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Genetic Tests and Inter-temporal Screening in Competitive Insurance Markets

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Abstract

We consider successive generations of non-altruistic individuals carrying either a good or bad gene. Daughters are more likely to inherit their mother's gene. Competitive insurers can perform a genetic test revealing an agent's gene. They can condition their quotes on the agent's or on her ancestors' genetic status. In equilibrium, generation one is bribed to take the test with an unconditional premium. The insurer uses this information to profitably screen a finite number of generations of their offspring. The offspring of good-gene carriers subsidize the tested generation.

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1. Introduction

In recent years genetic tests have developed rapidly. These tests enable the prediction of a higher than normal risk of developing specific diseases. For insurers genetic tests constitute new possibilities for more precise risk classification of their clients. However, these developments have started a debate on whether insurance companies should be allowed to use genetic information to calculate premia according to an applicant's genetic risk: to many people it seems unfair charging individuals identified with a higher than average risk of developing severe diseases substantially higher insurance premia.

Despite the intensive political discussion, the theoretical literature on genetic testing and health insurance has remained rather limited (Tabarrok (1994), Doherty and Thistle (1996), Doherty and Posey (1998), Strohmenger and Wambach (2000), Andersson (2001), Hoel and Iverson (2002), Hoy et al. (2003), Hoel et al (2006)). All of these papers consider Rothschild and Stiglitz (1976) type static one-period insurance markets and analyze the effects of genetic testing on the risk categorization of individuals in the spirit of Hoy (1982).

It is obvious, however, that genetic information may also allow inter-temporal discrimination. Information about parents' genes may allow an insurer to screen their offspring. If the parents carried the good gene, their children are less likely to develop a disease than if the parents carried the bad gene.[1] For example, every child of a person with Huntington's disease has a 50% chance of inheriting the gene mutation and developing the disease. Insurers use information on family medical history in underwriting decisions for children of Huntington's sufferers. Because each child has a 50% chance of early mortality, such children find it difficult to obtain insurance; and when they do, premiums are typically quite high; see Manson and Conko (2007) and Gutiérrez and Macdonald (2002). Obviously, such inter-temporal screening based on family medical history can also be achieved by conditioning on the parents' genetic status. Accordingly, it may be profitable for insurers to quote the offspring of good-gene carriers better rates than the offspring of bad-gene carriers. The purpose of this paper is to analyze the impact of genetic testing when such inter-temporal discrimination is possible.

In our model agents carry a good or a bad gene. Agents with the bad gene are more likely to develop a disease than agents with the good gene. We normalize the

[1]Inheritance of genetic diseases refers to whether the condition is inherited from the parents or "runs" in families. The level of inheritance of a condition depends on how important genetics are to the disease. Strongly genetic diseases are usually inherited, partially genetic diseases are sometimes inherited, and non-genetic diseases are not inherited; see, e.g., www.wrongdiagnosis.com/g/genetic/inherit.htm.

cost of treating the disease to one so that the fair price for full insurance equals the probability of developing the disease.

We consider successive generations of individuals carrying the good or the bad gene. Reproduction is asexual. Daughters are more likely to inherit their mother's gene. The fractions of the good- and bad-gene carriers are constant through time.

Risk averse individuals must purchase full insurance. They are not altruistic, i.e., they do not care about the well-being of their offspring. Agents do not know which genes they carry. However, insurers can perform a test which reveals an agent's genes. Insurers quote prices for the mandatory insurance which may be unconditional or depend on the agent's or her ancestors' test results. Test results and insurance rates are non-verifiable, i.e., it is not possible that an agent passes on information from one insurer to another. Moreover, descendants of a tested generation have no information about their ancestors' test results. Insurers engage in price competition.

Insurers cannot attract agents with non-loss making quotes conditional on the agents' genetic status. Competition ensures that a fair one-period pooling quote is available under which the individual is fully insured. Prices conditional on the genetic status expose the agent to premium risk to which she is averse. Accordingly, agents prefer the unconditional pooling contract; see Tabarrok (1994) or Doherty and Thistle (1996).

Nevertheless, an insurer can exploit the fact that agents are not altruistic. With a multi-period pricing strategy, the insurer can induce mothers to take the test and then use this information to profitably screen their offspring.

Our equilibria have the following structure: An insurer bribes the first generation to take the test with an unconditional quote which is below their average probability to fall sick; the insurer makes losses on the first generation. The insurer then uses this information about generation one to profitably screen their offspring. The offspring of the bad-gene carriers get fair quotes; the insurer breaks even on this group. By contrast, the offspring of the good-gene carriers get unfair quotes, and the insurer makes a profit on them. Price competition ensures that these profits equal the subsidy given to the first generation so that the net present value of expected profits is zero. Moreover, due to competition the price charged to the offspring of good-gene carriers is constant through time and equal to the price charged to the tested generation one. Insurers use the information about generation one to profitably screen a *finite* number of generations of their offspring. When the last offspring generation has been screened, the process starts all over again with the testing of the next generation.

Comparing these inter-temporal screening equilibria to fair unconditional pool-

ing in each period, one sees that the tested generation is clearly better off: they pay a price below their average probability of contracting the disease. The offspring of agents carrying good genes pay a price above their probability of developing the disease; they subsidize the tested generation. Nevertheless, they are still better off than under unconditional pooling. The offspring of mothers with the bad gene are worse off than under unconditional pooling: they pay the price reflecting their higher than average risk of developing the disease. Since the information about a mother's bad gene becomes less precise as one moves down the family tree, daughters of tested mothers pay a higher price than granddaughters and so on.

