. Proposition 19 shows that the monitoring of prevention is welfare-enhancing if genetic information is used in pricing. Proposition 16 yields the same result if genetic information is not used in pricing. Concerning the use of genetic information, Proposition 18 shows that if genetic information is used in health insurance pricing without allowing for a price discount for engagements in prevention, individuals who are likely to become a high-risk type would need to make such a large prepayment that they are better off if they bear the premium risk themselves. In other words,

[15]Since $EU^{\text{Sp}}(e^{\text{Sp}}, s^{\text{Sp}}; z_0)$ and $EU^{\text{GR}}(e^{\text{GR}}, s^{\text{GR}}; z_0)$ are continuous in $z_0$, $EU^{\text{Sp}} - EU^{\text{GR}} > 0$ for $z_0 = 1$ implies that there exists some $\hat{z}_0 < 1$ such that the same inequality holds for all $z_0 > \hat{z}_0$.

monitoring prevention might be the only chance to offer affordable premium risk coverage to individuals with a strong family history of chronic illness if the price of insurance takes genetic information into account.

## 5 Conclusion

This paper studies the interaction of prevention and insurance in the management of chronic health risks. Investing in prevention early in life reduces the probability of chronic diseases like diabetes or high blood pressure which classify individuals as a high-risk type. Guaranteed renewable insurance contracts provide protection against classification risk and cover the treatment costs of health losses. First, we analyze optimal prevention in isolation to get a feeling for the drivers of the prevention decision. We find that individuals invest more in prevention if the perspective of becoming a high-risk type is more deterrent or if they perceive their prevention technology as more productive. These comparative statics results hold both if we consider the prevention decision without any insurance markets and if spot insurance is offered later in life at a price depending on the purchaser's risk type. Comparing the two settings, we find that the introduction of spot insurance may raise or reduce the optimal effort level. Individuals do not always feel more comfortable and hence exert less effort in prevention if they know that they can insure health losses later in life as one might expect. Instead, we identify a loss size effect which has a negative effect on optimal prevention and a productivity effect which renders prevention more attractive when insurance is introduced.

When GR insurance is available as another tool of risk management, its interaction with prevention activities strongly depends on the use of genetic and behavioral information in insurance pricing. The technological progress over the past years has significantly increased insurers' ability to gather and analyze large amounts of data which can be used to assess a customer's health risk. We compare different regulatory regimes and discuss the pros and cons of regulatory restrictions on the use of genetic and behavioral information in health insurance pricing. Our results suggest that it may be a good compromise to condition the price of insurance on a purchaser's engagement in prevention but not on her genetic disposition. If investments in prevention are similarly effective for all GR purchasers, such a contract helps to reduce expected health expenditures, thereby increasing the accessibility and affordability of health insurance. Individuals with unfavorable genes do not face a price disadvantage and a large group of GR purchasers covers their premium risk at an attractive price. As the monitoring of prevention increases the pool of GR purchasers, it does not only eliminate moral hazard but it also helps to reduce adverse selection. If the productivity of prevention varies greatly between individuals, however, the ones with the most productive prevention technologies do not exploit their potential to reduce health costs. Therefore, there is a need for additional health campaigns targeted at the ones for whom prevention is most productive. For example, individuals whose family history indicates a genetic predisposition for diabetes or high blood pressure should exert more effort than those whose relatives have never suffered from these diseases. Hence, public health campaigns with a focus on individuals with a family history of diabetes or high blood pressure should be initiated.

If individuals shall not be confronted with higher health insurance premiums due to risk factors beyond their control but they shall be accountable for increased health costs resulting from voluntary lifestyle decisions, this means that the two sources of increased health costs have to be disentangled in the underwriting process. In practice, it may be rather difficult to decide whether a certain behavior results from someone's genetic disposition or from her conscious choice of effort. For example, it may be more difficult for someone with an unfortunate genetic endowment to do some sports in order to improve her risk type prospects. Nevertheless, the inclusion of health-related behavior in insurance is probably much more acceptable from an ethical point of view than the use of genetic information, and therefore, one should try to find solutions for contract design which disentangle the two as precisely as possible based on the current state of scientific research.

In our model, we focus on the financial consequences of health losses. Diseased individuals might not only suffer from the monetary losses resulting from treatment costs or lost income but also from the disease itself. Therefore, a state-dependent utility framework might be an interesting extension of our model. Another promising extension involves customers' privacy concerns which might also directly affect the value that individuals assign to insurance policies (Biener et al., 2020). Explicitly including the disutility which an insurance purchaser suffers from giving up her privacy in our model may yield some insights into the trade-off between privacy and the monetary benefits of effort-dependent GR contracts.

