Mutual Risk Sharing and FinTech:
The Case of Xiang Hu Bao

Hanming Fang, Xiao Qin, Wenfeng Wu, and Tong Yu[1]

January 2021

[1]Fang is from Department of Economics, University of Pennsylvania. Qin is from Antai College of Economics and Management, Shanghai Jiao Tong University. Wu is from Antai College of Economics and Management, Shanghai Jiao Tong University. Yu is from Carl H. Lindner College of Business, University of Cincinnati. Email addresses: hanming.fang@econ.upenn.edu; miniqin@sjtu.edu.cn, wfwu@sjtu.edu.cn, tong.yu@uc.edu. We are grateful for the comments and suggestions from Ruo Jia and the seminar participants of Ant Group, Modern Risk Society, technical support from Yan Zou and the Experiment & Data Center of Antai College of Economics and Management at Shanghai Jiao Tong University, and research assistance from Xin Li and Hang Su. All errors are our own.

Mutual Risk Sharing and FinTech: The Case of Xiang Hu Bao

Abstract

Literally meaning "mutual protection", Xiang Hu Bao (*XHB*) is a novel online platform operated by Alibaba's Ant Financial to facilitate mutual risk sharing of critical illness exposures among participants. It leverages the tech giant's platform and digital technology to lower the cost of participants enrollment and claim processing. Different from insurance applying sophisticated actuarial pricing models, *XHB* collects no premiums *ex ante* from its members instead equally allocates indemnities and administrative costs among participants *ex post* after each claims period. *XHB* also restricts coverage amount, particularly for older participants. We use a simple theoretical model to show that the third feature of *XHB* can lead to separating equilibrium, a la Rothschild-Stiglitz, where low-risk individuals enroll in *XHB* while more sophisticated high-risk individuals purchase critical illness insurance. Proprietary data from *XHB* shows that the prevalence rate of the covered illness among *XHB* members is indeed far below that of comparable critical illness insurance across different age groups. Our findings further suggest the role of advantageous selection in explaining the cost advantages of the FinTech-based mutual protection programs.

Keywords: Risk sharing; Mutual protection; Critical illness risk; FinTech

1 Introduction

The insurance business largely builds on the idea of the "law of large numbers" – when a large number of losses are pooled together, the uncertainty in average losses diminishes. Maintaining a high level of transparency and a low level of product market friction helps to attract participants and lower insurance prices. This, however, contrasts the reality. Joskow (1973), an influential work on the insurance industry almost half a century ago, characterizes the insurance industry as "the combination of state regulation, cartel pricing, and other legal peculiarities has resulted in the use of an inefficient sales technique, supply shortage, and overcapitalization." Despite the enormous changes in the financial market, little progress has been made in insurance since then. Schwarcz (2014) describes insurance regulations to be "transparently opaque", and echoing this view, Zanjani (2002), Koijen and Yogo (2015) and Koijen and Yogo (2016) present evidence on frictions in the insurance market. Data from National Association of Insurance Commissioner (NAIC) between 1990 and 2015 shows that insurers' operating expenses account for one third of insurance premiums charged by U.S. insurance companies. Roughly speaking, to cover the insurer's operating expenses, a dollar claim payment comes with an additional charge of 50 cents.

Dubbed as the *mutuality principle* or the Borch's theorem, Borch (1962) applies Arrow (1953)'s general equilibrium framework to characterize optimal risk sharing in the insurance market: in a frictionless market with an open access to participants, idiosyncratic risks do not matter to participants since such risks will be washed away among participants. What matters to participants is the uncertainty in market risk of the insurance portfolio and it is allocated among participants based on risk aversions. Consistent with the Litner-Sharpe capital asset pricing model, the mutuality principle is considered as a cornerstone of insurance economics. However its practical implication is quite limited due to the presence of market frictions. Marshall (1974) suggests that the traditional insurance paradigm differ from Borch's risk sharing idea that all agents (both individuals and institutions) act independently to form a pool to "insure" each other; insurance companies rather play a central role in the game – they pool risks from insurance buyers and insurance premiums are set to maximize their value (see e.g., Zanjani, 2002).