Our model is related to the set-up of Kunreuther and Pauly (1985).[2] In their model insurance firms learn about their customers' risks by observing claim records over time. An insurer has an information advantage on his established customers compared to his competitors. Kunreuther and Pauly analyze how the insurer can exploit this advantage in a competitive market. In their model a consumer's risk is constant through time. The insurer learns the risk over time and adjusts premia accordingly. In our set-up the mother's risk is only an imprecise signal of her daughter's risk. Through the test an insurer precisely learns the mother's risk. The content of this information deteriorates over time, however. Kunreuther and Pauly's equilibrium shares with our equilibrium the *lowballing* feature: new customers are attracted at a loss, while the insurer extracts rent from established customers.[3] In our framework mothers are induced to take the test at a loss; the offspring of mothers with the good gene are exploited profitably.

The paper is organized as follows. The next section introduces the basic model. In section three we introduce the genetic test. As a preliminary step we first consider the scenario where information about the genes of mothers may only be used to screen daughters. Granddaughters have to be tested anew. In the next subsection we allow the genetic information to be used for any number of generations of the offspring. Section 4 concludes.

2. The Model

We consider successive generations $t = 1, 2, \ldots$ of individuals. Each generation lives for one period. Each member $i \in [0, 1]$ of generation t (mother) has exactly one offspring (daughter) also named i. The size of all generations is thus the

[2] See also Nilssen (2000).

[3] The term lowballing is due to D'Arcy and Doherty (1990).

same. We normalize the size of the generations to 1, i.e., $f([0,1]) = 1$, where f is Lebesgue measure.[4]

An individual's health status H can be good g or bad b, i.e., $H(i,t) \in \{g,b\}$. The health status, in turn, is determined by the genetic status G, which can be of type ℓ or h, i.e., $G(i,t) \in \{\ell,h\}$. If an individual is of type h, the probability of being in health status b is $h \in (0,1)$; if she is of type ℓ, the probability is $\ell \in (0,h)$, i.e., lower than for the h-types. Denote the members of generation t with the ℓ-gene by ℓ_t and the ones with the h-gene by h_t. Let the fraction of the h-types in generation 1 be $f(h_1) < 1/2$, and the fraction of the ℓ-types accordingly $f(\ell_1) = 1 - f(h_1)$.

Let us now turn to the passing on of genes. Denote by $\phi_{\ell\ell}$ the transition probability that the daughter is of type ℓ given her mother is of type ℓ, by $\phi_{h\ell}$ the probability that the daughter is of type h if her mother is of type ℓ, and accordingly, $\phi_{\ell h}$ and ϕ_{hh} for the h-type mothers. These transition probabilities are constant through time.

A daughter is more likely to be of type ℓ if her mother is of this type; likewise, she is more likely to be of type h if her mother is as well. A daughter can, however, also be of the opposite genetic type as her mother. Formally, $1 > \phi_{\ell\ell} > \phi_{h\ell} > 0$ which implies $\phi_{\ell\ell} > 1/2$; $1 > \phi_{hh} > \phi_{\ell h} > 0$ so that $\phi_{hh} > 1/2$.

Let $\phi_{h\ell} = \phi_{\ell h} f(h_t)/f(\ell_t),\ t = 1,2,\ldots$. Then we have $f(h_{t+1}) = f(h_t) := f(h)$ and $f(\ell_{t+1}) = f(\ell_t) := f(\ell),\ t = 1,2,\ldots$; that is, the fraction of ℓ- and h-gene carriers are constant through time.[5]

To illustrate, consider the following example: $f(\ell) = 3/4$, $\phi_{\ell\ell} = 8/9$, and $\phi_{hh} = 2/3$. We will use this example throughout the text. A summary of the example with explicit derivations is given in the Appendix.

To sum up: We consider generations of size 1 in which the fractions of ℓ- and h-gene carriers are constant through time. The average probability to develop the disease is the same in each generation and equals $p(H(i,t) = b) = f(h)h + f(\ell)\ell := \bar{p}$. Let $h = 1/2$ and $\ell = 1/4$ so that in our example $\bar{p} = 5/16$.

If an individual is in bad condition b, she is sick and needs treatment. We normalize the cost of treating the disease to 1. Individuals are risk averse which is represented by their utility function $U(\cdot)$ over income with $U' > 0$ and $U'' < 0$.[6]

[4]For the sake of simplicity we consider a society with asexual reproduction; see, e.g., Becker and Tomes (1979).

[5]To see this, consider, e.g., $f(h_{t+1}) = f(h_{t+1} \cap h_t) + f(h_{t+1} \cap \ell_t) = f(h_t)\phi_{hh} + f(\ell_t)\phi_{h\ell} = f(h_t)\phi_{hh} + f(\ell_t)\phi_{\ell h} f(h_t)/f(\ell_t) = f(h_t)$.

[6]Our utility function is thus state independent. For an analysis with state contingent utility functions see Strohmenger and Wambach (2000).

Individuals have initial income $M > 1$. To keep matters simple we assume that insurance is mandatory and equal to the size of the treatment, i.e., individuals must purchase full insurance.[7] Individuals do not know which genes they carry. We further assume that agents are not altruistic, i.e., mothers do not care about the well-being of their offspring.[8]

Let us now turn to the insurers. We want to focus on equilibria in the spirit of Rothschild and Stiglitz (1976): The contracts that are offered in equilibrium make zero profits, and there exists no other contract that can generate positive profits given the equilibrium ones. We therefore set up a game having a Nash-equilibrium with the Rothschild and Stiglitz characteristics.