# A Appendix

## A.1 Second-order conditions

### A.1.1 No insurance

In the absence of insurance, it holds that

$$EU^{\text{No}}_{ee}(e) = u''(w_1 - e) - z_{ee}(z_0, e)(p_H - p_L)(v(w_2) - v(w_2 - l)) < 0,$$

i.e. $EU^{\text{No}}$ is a concave function and the second-order condition is globally fulfilled.

### A.1.2 Spot insurance

When spot insurance is purchased after the revelation of risk types, we obtain

$$EU^{\text{Sp}}_{ee}(e) = u''(w_1 - e) - z_{ee}(z_0, e)(v(w_2 - p_L l) - v(w_2 - p_H l)) < 0,$$

i.e. $EU^{\text{Sp}}$ is a concave function and the second-order condition is globally fulfilled.

### A.1.3 GR insurance

To increase readability, we omit arguments and define $u_{\text{GR}} := u(w_1 - e - P(e, z_0) - s)$ and $v_{\text{GR}} := v(w_2 - p_L l + s)$. The second partial derivatives of $EU^{\text{GR}}$ are given by

$$\begin{aligned} EU^{\text{GR}}_{ee} &= u''_{\text{GR}}(-1 - P_e)^2 + u'_{\text{GR}}(-P_{ee}), \\ EU^{\text{GR}}_{ss} &= u''_{\text{GR}} + v''_{\text{GR}} < 0, \\ EU^{\text{GR}}_{es} &= u''_{\text{GR}}(1 + P_e). \end{aligned}$$

Hence, the determinant of the associated Hessian matrix equals

$$\begin{aligned} D = EU^{\text{GR}}_{ee} EU^{\text{GR}}_{ss} - (EU^{\text{GR}}_{es})^2 &= \left[u''_{\text{GR}}(1 + P_e)^2 - u'_{\text{GR}} P_{ee}\right]\left[u''_{\text{GR}} + v''_{\text{GR}}\right] - \left[u''_{\text{GR}}(1 + P_e)\right]^2 \\ &= u''_{\text{GR}}(1 + P_e)^2 v''_{\text{GR}} - u'_{\text{GR}} P_{ee}\left[u''_{\text{GR}} + v''_{\text{GR}}\right]. \end{aligned}$$

It holds that $EU^{\text{GR}}_{ee} < 0$ and $D > 0$ if $P_{ee} > 0$, i.e. the second-order conditions are globally fulfilled if $P_{ee} > 0$. We show that this holds in the settings in which $e$ is observed by insurers. If both $e$ and $z_0$ are observed,

$$P_{ee}(e, z_0) = z_{ee}(e, z_0)(p_H - p_L)l > 0.$$

If only $e$ is observed by insurers,

$$P_{ee}(e,z_0^*) = \mathbb{E}\left[z_{ee}\left(z_0,e\right)\mid z_0 \geq z_0^*\right](p_H - p_L)l > 0,$$

i.e. the second-order conditions are fulfilled in both settings.

Finally we note that,

$$EU_{es}^{\mathrm{GR}}(e^{\mathrm{GR}}, s^{\mathrm{GR}}; z_0) = u''(w_1 - e^{\mathrm{GR}} - P(e^{\mathrm{GR}}, z_0) - s^{\mathrm{GR}})(1 + P_e(e^{\mathrm{GR}}, z_0)) = 0$$

due to the first-order condition (9).

### A.2 Spot insurance and saving

When savings are included in the model, expected utility under spot insurance is given by

$$EU^{\mathrm{Sp}}(e,s) = u(w_1 - e - s) + z(z_0,e)v(w_2 - p_H l + s) + (1 - z(z_0,e))v(w_2 - p_L l + s),$$

where $s$ denotes the endogenously determined amount of savings transferred between the two periods. Interior solutions $(e^{\mathrm{Sp}}, s^{\mathrm{Sp}})$ are characterized by the first-order conditions

$$\begin{aligned}
EU_e^{\mathrm{Sp}}(e^{\mathrm{Sp}}, s^{\mathrm{Sp}}) &= -u'(w_1 - e^{\mathrm{Sp}} - s^{\mathrm{Sp}}) - z_e(z_0, e^{\mathrm{Sp}})\left(v(w_2 - p_L l + s^{\mathrm{Sp}}) - v(w_2 - p_H l + s^{\mathrm{Sp}})\right) = 0, \\
EU_s^{\mathrm{Sp}}(e^{\mathrm{Sp}}, s^{\mathrm{Sp}}) &= -u'(w_1 - e^{\mathrm{Sp}} - s^{\mathrm{Sp}}) + \quad z(z_0, e^{\mathrm{Sp}})\, v'(w_2 - p_H l + s^{\mathrm{Sp}}) \\
&\quad + (1 - z(z_0, e^{\mathrm{Sp}}))\, v'(w_2 - p_L l + s^{\mathrm{Sp}}) = 0.
\end{aligned}$$

We assume the second-order conditions to be satisfied.