The remarkable progress in information technologies, including big data, blockchain and artificial intelligence in the past decade, can potentially present new venues of risk sharing and reshape risk management practices (OECD 2017). Like peer-to-peer lending facilities that offer online platforms to connect potential un- or under-financed borrowers to lenders, emerging FinTech platforms can take advantage of the new technologies to reach traditionally un-insured customers. This is exemplified by Xiang Hu Bao (*XHB*), an online mutual protection (also called "mutual aid") platform, sponsored by the Chinese FinTech giant Ant Financial. Launched in late 2018, *XHB* provides indemnity payments to members who are verified to have one of the 100 types of covered critical illnesses, such as thyroid cancer, breast cancer, lung cancer, critical brain injury, among others. Individuals between 30 days and 59 years of age who meet basic health and risk criteria are eligible to become members of *XHB*. The program has been spectacularly successful – by December 2019, only one year after its inception, *XHB* already had nearly 100 million members, a number that is comparable to the total number of policyholders holding critical illness insurance policies in China.

Participants, under *XHB*, are required to be responsible for equal shares of aggregate claim costs plus a small administrative fee covering operating costs. In return, they are eligible to receive a fixed indemnity (CNY300,000 for participants under 40 years old and CNY100,000 for participants of 40 years and older) once diagnosed (and confirmed) with a covered critical illness. *XHB* and a typical critical illness insurance are identical in terms of their claim payments but differ in pricing – *XHB* participants are additionally exposed to a pricing risk which is not in existence to insurance. For this concern, holding a constant indemnity, *XHB* (and any other similar mutual protection programs) shall charge a lower price than insurance. This is the first prediction from our theoretical setup and is consistent with the practice that *XHB* premium is far below the premium of critical illness insurance. *XHB* charges between CNY3 and CNY4 for a coverage of over 100 illnesses in a biweekly horizon. To make a fair comparison, we estimate the participation cost of "insurance" using the standard critical illness table published by the China Association of Actuaries (CAA) in 2020. The estimated "premium" is CNY12 for merely 6 leading critical illnesses and the cost increases to CNY15 for the coverage for 25 critical illnesses.

An important concern coming from the flat-premium arrangement is a potential high level of participation of high-risk individuals, i.e., the so-called adverse selection problem addressed by Rothschild and Stiglitz (1976). We show that this adverse selection incentive is substantially weakened under an incomplete coverage. The indemnity from *XHB* is below the typical medical costs to treat critical illness. As well, it is lower than the indemnity offered by conventional critical illness insurance. We demonstrate the existence of a separating equilibrium that low-risk individuals choose *XHB* while high-risk individuals purchase insurance. Supportive to this prediction, we find that younger people, who are healthier, are more likely to join *XHB* than older people – roughly 15% of the population between 20 and 39 years old joins *XHB* while the participation rate for people above 40 years old is 5%. The average incidence rate of *XHB* is far below that of critical illness insurance. Studying the incidence rates of the 50-59 group of *XHB* participants, we find that *XHB*'s average critical illness incidence rate of this age group is far below that of the *CAA* published incidence rate. The difference in incidence rates between *XHB* and the published rate is greater among the middle-age group (people between 40 and 59 years old) than that of the young participants below 40 years old.

The strength of the *XHB* comes from risk sharing of a large pool, which washes away idiosyncratic risks. Without a systemic shock leading to higher individual incidence rates in all ages, the *XHB* could operate smoothly. Critical illness insurance, on the other hand, typically charging a higher premium, determined ex-ante, than *XHB*'s participation costs, has an advantage in classifying risks and it often cedes risks to reinsurance companies. Insurance is more proficient in operating in sophisticated and less predictable risk exposures. This is consistent with the separating equilibrium idea – low risk individuals join mutual protection while high risk individuals buy insurance. In fact, the analysis using mutual protection product survey confirms this assertion – people with health insurance actually are less likely to participate in mutual aid programs. Catering a different consumer group, mutual protection is supplementary to commercial insurance products.