The mandatory insurance of 1 is provided by $n > 2$ insurance companies. Insurer $j, j = 1, \ldots, n$, quotes $q_t^j(\cdot)$ for the mandatory insurance in period t or remains inactive. The quotes may be unconditional or they may depend on the result of a genetic test which we describe in the next section. We will specify the contracts we allow for in detail below. In each period insurer 1 moves first; insurer 2 observes 1's choice and then moves second, and so on. Finally, consumers choose the most attractive contract; if consumers are indifferent between the offers of two insurers, they buy from the first mover. Insurers are risk neutral. They maximize the sum of expected profits over time. For the ease of exposition we set the discount rate to zero. Due to price competition equilibrium profits will be zero. If an insurer is indifferent between being inactive yielding zero profits or being active having customers and making zero profits, he opts for being active.[9]

Without the genetic test neither the first generation's insured know which genes they carry nor do insurers, implying that any discrimination among agents of generation 1 is impossible. From the second generation on insurers could try to condition their quotes on the medical history of an agent's ancestors. To focus

[7]Note that our mandatory insurance differs from the compulsory insurance in Hoel and Iversen (2002). There all agents pay the same price but the insurance may be less than complete. In our set-up insurance is full, yet prices may depend on individual risk.

[8]For our results to hold it is sufficient that mothers care less about their daughters' well-being than their own; see the discussion in the Conclusions.

[9]Under these assumptions along the equilibrium path insurer 1 offers a quote generating zero profits while the other insurers remain inactive. Since insurer 1 serves the entire market, in equilibrium the other insurers have no customers and thus opt to be inactive. If insurer 1 deviates from his equilibrium contract, insurer 2's equilibrium strategy specifies a contract generating zero-profits given insurer 1's out-of-equilibrium offer. See, e.g. the proof of Proposition 1. Kunreuther and Pauly (1985) also use this Stackelberg leader-follower model to derive Rothschild and Stiglitz type of equilibria.

on the role of genetic tests, we rule out this possibility.[10] Therefore, without the genetic test the insurers can offer only unconditional quotes in each period. We also rule out history-dependant strategies which might support collusion. Each period insurer $j, j = 1, \ldots, n$, will offer an unconditional quote q_t^j for the mandatory insurance of 1 or remain inactive.

Proposition 1: *Along the equilibrium path insurer 1 offers* $q_t^1 = \bar{p},\ t = 1, 2, \ldots$ *while insurers* $2, \ldots, n$ *are inactive in each period.*

Proof: In equilibrium insurer 1 serves the whole market in each period and makes zero profits. Since we rule out history-dependant strategies, it suffices to consider possible deviations in one period, say period 1. Insurer 1 will not charge a lower price because this entails losses. If insurer 1 quotes $q_1^1 > \bar{p}$, insurer 2 quotes $q_1^2 = \bar{p}$. To see this, consider insurer $n-1$. If he charges a price above $\bar{p}$, he will be undercut by insurer n and end up with no customers. Since firm $n-1$ prefers being active, he will charge $\bar{p}$. Working backwards yields that firm 2 charges $\bar{p}$, and so does insurer 1. Therefore, insurer 1 has no incentive to deviate. Given insurer 1's equilibrium quote, the other insurers cannot attract consumers with a non-loss-making quote. Thus they'd rather stay inactive. □

In our example insurer 1 offers the pooling rate of 5/16 each period. Under perfect information the ℓ-types would pay 1/4 while the h-types would be charged 1/2. Accordingly, the h-types benefit from asymmetric information: they are subsidized by the ℓ-types.

3. Genetic Test

Now assume a genetic test becomes available that reveals an individual's genes. We consider the case where only insurance companies can perform the test.[11] Let the test be costless. If an agent is tested, the insurer can condition his quote on her genetic status. Moreover, the quotes for the individual's descendants can also depend on the agent's test result. The test results and the insurance quotes are non-verifiable. This means that a consumer cannot use test results and quotes

[10] See, e.g., Kunreuther and Pauly (1985) for an analysis of such an experience rating.

[11] If the agents can take the test, the test results will also become known to the insurers. If the test shows the ℓ-gene, an agent will happily release this information to the insurer. If the test result is h, the information will be kept secret. Accordingly, those individuals who do not reveal their test are potentially at high risk. See Tabarrok (1994) and Doherty and Thistle (1996).

from, say, insurer 1 to get favorable rates from another insurer. To put this differently, if insurer 1 has tested an agent, he has a monopoly on this information which he can try to exploit over time. Moreover, we assume that descendants of a tested generation have no information about the test result, be it directly or indirectly through the quotes they get. Each generation has the same priors about its genetic status as generation 1.[12]

If, say, a period 1 agent accepts a conditional quote by an insurer, she commits to buy the insurance from this insurer even when the test shows that she carries the h-gene. It is thus not possible for a consumer to take the test with one insurer and switch to another insurer offering, say, a pooling contract if the test result is unfavorable.[13] Note that this assumption does *not* imply that the agent's descendants must buy insurance from this company. They are free to choose from all offers on the market. The only constraint a period 2 agent faces is that if she accepts a conditional quote in period 2, she has to buy this contract.