### A.3 Expected utility for the potential cutoffs $z_0^* = 0$ and $z_0^* = 1$

If the cutoff signal were given by $z_0^* = 0$, all individuals would be offered the GR contract with the prepayment $P(0) = \mathbb{E}[z_0](p_H - p_L)\, l > 0$. An individual receiving the lowest possible signal $z_0 = 0$, becomes a low-risk type for sure even if she does not invest in prevention. Since

$$\begin{aligned}
EU^{\mathrm{Sp}}(e^{\mathrm{Sp}}, s^{\mathrm{Sp}}; z_0 = 0) &= \max_s u(w_1 - s) + v(w_2 - p_L l + s) \\
&> u(w_1 - P(0) - s^{\mathrm{GR}}) + v(w_2 - p_L l + s^{\mathrm{GR}}) \\
&= EU^{\mathrm{GR}}(e^{\mathrm{GR}}, s^{\mathrm{GR}}; z_0^* = 0),
\end{aligned}$$

someone receiving the signal $z_0 = 0$ prefers spot insurance over GR insurance and $z_0^* = 0$ cannot be an informationally consistent cutoff.

If the cutoff signal were given by $z_0^* = 1$, the prepayment were given by $P(1) = (p_H - p_L)\, l$. Assuming an interior solution $e^{\mathrm{Sp}} > 0$ for an individual receiving the signal $z_0 = 1$, this yields

$$
\begin{aligned}
EU^{\mathrm{Sp}}(e^{\mathrm{Sp}}, s^{\mathrm{Sp}}; z_0 = 1) &= \max_{e,s} u(w_1 - e - s) + \quad z(1,e)\, v(w_2 - p_H l + s) \\
&\qquad\qquad + (1 - z(1,e))\, v(w_2 - p_L l + s) \\
&> \max_{s} u(w_1 - s) + v(w_2 - p_H l + s) \\
&= \max_{\tilde{s}} u(w_1 - P(1) - \tilde{s}) + v(w_2 - p_L l + \tilde{s}) \\
&= EU^{\mathrm{GR}}(e^{\mathrm{GR}}, s^{\mathrm{GR}}; z_0^* = 1),
\end{aligned}
$$

where we used $e^{\mathrm{Sp}} > 0$ and $z(1,0) = 1$ for the inequality in the second line, and defined $\tilde{s} := s - (p_H - p_L)l = s - P(1)$ in the third line. This implies that $z_0^* = 1$ cannot be an informationally consistent cutoff either.

## A.4 Partial derivatives of the premium risk prepayment

We calculate the partial derivatives of the actuarially fair premium risk prepayment $P(e, z_0^*) = \mathbb{E}\left[z\left(z_0, e\right) \mid z_0 \geq z_0^*\right](p_H - p_L)\, l$ in the setting in which the effort in prevention is observed by insurers but an individual's genetic disposition is private knowledge. We denote the density of the distribution of the signal $z_0$ by $f$ and its cumulative distribution function by $F$ and calculate

$$
\begin{aligned}
P_e(e, z_0^*) &= \mathbb{E}\left[z_e\left(z_0, e\right) \mid z_0 \geq z_0^*\right](p_H - p_L)\, l, \\
P_{z_0^*}(e, z_0^*) &= \frac{d}{dz_0^*}\left(\frac{\int_{z_0^*}^1 z(z_0, e) f(z_0)\, dz_0}{1 - F(z_0^*)}\right)(p_H - p_L)\, l \\
&= \frac{-z(z_0^*, e) f(z_0^*)(1 - F(z_0^*)) + f(z_0^*)\int_{z_0^*}^1 z(z_0, e) f(z_0)\, dz_0}{(1 - F(z_0^*))^2}(p_H - p_L)\, l, \\
P_{ez_0^*}(e, z_0^*) &= \frac{-z_e(z_0^*, e) f(z_0^*)(1 - F(z_0^*)) + f(z_0^*)\int_{z_0^*}^1 z_e(z_0, e) f(z_0)\, dz_0}{(1 - F(z_0^*))^2}(p_H - p_L)\, l.
\end{aligned}
$$

Since $z_e < 0$, it holds that $P_e < 0$. Moreover, $z_{z_0} > 0$ implies $\int_{z_0^*}^1 z(z_0, e) f(z_0)\, dz_0 > z(z_0^*, e)(1 - F(z_0^*))$, and thus $P_{z_0^*} > 0$. Analogously, we obtain $P_{ez_0^*} > (=, <)\ 0$ if $z_{ez_0} > (=, <)\ 0$, i.e. if the prevention technology exhibits ID (CD, DD).