Moreover, *XHB*'s association with Alipay, an online payment giant in China, offers it a huge information advantage. First, *XHB* enrollment is conducted online. To be eligible to get enrolled in *XHB*, one (or her/his immediate family member) must be an Alipay account member meeting a credit score requirement. The requirements on credit scores and that all *XHB* subscribers are internet users make *XHB* subscribers healthier. In addition, as a side benefit the incentive to stay with Alipay lowers users' propensity to engage in fraudulent activities. Second, *XHB* adopts an artificial intelligence (*AI*) based platform for claim handling and decisions that greatly optimizes, and as a result reduces, human involvement in the process. This platform not only helps *XHB* to cut its labor costs, but also makes the claim processing more standardized and objective. It contributes significantly to the system's low operational costs (reflected in it 8% administrative cost charge, far below that of insurance firms). Finally, the effectiveness of *XHB* also comes from its interesting public notification and appeal panel systems – all the critical illness claims confirmed by *XHB* professionals must be publicly announced among participants; as detailed in Section 2, disputes may lead to dismissal of a claim.

In a related insightful study, Carbrales, Calvo-Armengol, and Jackson (2003) examine a primitive mutual risk sharing program, namely "La Crema", meaning mutual farm insurance, which apply a special way to determine how much a household is reimbursed in the case of a fire and how payments are apportioned among other households – solely relying on households' announced property value. They conclude that as the size of the society becomes large, the benefit from deviating from truthful reporting vanish, resulting in equilibria of the mechanism nearly truthful and approximately Pareto efficient. Carbrales et al. (2003) highlight two key features of mutual farm insurance: i) severe penalty in case a member commits fraud and ii) the arrangement being made in tightly knot society; given that each household is insured by its neighbors, the neighbors have an incentive to monitor the behavior of a given household. In contrast, *XHB* does little in punishing bad behavior (such as frauds) and members are not tightly connected with each other. *XHB*'s use of FinTech and the involvement of the appeal panel system serve important roles to deter frauds and achieve a relatively high efficiency in claim processing.

Finally, we use survey data on mutual protection participants conducted by Ant Financial in 2019 to shed further light on the motives of mutual risk sharing program participants. Using logistic regressions, we find that people from more economically developed regions are more likely to participate in the mutual aid programs and that younger people are more willing to enroll in mutual protection programs than older people do. The evidence also suggests that high-incomers are more willing to participate in the programs than low-incomers do. These findings are in line with the positive role of advantageous selection in health risk management (Fang, Keane, and Silverman, 2008).

The remainder of the paper is structured as follows. Section 2 offers the institutional background of *XHB*. Then in Section 3, we present a simple model to contrast mutual protection against critical illness insurance. Sections 4 and 5 introduce data and discuss empirical findings. We conclude in Section 6.

2 Institutional Background

2.1 Xiang Hu Bao

Xiang Hu Bao was initially launched as a peer-to-peer insurance by Ant Financial, partnering with Trust Mutual Life, in October 2018.[1] Trust Mutual Life quit a month later to make *XHB* a pure online mutual aid program. *XHB* hosts two programs: the critical illness program (*CIP*) for young and middle-aged participants between 30 days and 59 years and the senior program (*SP*) for senior participants 60 to 70 years old. Accordingly, participants of *CIP* stay in a pool where sick members receive CNY300,000 and CNY100,000 (or a reduced amount under a prorated participation cost) depending on their ages (detailed below) whereas senior participants stay in another pool and receive CNY10,000 once confirmed to have a critical malignant tumor.[2]

Table 1 describes the coverage of *XHB* at different stages. In its first version ("V1") effective from October 2018 to April 2019, it covers 99 critical illnesses and critical malignant tumors. The indemnity for a young and middle-aged participant diagnosed with critically ill is CNY300,000 (USD43,000) and the indemnity is reduced to CNY100,000 for an ill participant at or above 40 years. In the second version ("V2"), *XHB* reclassifies two severe critical illnesses to mild critical illnesses with indemnity of CNY100,000 and CNY50,000, respectively for young and middle-aged participants. Next, in the third version ("V3") starting in January 2020 and ending in May 2020, *XHB* additionally covers 5 rare illnesses while it stops mild illness coverage. Finally, the most recent version ("V4") *XHB* additionally offers reduced indemnities for critical illnesses – CNY100,000 for participants below 40 years and CNY50,000 for participants 40 years and older. The participation costs for these participants are charged on a proportional basis.