First note that it is not possible to attract individuals with a one-period contract conditional on the test results $\mathbf{q}_t^j = (q_t^j(G(i,t) = \ell), q_t^j(G(i,t) = h)) := (q_t^j(\ell^t), q_t^j(h^t))$ with $q_t^j(\ell^t) \neq q_t^j(h^t)$. In particular, prices $q_t^1(\ell^t) < \bar{p} < q_t^1(h^t)$ where the agent gets a better quote if she has the ℓ-gene than if she carries the h-gene attract no customers.

Lemma 1: *No firm offers a one-period contract* $\mathbf{q}_t^j = (q_t^j(\ell^t), q_t^j(h^t))$ *with* $q_t^j(\ell^t) \neq q_t^j(h^t)$ *in equilibrium.*

Proof: Suppose insurer 1 tries to attract individuals with prices $q_t^1(\ell^t) \neq q_t^1(h^t)$ conditional on the test outcome. If consumers accept this contract, they have to buy insurance from firm 1. Since all agents of generation t have the same priors, they either all buy the contract or nobody does. If they accept the offer, firm 1 thus has customers of both types and will offer only quotes that do not yield expected losses, i.e., $f(h)q_t^1(h^t) + f(\ell)q_t^1(\ell^t) \geq \bar{p}$.

[12] If, say, agents of generation 2 are aware of their mother's genetic status, they know whether they have a high or a low probability of falling ill. An insurer who doesn't know the mothers' test results can screen the two groups by offering, e.g., contracts exposing agents to some price risk as described in Lemma 1; daughters of ℓ mothers are more willing to accept the risk than daughters of h mothers. To keep the model tractable, we rule out this possibility.

[13] If this kind of shopping were allowed for, unconditional pooling offers are not possible: only h-gene carriers would demand the pooling contract rendering it unprofitable. See, e.g., Emons (2001) for an analysis of such a shopping behavior by consumers in the presence of imperfect tests.

Then insurer 2 will offer the unconditional contract $q_t^2 = \bar{p}$. With insurer 2's quote the individual's utility is $U(M - \bar{p})$: the agent is fully insured and bears no risk at all. With 1's conditional prices the expected utility amounts to $f(\ell)U(M - q_t^1(\ell^t)) + f(h)U(M - q_t^1(h^t))$: the agent is fully insured but bears the price risk generated by the genetic test. Jensen's inequality together with the fact that the conditional prices do not yield losses imply that the agents are better off with the fair pooling quote $\bar{p}$. □

Conditional pricing introduces risk to which the agents are averse. Consumers prefer unconditional pooling; see Tabarrok (1994).

Given that a one-period pricing strategy conditional on the test results does not work out, an insurer can try to exploit the fact that agents are not altruistic. With a multi-period pricing strategy he can try to induce mothers to take the test and then use this information to profitably screen their offspring.

To induce agents of generation t to take the test, insurer 1 must offer them terms generating at least the expected utility of $U(M - \bar{p})$; otherwise insurer 2 can attract this generation with an unconditional pooling offer. Since agents are risk averse and insurers risk neutral, the best way to achieve this is by requiring to take the test and then quoting $q_t^1 \leq \bar{p}$ which is not conditional on the test outcome. For the agents' daughters the insurer then quotes $\mathbf{q}_{t+1}^1 = (q_{t+1}^1(G((i,t) = \ell), q_{t+1}^1(G(i,t) = h)) := (q_{t+1}^1(\ell^t), q_{t+1}^1(h^t))$, for their granddaughters $\mathbf{q}_{t+2}^1 = (q_{t+2}^1(G(i,t) = \ell), q_{t+2}^1(G(i,t) = h)) := (q_{t+2}^1(\ell^t), q_{t+2}^1(h^t))$, and so on.

3.1 Two-period Pricing Strategy

To fix ideas, suppose insurer j induces generation 1 to take the test and then uses the genetic information about mothers to make a profit on their daughters. The insurer may not use the information about mothers to screen granddaughters. He has to start the process again by testing granddaughters. We consider at the moment only such two-period pricing strategies $(q_t^j, \mathbf{q}_{t+1}^j)$ together with the one-period pricing strategy q_t^j, i.e., unconditional pooling. We will drop this assumption in the next section.

We will now construct an equilibrium where insurer 1 offers the same two-period contract in each odd period. The contract breaks even over the two generations. The other insurers remain inactive. Given insurer 1's offer, they cannot profitably enter with a one- or two-period contract.

Company 1 offers quotes q_1^1 and $\mathbf{q}_2^1 = (q_2^1(\ell^1), q_2^1(h^1))$. Here q_1^1 is the quote for generation 1 given they take the test; $q_2^1(\ell^1)$ $[q_2^1(h^1)]$ is the quote for daugh-

ters whose mothers were of type ℓ [h]. To determine profits we need to define the daughter's probability of falling ill conditional on the mother's genetic status $p(H(i,2) = b|G(i,1) = \ell) = \ell\phi_{\ell\ell} + h\phi_{h\ell} := p(b^2|\ell^1)$ and $p(H(i,2) = b|G(i,1) = h) = \ell\phi_{\ell h} + h\phi_{hh} := p(b^2|h^1)$. In our example $p(b^2|\ell^1) = 5/18$ and $p(b^2|h^1) = 5/12$.