## A.5 Mathematical proofs

### A.5.1 Proof of Proposition 1

To see how changes in exogenous parameters affect individuals' risk management decision, we apply the implicit function theorem on the first-order condition for optimal prevention given in (1). For the sake of readability, we omit arguments and define $v_l := v(w_2 - l)$ and $v_n := v(w_2)$. For changes in the parameters of the loss lottery, we obtain

$$\frac{de^{\text{No}}}{dp_H} = -\frac{EU^{\text{No}}_{ep_H}}{EU^{\text{No}}_{ee}} = -\frac{-z_e(v_n - v_l)}{EU^{\text{No}}_{ee}} > 0,$$

$$\frac{de^{\text{No}}}{dp_L} = -\frac{EU^{\text{No}}_{ep_L}}{EU^{\text{No}}_{ee}} = -\frac{z_e(v_n - v_l)}{EU^{\text{No}}_{ee}} < 0,$$

$$\frac{de^{\text{No}}}{dl} = -\frac{EU^{\text{No}}_{el}}{EU^{\text{No}}_{ee}} = -\frac{-z_e(p_H - p_L)v'_l}{EU^{\text{No}}_{ee}} > 0.$$

Concerning the effect of a change in the signal $z_0$ which informs an agent about her odds in the risk type lottery, we compute

$$\frac{de^{\text{No}}}{dz_0} = -\frac{EU^{\text{No}}_{ez_0}}{EU^{\text{No}}_{ee}} - \frac{-z_{ez_0}(p_H - p_L)(v_n - v_l)}{EU^{\text{No}}_{ee}}.$$

The sign of this expression depends on the sign of the cross-derivative $z_{ez_0}$, which determines the relationship between the marginal productivity of the agent's prevention technology, $z_e$, and her risk type endowment, $z_0$. It holds that $\frac{de^{\text{No}}}{dz_0} > (=, <)\ 0$ if $z_{ez_0} < (=, >)\ 0$.

### A.5.2 Proof of Proposition 2

In order to examine how the exogenous parameters of the model affect the optimal effort level, we apply the implicit function theorem on the first-order condition (3). To increase readability, we omit arguments and set $v_L := v(w_2 - p_L l)$ and $v_H := v(w_2 - p_H l)$. We begin with the effects of changes in the parameters of the loss lottery, which are given by

$$\frac{de^{\text{Sp}}}{dp_H} = -\frac{EU^{\text{Sp}}_{ep_H}}{EU^{\text{Sp}}_{ee}} = -\frac{-z_e l v'_H}{EU^{\text{Sp}}_{ee}} > 0,$$

$$\frac{de^{\text{Sp}}}{dp_L} = -\frac{EU^{\text{Sp}}_{ep_L}}{EU^{\text{Sp}}_{ee}} = -\frac{z_e l v'_L}{EU^{\text{Sp}}_{ee}} < 0,$$

$$\frac{de^{\text{Sp}}}{dl} = -\frac{EU^{\text{Sp}}_{el}}{EU^{\text{Sp}}_{ee}} = -\frac{-z_e(p_H v'_H - p_L v'_L)}{EU^{\text{Sp}}_{ee}} > 0.$$

To investigate how an individual's information about her risk type endowment, which is encoded in the signal $z_0$, affects her prevention decision, we compute

$$\frac{de^{\text{Sp}}}{dz_0} = -\frac{EU^{\text{Sp}}_{ez_0}}{EU^{\text{Sp}}_{ee}} = -\frac{-z_{ez_0}(v_L - v_H)}{EU^{\text{Sp}}_{ee}},$$

which yields $\frac{de^{\text{Sp}}}{dz_0} > (=, <)\ 0$ if $z_{ez_0} < (=, >)\ 0$.