Figure 1 introduces the procedures of *XHB*'s enrollment and claims. Shown in Panel A, the first step to participate in *XHB* is to file an application with the authentic identity. To enter a

[1] Presumably an insurance product, the initial version of *XHB* committed a ceiling of CNY188 on the member payments in a year. Such a premium guarantee becomes a verbal consent after the insurance partner left *XHB*.

[2] *XHB* is not the only mutual protection product in China, but it is the biggest. Other mutual protection programs include Water Drop Mutual, Meituan Mutual, and Qingsong Mutual, among others.

90-day waiting period, the applicant needs to commit that he/she has a clean history of severe critical illness on *XHB* illness list (See Appendix A1).[3] An additional requirement is that one must have an account with Alipay and maintain a reasonably high credit score (with a minimum 600 points out of the maximum of 800 points). If a participant is diagnosed with a critical illness in a 90-day probation period, the trial membership would be terminated and paid subscription will be refunded.

In Panel B of Figure 1, we describe *XHB*'s claim process. When a participant submits a critical illness claim request, supporting evidence must be submitted via the Alipay application. In order to prevent from potential frauds, *XHB* applies the proprietary consortium blockchain technology, which ensures the process is tamper-proof. After *XHB* receives a claim application, it perform a preliminary review, followed by face-to-face visits to the applicant and field investigation on the medical experiences by professionals. After the investigations are completed, the case is notified to the public on 7th and 21st of each month (i.e., announcement day). If there is no dispute on the results, after 3-day public notification, the payment will be shared among all *XHB* participants on the 14th and 28th of each month (i.e., payment day). The payment will be made to the claimant within seven days after the payment day.

In the full sample period, 1,164 claims (i.e., 2,328 per month) on average are paid in each payment period. As *XHB* experienced an explosive growth in the first half year of its inception and it has a waiting period, the number of claims in the beginning was low. For this purpose, we exclude data in the early stage of *XHB* from 201901#1 to 201909#1. After the second period in September 2019, on average 1,915 claims (3,830 per month) are paid in each period.

In case that an applicant disagrees with the *XHB* claim result, he/she can request a second

[3]Specifically, *XHB* requires no more than 30 days of continuous medication and no more than 15 days of hospitalization within 2 recent years, no current treatment in hospital, no previous or present disease or symptom like malignant tumors, carcinoma in situ and etc.

review by a panel of qualified *XHB* members.[4] There are altogether 6 disputed cases from Oct. 2018 to Sep. 2020, indicating that second investigation is a rare phenomenon and the false rejection rate of the claim settlement is quite low.

As long as claims are approved, the participant will receive a one-time lump-sum payout. In Figure 1, we show how *XHB* works. On 7th and 21st of each month, Ant Financial publically announces names and background information for patients meeting payment requirements. Disputed claims are escalated to an online review board that consists of qualified volunteer participants. Claim payments made by *XHB* plus an 8% markup are equally distributed to participants.

2.2 Critical Illness Insurance

The first critical illness insurance policy was launched on October 6, 1983 in South Africa under the name "Dread Illness Insurance". The original form of critical illness insurance covered four primary human health conditions: cancer, stroke, heart attack, and coronary bypass surgery. The coverage was accepted into many insurance markets around the world and started in China in 1995. Different from *XHB* offering a short-term (bi-weekly) coverage, critical illness coverages are offered for a much longer horizon, e.g., one year or multiple years, known as term critical illness policies and even whole-life critical illness policies.[5] In 2019, critical illness insurance covers around 100 million people, in a comparable size to the *XHB* participants. The same set of illnesses are covered under critical illness insurance and *XHB*.