With this two-period pricing strategy, the insurer's profits amount to

$$\begin{aligned} \pi_1^1 &= q_1^1 - \bar{p} \quad \text{and} \\ \pi_2^1 &= [q_2^1(\ell^1) - p(b^2|\ell^1)]f(\ell) + [q_2^1(h^1) - p(b^2|h^1)]f(h). \end{aligned}$$

The second period profit is explained as follows: There are $f(\ell)$ [$f(h)$] daughters whose mothers had the ℓ- [h]-gene. The insurer's profits on the first group is the quote $q_2^1(\ell^1)$ minus the expected probability of developing the disease conditional on the mothers' ℓ-genes $p(b^2|\ell^1)$; for the second group profits are the quote $q_2^1(h^1)$ minus the expected probability of developing the disease conditional on the mothers' h-genes $p(b^2|h^1)$.

Let us first consider the quote $q_2^1(h^1)$ the insurer charges daughters whose mothers were of type h. Recall that in our equilibrium we construct the quote $q_2^1(\ell^1)$ in such a way that the agents with type ℓ-mothers buy from firm 1. Insurer 1 will not charge $q_2^1(h^1) < p(b^2|h^1)$ because this reduces his period two profit. If $q_2^1(h^1) > p(b^2|h^1)$, firm 2 will offer $q_2^2 = p(b^2|h^1)$. Given daughters with ℓ-mothers buy from insurer 1, insurer 2 attracts only daughters of h-mothers and breaks even with his quote. Accordingly, $q_2^1(h^1) \geq p(b^2|h^1)$. If the equality holds, the insurer serves this group while making zero profits; if the inequality is strict, he loses this group and also makes zero profits. Thus, quoting $q_2^1(h^1) = p(b^2|h^1)$ and serving this group is an equilibrium action.

Hence, insurer 1 can only make a profit on agents with type ℓ-mothers. This profit is constrained, however. First note that $q_2^1(\ell^1) \leq \bar{p}$. If this were not the case, company 2 will offer the unconditional quote $q_2^2 = \bar{p}$. He attracts the whole generation 2 and makes zero-profits. Firm 1 would end up with no customers in period 2.

Yet $q_2^1(\ell^1)$ is further restricted by q_1^1. To see this, suppose insurer 1 makes zero profits with his two-period pricing strategy $(q_1^1, \mathbf{q}_2^1 = (q_2^1(\ell^1), p(b^2|h^1)))$, i.e., $\pi_1^1 + \pi_2^1 = 0$. Now let $q_2^1(\ell^1) > q_1^1$. Then insurer 2 offers $(q_2^2, \mathbf{q}_3^2 = (q_2^2, p(b^3|h^2))$ where q_2^2 is such that $\pi_2^2 + \pi_3^2 = 0$. Since both two-period contracts break even and $q_2^1(\ell^1) > q_1^1$, we have $q_2^2 < q_2^1(\ell^1))$. Thus insurer 2 attracts both groups in period 2 who happily take the test, and breaks even over the two periods. Insurer 1 has no period-two customers and overall suffers losses.

Consequently, the equilibrium contract has the feature $q_2^1(\ell^1) = q_1^1$ and must generate expected zero profits. Formally, $\pi_1^1 = q_1^1 - \bar{p}$, $\pi_2^1 = [q_1^1 - p(b^2|\ell^1)]f(l)$, and

$\pi_1 + \pi_2 = 0$. Solving for q_1^1 yields

$$q_1^1 = \frac{\bar{p} + f(\ell)p(b^2|\ell^1)}{1 + f(\ell)}. \tag{1}$$

If insurer 1 offers this contract, no other insurer can attract customers in period 1 or 2 with a non-loss making offer. If insurer 1 deviates he either makes losses or has no customers.

To summarize our findings:

Proposition 2: *Suppose firms are restricted to one- and two-period pricing strategies. Then there exists an equilibrium where along the equilibrium path firm 1 charges generation 1* q_1^1 *as defined by* (1) *and generation 2* $q_2^1(\ell^1) = q_1^1$, $q_2^1(h^1) = p(b^2|h^1)$. *The process starts all over again with generations* $3, 5, \ldots$. *Firm 1 serves the entire market and the other firms are inactive.*

The quote $q_2^1(\ell^1) = q_1^1$ is unfair and the insurer makes a profit on the daughters whose mothers had the good gene. This group is free to switch to another insurer. Yet no other insurer can make a better offer to them. The competition has no information about the second generation and thus can only offer unconditional pooling or the equilibrium set of contracts. Unconditional pooling is worse for this group. Offering the equilibrium set of contracts, i.e., offering the subsidized rate conditional on taking the test and exploiting the information in the next generation doesn't attract customers either. By testing the first generation, insurer 1 obtains a monopoly for the information about their genetic status which he uses to exploit the daughters of the good-gene mothers. Bertrand competition ensures that the price the insurer pays for obtaining this monopoly equals the profit it makes in the second round having this monopoly. The equilibrium is thus of the lowballing type.

In each odd period, say period 1, firm 1 induces all agents to take the test at a quote q_1^1 below the average probability to fall sick $\bar{p}$. In our example $q_1^1 = 75/252 < 5/16 = \bar{p}$ and $\pi_1^1 = -15/1008$. In each even period the insurer recoups his investment with the daughters whose mothers had the ℓ-gene, $p(b^2|\ell^1) < q_2^1(\ell^1) = q_1^1$. In our example $p(b^2|\ell^1) = 5/18$ and $\pi_2^1 = 15/1008$.