### A.5.3 Proof of Proposition 3

Since expected utility, $EU^{\text{Sp}}$, is a concave function of the effort level, $e$, it holds that $e^{\text{Sp}} > (=, <)\ e^{\text{No}}$ if and only if $EU_e^{\text{Sp}}(e^{\text{No}}) > (=, <)\ 0$. Therefore, we evaluate the first-order expression in the setting with spot insurance at the optimal effort level without insurance. Utilizing the first-order condition (1), we obtain

$$EU_e^{\text{Sp}}(e^{\text{No}}) = -z_e(z_0, e^{\text{No}})\left[v(w_2 - p_L l) - v(w_2 - p_H l) - (p_H - p_L)(v(w_2) - v(w_2 - l))\right].$$

Since the probability of becoming a high-risk type is uniformly decreasing in the effort level, the sign of the first-order expression equals that of the bracketed term, which is positive (equal to zero, negative) if and only if

$$\frac{v(w_2 - p_L l) - v(w_2 - p_H l)}{p_H l - p_L l} > (=, <)\ \frac{v(w_2) - v(w_2 - l)}{l}.$$

Hence, in order to determine the sign of $EU_e^{\text{Sp}}(e^{\text{No}})$, we have to compare the difference quotients of $v$ over the intervals $[w_2 - p_H l, w_2 - p_L l]$ and $[w_2 - l, w_2]$. These can be visualized graphically as the slopes of the respective secant lines (see Figure 3). Since $v$ is concave, there exists a unique $p^c \in (0, 1)$ such that

$$\frac{v(w_2) - v(w_2 - l)}{l} = v'(w_2 - p^c l)$$

by the mean value theorem. That is, the slope of the secant line over $[w_2 - l, w_2]$ equals that of the tangent line at $w_2 - p^c l$. Therefore, the concavity of $v$ yields $\frac{v(w_2 - p_L l) - v(w_2 - p_H l)}{p_H l - p_L l} > v'(w_2 - p^c l)$ if $p_L \geq p^c$ whereas $\frac{v(w_2 - p_L l) - v(w_2 - p_H l)}{p_H l - p_L l} < v'(w_2 - p^c l)$ if $p_H \leq p^c$.

### A.5.4 Proof of Proposition 5

For an individual receiving the signal $z_0$, it holds that

$$\begin{aligned}
EU^{\text{Sp}}(e^{\text{Sp}}, s^{\text{Sp}}; z_0) = u(w_1 - e^{\text{Sp}} - s^{\text{Sp}}) + \quad & z(z_0, e^{\text{Sp}})\, v(w_2 - p_H l + s^{\text{Sp}}) \\
& + (1 - z(z_0, e^{\text{Sp}}))\, v(w_2 - p_L l + s^{\text{Sp}}) \\
\leq u(w_1 - e^{\text{Sp}} - s^{\text{Sp}}) &+ v(w_2 - z(z_0, e^{\text{Sp}}) p_H l - (1 - z(z_0, e^{\text{Sp}})) p_L l + s^{\text{Sp}}) \\
= u(w_1 - e^{\text{Sp}} - P(e^{\text{Sp}}, z_0) - \tilde{s}) &+ v(w_2 - p_L l + \tilde{s}) \\
= EU^{\text{GR}}(e^{\text{Sp}}, \tilde{s}; z_0)&,
\end{aligned}$$

where we used the concavity of $v$ for the inequality in the second line and defined $\tilde{s} := s^{\text{Sp}} - z(z_0, e^{\text{Sp}})(p_H - p_L)l = s^{\text{Sp}} - P(e^{\text{Sp}}, z_0)$ in the third line. Since $(e^{\text{GR}}, s^{\text{GR}})$ maximizes $EU^{\text{GR}}(e, s; z_0)$, this yields $EU^{\text{Sp}}(e^{\text{Sp}}, s^{\text{Sp}}; z_0) \leq EU^{\text{GR}}(e^{\text{GR}}, s^{\text{GR}}; z_0)$ for all $z_0$ and all individuals (weakly) prefer GR insurance over spot insurance. As we assume an interior solution $e^{\text{Sp}} > 0$ for all $z_0 \in (0, 1]$, it holds that $z(z_0, e^{\text{Sp}}) \in (0, 1)$ and the inequality in the second line is strict for all $z_0 \in (0,1]$. That is, only certain low risks receiving the signal $z_0 = 0$ are indifferent between spot and GR insurance and all others strictly prefer GR insurance over spot insurance.

### A.5.5 Proof of Proposition 6

Since the second-order conditions are globally satisfied, i.e. $EU^{\text{GR}}(e, s; z_0)$ is a concave function of $e$ and $s$, we can apply the following Lemma from Gollier (2001, p. 151) to compare the optimal effort level in the setting with GR insurance to the optimal effort level when only spot insurance is available.