Like *XHB* but different from commercial medical insurance offering reimbursement to actual medical costs up to a certain limit, critical illness insurance offers lump-sum indemnities to claimants. While covered illnesses for critical illness insurance and mutual protection programs are comparable, critical illness insurance offers more options and better coverages than those of

[4]Only an *XHB* member, after 30 days since the first enrollment and the completion of a qualification test, is eligible to serve as a panel member. The procedure is as follows: Ant Shengxin (a third-party network platform of Alipay Financial Services Group releases controversial cases in advance. After the formal procedure of the panel starts, Ant Shengxin invites the panel members randomly, based on the numbers of controversial cases. The panel members who have received the invitation need to vote in 24 hours. The result is only valid if 1000 or more valid votes are collected. The applicant can get payment if supported by 50% or more panel members. For example, if 100,000 panel members participate in a certain case, a favorable decision is reached in case that the applicant gets at least 50001 supportive votes and the applicant will be paid; Otherwise, the result would be a denial and the applicant cannot receive any compensation.

[5]In China, term policies are often available for institutional purchasers and individuals purchase whole-life critical illness policies.

XHB and other mutual aid products. As such, mutual aid products are viewed to be supplement to insurance.

Different from *XHB* offering one-time payment to each participant diagnosed with critical illness, critical illness insurance often allows multiple payments – it breaks down critical illnesses into several categories and buyers will receive one claim payment for each category.

The costs to participate in *XHB* and critical illness insurance are strikingly different – critical illness insurance is priced much higher than *XHB*. For example, the annual premium of a whole-life critical illness insurance is could exceed CNY5,000 for a 35-year female, comparing with roughly CNY100 for *XHB*.[6] To make a fair comparison with insurance, we estimate the participation cost of "insurance" using the standard critical illness table published by the IC Table published by the China Association of Actuaries in 2020 (detailed in the Data section) and use the population distribution published by China Statistics Bureau to model the participants' distribution – the estimated "premium" is CNY12 for merely 6 leading critical illnesses and the cost increases CNY15 for the coverage for 25 critical illnesses. This suggests the critical illness incidence rate for *XHB* is much lower than that of a comparable insurance product.

A prominent difference between insurance and *XHB* is that insurance premiums are charged ex-ante while participation costs of *XHB* is charged ex-post. A clear benefit of an ex-ante arrangement is the deterministic premium. However, insurance is required to set reserve for uncertainty future losses. Such reserve is costly (cites) and naturally inflates insurance costs. It becomes increasingly costly when insurers stay at the central stage in the price setting game. On the flipping side, *XHB* is a platform for participants cross insure each others. As there is no role of the central player, insurance firms, in the platform, participants face uncertainties. The uncertainty would be manageable when future claim costs are expected to be stable.

3 Simple Model

The model starts from a comparison of *XHB* and critical illness insurance – as the participation cost of the mutual protection program is charged ex post, there is a potential pricing discount for *XHB*. We then show that the coverage gap between the indemnity and the loss helps to lower high-risk

[6] We note that the coverage under critical illness insurance is much more comprehensive than *XHB*.

individuals' participation. Finally, we demonstrate that, when insurance offers a better coverage than mutual protection, there is a potential separating equilibrium that high-risk individuals buy insurance while low-risk individuals participate in the mutual protection program. As *XHB* offers lower coverage to old participants, high risk individuals are more likely to buy critical illness insurance among old people than in young people.

3.1 Pricing Discount of Mutual Protection

Individual s belongs to age group i therefore she is eligible for the critical illness program for the i-th age group. The incidence rate for the i-th group at time t is p_{it}.

$$p_{it} = p_i + u_{it} \tag{1}$$

p_i is the expected value of the ith group's incidence rate and u_{it} is a random error with a mean 0 and the standard deviation of σ_i.

To join or to continue to stay in the pool, the individual pays a participation cost or a premium, π_t^1 (the superscript "1" denotes mutual protection), in exchange for a fixed indemnity, k, once he is diagnosed with a critically illness.

$$\pi_{it}^1 = p_{it} k (1 + \lambda_1) \tag{2}$$

where λ_1 is the pool's expense rate.