Let us use the example to show that in equilibrium indeed $q_2^1(\ell^1) = q_1^1$. Suppose on the contrary that insurer 1 charges, e.g., $q_1^1 = 291/1008 < 75/252$ and $q_2^1(\ell^1) = 78/252$. With these prices $\pi_1^1 + \pi_2^1 = 0$. Yet now insurer 2 will offer the equilibrium contract $q_2^2 = 75/252$ and $\mathbf{q}_3^2 = (75/252; 5/12)$. He attracts both groups in period 2 and everybody takes the test. His profits in period 3 on daughters of ℓ-mothers compensate his losses from period 2.

Let us compare this two-period pricing equilibrium with the one-period one where firms charge $\bar{p}$ in each period. The tested generations are clearly better off because they pay a price below their average probability of becoming sick. By paying the price q_1^1 above their probability of falling ill $p(b^2|\ell^1)$, daughters of type ℓ-mothers cross-subsidize the entire preceding generation. Yet they are still better off than under one-period pooling. By contrast, daughters of type h-mothers are worse off than in the one-period pooling equilibrium. To summarize: In the two-period pricing equilibrium the tested generations and their offspring with type ℓ-mothers gain at the expense of their descendants with type h-mothers.

3.2. Arbitrary Pricing Strategies

We have seen that the two-period pricing strategy drives out the one-period one. The next question to ask is whether insurer 1 should use his informational advantage about generation 1 for generations $3, 4, \ldots$ as well. To answer this question we allow now for arbitrary pricing policies.

As a first step we define k-period pricing policies starting from generation 1 on. Under such a policy generation 1 is tested and their genetic information is then used on $(k-1)$ generations of their offspring. Define $p(H(i,t) = b|G(i,1) = \ell) := p(b^t|\ell^1),\ t = 2, \ldots$.

Definition 1: *A k-period pricing policy is given as follows. For $k = 2, 3, \ldots$ the quotes $q_{1,k}$, $\mathbf{q}_{t,k} = (q_{1,k}, p(b^t|h^1))$, give rise to profits $\pi_1 = \bar{p} - q_{1,k}$ and $\pi_t = [q_{1,k} - p(b^t|\ell^1)]f(\ell),\ t = 2, \ldots, k$. The zero profit condition $\sum_{t=1}^{k} \pi_t = 0$ then gives us*

$$q_{1,k} = \frac{\bar{p} + f(\ell)\sum_{t=2}^{k} p(b^t|\ell^1)}{1 + (k-1)f(\ell)}. \tag{2}$$

Let $q_{1,1} = \bar{p}$; with one-period pricing only unconditional pooling is possible.

We have defined k-period pricing rather narrowly. We have already taken into account that k-period pricing must lead to zero profits. Moreover, we have determined $q_{1,k}$ such that it is an equilibrium if only one-period and k-period pricing are allowed for. A firm offering $q_{1,k}$ as defined by (2) cannot be driven out of the market by the one-period pooling price $q_{1,1} = \bar{p}$. We have $q_{1,k} < \bar{p}$ because $p(b^k|\ell^1) < \bar{p}$ for all $k = 2, 3, \ldots$.

It is, however, unclear which k-period pricing policy firms will follow. If, e.g., $q_{1,3} > q_{1,4}$, a firm with the 3-period pricing policy will be driven out of the market by a firm using the 4-period one. In a second step we analyze, therefore, the prices $q_{1,k},\ k = 1, 2 \ldots$ in detail. It turns out that these prices are U-shaped in k.

Lemma 2: *The set of quotes* $\{q_{1,k}\},\ k = 1, 2, \ldots,$ *defined by* (2) *is U-shaped in* k *and attains its minimum at some finite* $\kappa \geq 2$.

Proof: Straightforward computations show that $q_{1,1} = \bar{p} > q_{1,2}$. Next note that

$$q_{1,k} < (\geq)\ q_{1,k+1} \quad \Leftrightarrow$$

$$\bar{p} - p(b^{k+1}|\ell^1) < (\geq)\ f(\ell)[(k-1)p(b^{k+1}|\ell^1) - \sum_{t=2}^{k} p(b^t|\ell^1)], \quad k = 2, 3, \ldots.$$

The LHS is positive and monotonically decreasing in k with $\lim_{k\to\infty} \text{LHS} = 0$. The RHS is positive and increasing in k. Consequently, either $\kappa = 2$ or it is defined by the k where the strict inequality first holds. $q_{1,k}$ is decreasing in k for $k < \kappa$ and increasing for $k > \kappa$. □

Lemma 2 states that a κ-period pricing strategy leads to the lowest price $q_{1,k}$ that can be charged to the tested generation 1 and all $(k-1)$ descendant generations of the ℓ^1-types. In our example $\kappa = 3$. We have $\bar{p} = 5/16,\ p(b^2|\ell^1) = 5/18,\ p(b^3|\ell^1) = 95/324,\ p(b^4|\ell^1) = 220/729,\ q_{1,1} = 5/16,\ q_{1,2} = 75/252,\ q_{1,3} = 8/27$, and $q_{1,4} = 2820/9427 > q_{1,3}$.

Increasing the pricing strategy from k to $k+1$ increases profits by $\pi_{k+1} = (q_{1,k+1} - p(b^{k+1}|\ell^1))f(\ell)$. If $\pi_{k+1} > 0$, the profits made on the descendants of types ℓ^1 increase. Hence, $q_{1,k+1} < q_{1,k}$. The tested generation gets a larger cross-subsidy so that total profits sum up to zero.