**Lemma 1.** *Let $f : \mathbb{R}^2 \to \mathbb{R}$ be a concave function in the variables $(e, s)$, that is, $f_{ee} < 0$ and $f_{ee}f_{ss} - f_{es}^2 > 0$, which is maximal at $(e^*, s^*)$. Let $\bar{e} \in \mathbb{R}$ be a value we want to compare $e^*$ with. Then, $e^* > \bar{e}$ if and only if $f_e(\bar{e}, \hat{s}) > 0$ where $\hat{s}$ is the value that maximizes $f(\bar{e}, s)$.*

Let $\hat{s}$ be the level of saving that maximizes $EU^{\text{GR}}(e^{\text{Sp}}, s; z_0)$. That is, $\hat{s}$ solves the first-order condition

$$EU_s^{\text{GR}}(e^{\text{Sp}}, \hat{s}; z_0) = -u'(w_1 - e^{\text{Sp}} - P(e^{\text{Sp}}, z_0) - \hat{s}) + v'(w_2 - p_L l + \hat{s}) = 0.$$

According to Lemma 1, $e^{\text{GR}} > e^{\text{Sp}}$ if and only if $EU_e^{\text{GR}}(e^{\text{Sp}}, \hat{s}; z_0) > 0$, which holds if and only if $P_e(e^{\text{Sp}}, z_0) + 1 < 0$. We have

$$\begin{aligned}
P_e(e^{\text{Sp}}, z_0) &= z_e(z_0, e^{\text{Sp}})(p_H - p_L)l \\
&= \frac{-u'(w_1 - e^{\text{Sp}} - s^{\text{Sp}})}{v(w_2 - p_L l + s^{\text{Sp}}) - v(w_2 - p_H l + s^{\text{Sp}})}(p_H - p_L)l \\
&= -\frac{z(z_0, e^{\text{Sp}})v'(w_2 - p_H l + s^{\text{Sp}}) + (1 - z(z_0, e^{\text{Sp}}))v'(w_2 - p_L l + s^{\text{Sp}})}{v(w_2 - p_L l + s^{\text{Sp}}) - v(w_2 - p_H l + s^{\text{Sp}})}(p_H - p_L)l,
\end{aligned}$$

where we used $EU_e^{\text{Sp}}(e^{\text{Sp}}, s^{\text{Sp}}; z_0) = 0$ for the equality in the second line and $EU_s^{\text{Sp}}(e^{\text{Sp}}, s^{\text{Sp}}; z_0) = 0$ in the third line. Hence, $P_e(e^{\text{Sp}}, z_0) + 1 < 0$ if and only if

$$\begin{aligned}
z(z_0, e^{\text{Sp}})v'(w_2 - p_H l + s^{\text{Sp}}) + (1 - z(z_0, e^{\text{Sp}}))v'(w_2 - p_L l + s^{\text{Sp}}) \\
> \frac{v(w_2 - p_L l + s^{\text{Sp}}) - v(w_2 - p_H l + s^{\text{Sp}})}{(p_H - p_L)l}.
\end{aligned}$$

The left-hand side is a convex combination of the slope of $v$ at the wealth levels $w_2 - p_H l + s^{\text{Sp}}$ and $w_2 - p_L l + s^{\text{Sp}}$. The right-hand side represents the slope of the secant line between these two wealth levels. Due to the concavity of $v$, it holds that $v'(w_2 - p_H l + s^{\text{Sp}}) > \frac{v(w_2 - p_L l + s^{\text{Sp}}) - v(w_2 - p_H l + s^{\text{Sp}})}{(p_H - p_L)l} > v'(w_2 - p_L l + s^{\text{Sp}})$. Let $z^c \in (0,1)$ such that $z^c v'(w_2 - p_H l + s^{\text{Sp}}) + (1 - z^c)v'(w_2 - p_L l + s^{\text{Sp}}) = \frac{v(w_2 - p_L l + s^{\text{Sp}}) - v(w_2 - p_H l + s^{\text{Sp}})}{(p_H - p_L)l}$. Then, $P_e(e^{\text{Sp}}, z_0) + 1 < 0$ if and only if $z(z_0, e^{\text{Sp}}) > z^c$.