As an important feature of mutual protection programs, the participation cost to be with the pool is uncertain. This is highlighted in Eq. (2) – p_{it} is stochastic and it is shared by participants in pool i. Consider that individual s is risk averse and has a risk aversion of A_s. She has an endowed wealth stream of $w_{s,t}$ at time t and $w_{s,t+1}$ at time $t+1$. Participating in the pool subjects the agent to two sources of uncertainties: i) pricing uncertain and ii) whether the agent could be affected by a critical illness in the subsequent period. Denote the subsequent incidence rate for agent s is $p_{s,t+1}$ and the loss amount is o, his expected utility to join the pool i can be written as below:

$$E[u^1(w_{st}, w_{s,t+1})] = \underbrace{E[u(w_{st} - \pi_{it}^1)]}_{EU_t} + \underbrace{\beta[(1 - p_{s,t+1})u(w_{s,t+1}) + p_{st} u(w_{s,t+1} - o + k)]}_{EU_{t+1}} \tag{3}$$

In Eq. (3), β is a discount factor on the expected utility of the wealth at $t+1$. For a typical mutual protection product like *XHB*, β is close to 1 given a short interval between t and $t+1$. Also, for simplicity, we assume the same utility function is applicable to the wealth at t and $t+1$.

Next, consider the agent s buys insurance that sets a deterministic premium. For simplicity, we assume the insurer knows the expected incidence rate of the i-th group, and the insurance policy offers an identical coverage k to the mutual protection of age group i. Using "2" to denote insurance, we express the insurance premium to age group i as

$$\pi_{it}^2 = p_i k(1+\lambda_2) \tag{4}$$

where λ_2 is the expense rate of insurance.

The individual's expected utility after purchasing insurance is

$$E[u^2(w_{st}, w_{s,t+1})] = u(w_{st} - \pi_{it}^2) + E[\beta[(1-p_{s,t+1})u(w_{s,t+1}) + p_{st}u(w_{s,t+1} - o + k)] \tag{5}$$

Taking the difference between expected utilities of joining mutual protection program and purchasing insurance, the expected utility associated with wealth at $t+1$ cancels out. Therefore, we have

$$\Delta Eu = E[u^1(w_{st}, w_{s,t+1})] - E[u^2(w_{st}, w_{s,t+1})] = E[u(w_{st} - \pi_{it}^1)] - u(w_{st} - \pi_{it}^2) \tag{6}$$

Applying the Arrow-Pratt approximation, we express the expected utility of the mutual protection participant from his wealth at t as below:

$$E[u(w_{st} - \pi_{it}^1)] = u[v_{st}^1 - \Pi_s^i] \tag{7}$$

where $v_{st}^1 = w_{st} - p_i k(1+\lambda_1)$ and $\Pi_s^i = 1/2A_s[k(1+\lambda_1)]^2\sigma_i^2$.

Π_s^i is the risk premium to compensate the extra pricing risk taken by individual s when participating in the mutual protection pool i.

Setting $v_{st}^2 = w_{st} - p_i k(1+\lambda_2)$, we simplify the difference as,

$$\Delta Eu = u[v_{st}^1 - \Pi_s^i] - u(v_{st}^2) \tag{8}$$

In equilibrium, the expected utility from participating in the mutual protection program at time t equates the expected utility from insurance purchase, $\Delta Eu = 0$.

Equivalently, we have $\Delta v = k * p_i * (\lambda_2 - \lambda_1) - \Pi_s^i = 0$. That is,

$$E(\pi_{it}^1) = \pi_i^2 - \Pi_s^i \tag{9}$$

This results in an important condition for relative pricing of mutual protection programs and insurance.

Proposition 1 (Mutual Protection Pricing Discount) *Due to the pricing uncertainty of mutual protection,* XHB *is expected to charge a lower price than insurance:* $E(\pi_{it}^1) = \pi_i^2 - \Pi_s^i$.

The proposition implies that $\lambda_1 - \lambda_2 < 0$ – in equilibrium, the expense rate of mutual protection is lower than that of insurance.

Given $\Pi_s^i = 1/2 A_s[k(1+\lambda_1)]^2\sigma_i^2$, the price discount of *XHB* is determined by i) individuals' risk aversion, ii) the magnitude of administrative cost rate, and iii) variance of the group's incidence rate. Putting differently, the discount would be lower when the participants' risk aversion is lower, administrative cost is lower, and when the group's incidence rate is more predictable. This is explored in the next subsection.