Conversely, if $\pi_{k+1} < 0$, $q_{1,k+1} > q_{1,k}$. The profits made on the offspring of types ℓ^1 decreases and so does the subsidy for the tested generation. Straightforward computations show that $\pi_{k+1} < 0$ is equivalent to $q_{1,k} < p(b^{k+1}|\ell^1)$. If the price $q_{1,k}$ charged under k-period pricing is lower than the conditional probability of falling ill of generation $k+1$, adding this cohort lowers the profits made on the descendants of types ℓ^1's. The existence of such a critical cohort is ensured because $p(b^{k+1}|\ell^1)$ converges to $\bar{p}$ as k becomes large.

To put it differently: The informational advantage of having tested generation 1 dissipates with successive generations: $p(b^{k+1}|\ell^1)$ increases with k and converges to $\bar{p}$. Adding additional generations to the pricing strategy becomes less and less attractive as one moves down the family tree.

As long as it is profitable to add a generation to the pricing policy, the price q_1^1 falls. If the additional generation adds to profits made on the offspring of the tested generation 1, the price q_1^1 has to fall so that overall profits sum up to zero. Yet, there is some generation $(\kappa+1)$ where $p(b^{\kappa+1}|\ell^1)$ exceeds the price $q_{1,\kappa}$ charged

under the κ-period pricing policy. Adding this generation to the pricing policy lowers profits made on the offspring and actually increases q_1. This reasoning is similar to the well-known textbook result that average costs are decreasing as long as they are higher than marginal costs and increasing when the are smaller than marginal costs.

It is now clear what an equilibrium looks like:

Proposition 3: *Suppose firms are restricted to k-period pricing policies as defined in Definition 1. Then there exists an equilibrium where along the equilibrium path firm 1 follows a κ-period pricing policy with κ defined by Lemma 2. It charges the first generation $q^1_{1,\kappa}$ as defined by (2) and its offsprings $q^1_{t,\kappa}(\ell^1) = q^1_{1,\kappa}$, $q^1_{t,\kappa}(h^1) = p(b^t|h^1)$, $t = 2, \ldots, \kappa$. The procedure starts all over again with generations $\kappa + 1, 2\kappa + 1, \ldots$. Firm 1 serves the entire market and the other firms are inactive.*

If firm 1 charges $q_{1,\kappa}$, it cannot be driven out of the market by another pricing policy because they all command higher prices. Let us compare the κ-period pricing equilibrium to the one-period pooling equilibrium $q_{1,1} = \bar{p}$. The advantage of the tested generation 1 and the descendants of the types ℓ^1 is greatest because $q_{1,\kappa}$ is minimal. Bertrand competition ensures that the surplus of these groups is maximized.

What about the offspring of the types h^1? They are worse off than under under pooling because $p(b^t|h^1) > \bar{p},\ t = 2, 3, \ldots$. Note that $p(b^t|h^1)$ is decreasing in t. Generation $(t + 1)$ gets a lower quote than generation t because the information about them from their ancestor is less precise. Accordingly, daughters of tested h-mothers suffer more than granddaughters and so on if genetic tests become available.

4. Conclusions

The purpose of this paper is to analyze inter-temporal screening through genetic tests. We show that generation one is bribed to take the test with an unconditional quote. The insurer then uses this information to profitably screen a finite number of generations of their offspring. The offspring of good-gene carriers subsidize the tested generation. Yet they are still better off than under unconditional pooling. The offspring of bad-gene carriers lose compared to pooling because they have to pay a price reflecting their higher than average risk of developing the disease.

In this paper we abstract from many important aspects of genetic tests in health insurance markets. We assume that only insurers can take the test. The test results and the insurance rates are non-verifiable so that the information cannot be

passed on to other insurers. The testing insurance company thus has a monopoly on the information, which it can exploit over time. Agents cannot take the test themselves so that we do not run into the problems of strategic revelation of the results.[14] Moreover, the assumption of compulsory complete insurance rules out further screening possibilities of the insurers. Finally, since we discuss generations, the time dimension will be measured in terms of decades. Technological advances will likely occur over this kind of epoch of time which may render the informational advantage of the test obsolete.

The assumption that agents are non-altruistic is, on the other hand, not critical; all we need is that they care about their own more than the well-being of their offspring. To be more precise, if a mother takes the test, she reduces her offspring's ex ante expected utility by exposing them to premium risk. This reduces an altruistic mother's utility. Yet she gains directly from her reduced premium. As long as the gain from the lower premium is higher than the loss she experiences from making her offspring worse off, our results continue to hold.

The cost of the test may also be positive. As long as the test cost is below the profits made on the screened generations, our results still hold qualitatively. Only when the test cost exceeds these profits, does inter-temporal screening not pay.

We hope that despite these simplifying assumptions we shed some light on how inter-temporal screening with genetic tests might work. We are able to identify the winners and the losers compared to the unconditional pooling situation. We highlight the assumptions necessary to support inter-temporal screening. If, e.g., test results and insurance rates are verifiable and given to the consumer, the process as described no longer works: Daughters of good-gene carriers have proof of their low probability of becoming sick and competition ensures that they get a fair rate. Thus, if one wants to rule out inter-temporal screening, it suffices to give agents this information in a verifiable way. This might be another argument to give agents access to their health records.

[14] Agents may also wish to take the test because they are concerned about their health and optimal treatment; see, e.g., Doherty and Posey (1998).

Appendix

In this Appendix we repeat the example scattered over the text in more detail. We assume the following primitives: $f(\ell) = 3/4$, $\phi_{\ell\ell} = 8/9$, $\phi_{hh} = 2/3$, $\ell = 1/4$, and $h = 1/2$; all other values follow from these primitives.