### A.5.6 Proof of Proposition 12

We calculate

$$
\begin{aligned}
\frac{de^{\mathrm{GR}}}{dz_0^*} &= -\frac{1}{D}\left(EU_{ss}^{\mathrm{GR}} EU_{ez_0^*}^{\mathrm{GR}} - EU_{es}^{\mathrm{GR}} EU_{sz_0^*}^{\mathrm{GR}}\right), \\
\frac{ds^{\mathrm{GR}}}{dz_0^*} &= -\frac{1}{D}\left(EU_{ee}^{\mathrm{GR}} EU_{sz_0^*}^{\mathrm{GR}} - EU_{es}^{\mathrm{GR}} EU_{ez_0^*}^{\mathrm{GR}}\right),
\end{aligned}
$$

with $D = EU_{ee}^{\mathrm{GR}} EU_{ss}^{\mathrm{GR}} - (EU_{es}^{\mathrm{GR}})^2$. An increase in the cutoff signal may affect the optimal level of effort and saving both directly, which is represented by the respective first terms in parentheses, and indirectly in consequence of a change in the optimal level of saving and effort, respectively, which is reflected in the respective second terms in parentheses. Using the calculations concerning the second-order conditions in Appendix A.1.3, we obtain

$$
\operatorname{sgn}\left(\frac{de^{\mathrm{GR}}}{dz_0^*}\right) = \operatorname{sgn}\left(EU_{ez_0^*}^{\mathrm{GR}}\right) \text{and} \operatorname{sgn}\left(\frac{ds^{\mathrm{GR}}}{dz_0^*}\right) = \operatorname{sgn}\left(EU_{sz_0^*}^{\mathrm{GR}}\right),
$$

i.e. indirect effects are absent. Concerning the direct effects, we calculate

$$
\begin{aligned}
EU_{ez_0^*}^{\mathrm{GR}} &= u''(w_1 - e^{\mathrm{GR}} - P(e^{\mathrm{GR}}, z_0^*) - s^{\mathrm{GR}})(-P_{z_0^*}(e^{\mathrm{GR}}, z_0^*))(-P_e(e^{\mathrm{GR}}, z_0^*) - 1) \\
&\quad + u'(w_1 - e^{\mathrm{GR}} - P(e^{\mathrm{GR}}, z_0^*) - s^{\mathrm{GR}})(-P_{ez_0^*}(e^{\mathrm{GR}}, z_0^*)), \\
EU_{sz_0^*}^{\mathrm{GR}} &= -u''(w_1 - e^{\mathrm{GR}} - P(e^{\mathrm{GR}}, z_0^*) - s^{\mathrm{GR}})(-P_{z_0^*}(e^{\mathrm{GR}}, z_0^*)).
\end{aligned}
$$

The first line is equal to $0$ due to the first-order condition (9). Hence, the calculations of the partial derivatives of $P(e^{\mathrm{GR}}, z_0^*)$ in Appendix A.4 together with $u' > 0$ and $u'' < 0$ yield $\frac{de^{\mathrm{GR}}}{dz_0^*} < (=, >)\ 0$ if the prevention technology exhibits ID (CD, DD) and $\frac{ds^{\mathrm{GR}}}{dz_0^*} < 0$.

## A.6 Overview of the results about the interaction of prevention and guaranteed renewable insurance

The following table provides an overview of the main results of section 4.

Table 1: Overview of the results about the interaction of prevention and GR insurance

| **Setting** | **Premium risk prepayment depends on...** | **How much do GR purchasers invest in prevention?** | **Who purchases GR insurance?** | **Implications** |
|---|---|---|---|---|
| Symmetric information | $e$ and $z_0$ | Minimize personal expected lifetime health expenditures | Everyone | Efficient choice of effort and efficient risk allocation;<br>But: Unfavorable genes result in a price disadvantage |
| No individual underwriting of GR insurance | - | Nothing | Nobody or only individuals who are likely to become a high-risk type | High long-term health costs;<br>Complete unraveling of the market for GR insurance possible |
| Monitoring of prevention only | $e$ | Minimize the expected lifetime health expenditures of an "average purchaser" | Individuals who are likely to become a high-risk type;<br>More individuals than with no underwriting at all | Significant reduction in long-term health costs if prevention is similarly productive for all;<br>No price disadvantage due to unfavorable genes;<br>Pareto-dominates no underwriting |
| Use of genetic information only | $z_0$ | Nothing | Nobody or only some individuals;<br>Individuals who are likely to become a high-risk type never purchase GR insurance | High long-term health costs;<br>Complete unraveling of the market for GR insurance possible;<br>Pareto-dominated by symmetric information |

*Notes*: The table provides an overview of the main results in section 4.

## References


Akerlof, G. A. (1970). The market for "lemons": Quality uncertainty and the market mechanism. The Quarterly Journal of Economics 84(3), 488–500.

Barigozzi, F. and D. Henriet (2011). Genetic information: Comparing alternative regulatory approaches when prevention matters. Journal of Public Economic Theory 13(1), 23–46.

Biener, C., M. Eling, and M. Lehmann (2020). Balancing the desire for privacy against the desire to hedge risk. Journal of Economic Behavior & Organization 180, 608–620.