Agents are either of type ℓ or type h. This gives us immediately $f(h) = 1/4$, $\phi_{h\ell} = 1/9$, and $\phi_{\ell h} = 1/3$.

The average probability of developing the disease in each generation is

$$\bar{p} = \ell f(\ell) + h f(h) = 5/16.$$

The probability that a daughter develops the disease given her mother was of type ℓ is

$$p(b^2|\ell^1) = \ell\phi_{\ell\ell} + h\phi_{h\ell} = 5/18;$$

if the mother was of type h, we compute

$$p(b^2|h^1) = \ell\phi_{\ell h} + h\phi_{hh} = 5/12.$$

The probability that a granddaughter develops the disease given her grandmother was of type ℓ is

$$\begin{aligned} p(b^3|\ell^1) &= \ell[\phi_{\ell\ell}\phi_{\ell\ell} + \phi_{\ell h}\phi_{h\ell}] + \\ &\quad h[\phi_{h\ell}\phi_{\ell\ell} + \phi_{hh}\phi_{h\ell}] = 95/325; \end{aligned}$$

if the mother was of type h, we get

$$\begin{aligned} p(b^3|h^1) &= \ell[\phi_{\ell\ell}\phi_{\ell h} + \phi_{\ell h}\phi_{hh}] + \\ &\quad h[\phi_{h\ell}\phi_{\ell h} + \phi_{hh}\phi_{hh}] = 10/27. \end{aligned}$$

Finally, the probability that a grand-granddaughter develops the disease given her grand-grandmother was of type ℓ is

$$\begin{aligned} p(b^4|\ell^1) &= \ell[\phi_{\ell\ell}\phi_{\ell\ell}\phi_{\ell\ell} + \phi_{\ell h}\phi_{h\ell}\phi_{\ell\ell} + \\ &\quad \phi_{\ell\ell}\phi_{\ell h}\phi_{h\ell} + \phi_{\ell h}\phi_{hh}\phi_{h\ell}] + \\ &\quad h[\phi_{h\ell}\phi_{\ell\ell}\phi_{\ell\ell} + \phi_{hh}\phi_{h\ell}\phi_{\ell\ell} + \\ &\quad \phi_{h\ell}\phi_{\ell h}\phi_{h\ell} + \phi_{hh}\phi_{hh}\phi_{h\ell}] = 220/729. \end{aligned}$$

References

Andersson Frederik. 2001. "Adverse Selection and Bilateral Asymmetric Information." *Journal of Economics* 74: 173-195.

Becker, Gary and Nigel Tomes. 1979. "An Equilibrium Theory of Income and Intergenerational Mobility." *Journal of Political Economy* 87: 1153-1189.

D'Arcey, Stephen and Neil Doherty. 1990. "Adverse Selection, private Information, and Lowballing in Insurance Markets." *Journal of Business* 63: 145-164.

Doherty, Neil and Paul Thistle. 1996. "Adverse Selection with Endogenous Information in Insurance Markets." *Journal of Public Economics* 63: 83-102.

Doherty, Neil and Lisa Posey. 1998. "On the Value of a Checkup: Adverse Selection, Moral Hazard and the Value of Information." *Journal of Risk and Insurance* 65: 189-211.

Emons, Winand. 2001. "Imperfect Tests and Natural Insurance Monopolies." *Journal of Industrial Economics* 49: 247-268.

Gutiérrez, Christina and Angus Macdonald. 2002. "Huntington's Disease and Insurance." www.ma.hw.ac.uk/ angus/papers/hd3a.pdf

Hoel, Michael and Tor Iverson. 2002. "Genetic Testing when there is a Mix of Compulsory and Voluntary Health Insurance." *Journal of Health Economics* 21: 253-270.

Hoel, Michael, Iverson, Tor, Nilssen Tore, and Jon Vislie. 2006. "Genetic Testing in competitive insurance Markets with repulsion from Chance." *Journal of Health Economics* 25: 847-860.

Hoy, Michael. 1982. "Categorizing Risks in the Insurance Industry." *Quarterly Journal of Economics* 97: 321-336.

Hoy, Michael, Fabienne Orsi, François Eisinger, and Jean Paul Moatti. 2003. "The Impact of Genetic Testing on Health Care Insurance." *The Geneva Papers on Risk and Insurance* 28: 203-221.

Kunreuther, Howard and Mark Pauly. 1985. "Market Equilibrium with private Knowledge: An Insurance Example." *Journal of Public Economics* 26: 269-288.

Neil Manson and Gregory Conko. 2007. "Genetic Testing and Insurance: Why the fear of "Genetic Discrimination Does not Justify Rgulation."
cei.org/pdf/5855.pdf

Nilssen, Tore. 2000. "Consumer Lock-in with Asymmetric Information." *International Journal of Industrial Organization* 18: 641-666.

Rothschild, Michael and Joseph Stiglitz. 1976. "Equilibrium in Competitive Insurance Markets: An Essay on the Economics of Imperfect Information." *Quarterly Journal of Economics* 90: 630-649.

Strohmenger Rainer and Achim Wambach. 2000. "Adverse Selection and Categorical Discrimination in the Health Insurance Markets: the Effects of Genetic Tests." *Journal of Health Economics* 19: 197-218.
Tabarrok, Alexander. 1994. "Genetic Testing: An Economic and Contractarian Analysis." *Journal of Health Economics* 13: 75-91.