Bolnick, H. J., A. L. Bui, A. Bulchis, C. Chen, A. Chapin, L. Lomsadze, A. H. Mokdad, F. Millard, and J. L. Dieleman (2020). Health-care spending attributable to modifiable risk factors in the USA: An economic attribution analysis. The Lancet Public Health 5(10), e525–e535.

Bond, E. W. and K. J. Crocker (1991). Smoking, skydiving, and knitting: The endogenous categorization of risks in insurance markets with asymmetric information. Journal of Political Economy 99(1), 177–200.

Crainich, D. (2017). Self-insurance with genetic testing tools. Journal of Risk and Insurance 84(1), 73–94.

Crocker, K. J. and A. Snow (1986). The efficiency effects of categorical discrimination in the insurance industry. Journal of Political Economy 94(2), 321–344.

Dionne, G. and C. Rothschild (2014). Economic effects of risk classification bans. The Geneva Risk and Insurance Review 39(2), 184–221.

Ehrlich, I. and G. S. Becker (1972). Market insurance, self-insurance, and self-protection. Journal of Political Economy 80(4), 623–648.

Einav, L. and A. Finkelstein (2011). Selection in insurance markets: Theory and empirics in pictures. Journal of Economic Perspectives 25(1), 115–138.

Frick, K. (1998). Consumer capital market constraints and guaranteed renewable insurance. Journal of Risk and Uncertainty 16(3), 271–278.

Gollier, C. (2001). The economics of risk and time. Cambridge, MA: The MIT Press.

Hoy, M. (1982). Categorizing risks in the insurance industry. The Quarterly Journal of Economics 97(2), 321–336.

Hoy, M. (1989). The value of screening mechanisms under alternative insurance possibilities. Journal of Public Economics 39(2), 177–206.

Hoy, M., A. Mirza, and A. Sadanand (2021). Guaranteed renewable life insurance under demand uncertainty. Journal of Risk and Insurance 88(1), 131–159.

Hoy, M. and M. Ruse (2005). Regulating genetic information in insurance markets. Risk Management and Insurance Review 8(2), 211–237.

Menegatti, M. and F. Rebessi (2011). On the substitution between saving and prevention. Mathematical Social Sciences 62(3), 176–182.

Miyazaki, H. (1977). The rat race and internal labor markets. The Bell Journal of Economics 8(2), 394–418.

Mossin, J. (1968). Aspects of rational insurance purchasing. Journal of Political Economy 76(4, Part 1), 553–568.

Pauly, M. V., H. Kunreuther, and R. Hirth (1995). Guaranteed renewability in insurance. Journal of Risk and Uncertainty 10(2), 143–156.

Peter, R., A. Richter, and P. Steinorth (2016). Yes, no, perhaps? Premium risk and guaranteed renewable insurance contracts with heterogeneous incomplete private information. Journal of Risk and Insurance 83(2), 363–385.

Peter, R., A. Richter, and P. Thistle (2017). Endogenous information, adverse selection, and prevention: Implications for genetic testing policy. Journal of Health Economics 55, 95–107.

Polborn, M. K. (2008). Endogenous categorization in insurance. Journal of Public Economic Theory 10(6), 1095–1113.

Rothschild, M. and J. Stiglitz (1976). Equilibrium in competitive insurance markets: An essay on the economics of imperfect information. The Quarterly Journal of Economics 90(4), 629–649.

Said, M. A., N. Verweij, and P. van der Harst (2018). Associations of combined genetic and lifestyle risks with incident cardiovascular disease and diabetes in the UK biobank study. JAMA Cardiology 3(8), 693–702.

Shook, R. P., D.-c. Lee, X. Sui, V. Prasad, S. P. Hooker, T. S. Church, and S. N. Blair (2012). Cardiorespiratory fitness reduces the risk of incident hypertension associated with a parental history of hypertension. Hypertension 59(6), 1220–1224.

Spence, M. (1978). Product differentiation and performance in insurance markets. Journal of Public Economics 10(3), 427–447.

Swiss Re (2021). Short-term health insurance: a growth engine for China's P&C insurers. Available online at: https://www.swissre.com/institute/research/sigma-research/Economic-Insights/short-term-health-insurance-china.html [Accessed 2021-07-05].

Thaler, R. H. (1999). Mental accounting matters. Journal of Behavioral Decision Making 12(3), 183–206.

The Geneva Association (2020). Digital health: Is the euphoria justified? Authors: A. Bhattacharya-Craven, A. B. Cohen, and S. Ghafur.