3.2 Coverage Gap and Incentive to Participate

A prominent feature of *XHB* (and other mutual protection programs) is the coverage gap between the critical illness medical cost and the indemnity. Specified in Eq. (3), we denote an individual's expected utility to stay with the mutual protection program as $Eu^1(w_{st}, w_{st+1})$.

Now consider the case that an individual neither participates in *MP* nor purchases insurance. Denoting the case as "0", we express the individual's expected utility as:

$$E[u^0] = u(w_{st}) + \beta[(1 - p_{st})u(w_{s,t+1}) + p_{st}u(w_{s,t+1} - o)] \tag{10}$$

The utility gain from participating in *MP* can be specified as the difference in expected utilities between an *MP* participant and a non-participant.

$$\begin{aligned} \Delta Eu &= E[u^1] - E[u^0] \\ &= E[u(w_{st} - \pi_t^1)] - u(w_{st}) + \beta[p_{st}u(w_{s,t+1} - o + k) - p_{st}u(w_{s,t+1} - o)] \end{aligned} \tag{11}$$

The first order condition of ΔEu with respect to p_{st}, the individual's *actual* incidence rate (the effect of incidence rates on participation utility gain) is stated below:

$$\frac{\partial \Delta Eu}{\partial p_{st}} = \beta u(w_{s,t+1} - o + k) - u(w_{s,t+1} - o) \tag{12}$$

Eq. (12) states that the effect p_{st} on the additional expected utility coming from participating in the *MP* program is determined by $u(w_{s,t+1} - o + k) - u(w_{s,t+1} - o)$, the difference of time $t+1$ utility with an indemnity and without it, which is always positive. Under this condition, riskier individuals are more likely to participate in *MP*. This point is further elaborated in Figure 2 which shows that an individual's wealth in the no-loss state (W_1) and the loss state (W_2). In the graph, E represents an individual's payoffs in two wealth states without participating in *MP* while X represents the payoff combinations when the individual joins *MP*. Using the coordinates of E and X provided in Table 2, we specify the slope of the budget line as below:

$$\frac{\Delta W_2}{\Delta W_1} = \frac{E(\pi_1 - k)}{E(\pi_1)} = 1 - \frac{1}{E[p_i(1+\lambda_1)} \tag{13}$$

The budget line has a negative slope given the expected incidence rate is (far) below 1. Figure 2 plots indifference curves of two individuals: the high p_{st} individual has a flatter indifference curve than the low p_{st} individual does, following the idea that the high p_{st} individual is more willing to sacrifice wealth in the no-loss state to exchange for a unit increase of wealth in the loss state. Figure 2 shows that at X the high p_{st} individual achieve more utility gains than a low p_{st} individual does.

Next, we look at how the coverage gap between the loss and the indemnity ($g = o - k$) affects high illness group agents' incentives.

$$\frac{\partial^2 \Delta Eu}{\partial p_{st} \partial g} = -\beta u'(w_{s,t+1} - g) < 0 \tag{14}$$

It states that, the effect of coverage gap on participation incentive is inversely related to the individual's marginal utility at $t+1$. Under Eq. (14), a greater coverage gap, g, lowers the incentives of high risk individuals to join *MP*.

Consider a different point, *X'* on the budget line. As shown in Figure 2, *X'* stays below X; *X'* lets the the high risk individual reach a lower utility level than X does.

Proposition 2 (Participant Incentives and Coverage Gap) *While high risk agents are more likely to participant in* XHB*, coverage gap lowers such incentives.*

It is worth noting that participants 40 years old above receive lower indemnity from *XHB* than those below 40 years old while all participants pays the same participation cost as the latter group. This results in a lower coverage but higher participation cost for the high risk individuals, making *MP* less attractive to high risk old individuals than it does to young individuals.

3.3 Choice between Mutual Protection and Insurance

Now we consider the case that mutual protection and insurance offer different indemnities. We derive conditions for an agent's optimal choice in these two options: i) joining a mutual protection program offering a low protection, k_1, and ii) insurance offering a high protection, k_2. Accordingly, the premiums for mutual protection and insurance, π_t^1 and π_t^2, are

$$\pi_t^1 = p_t(1+\lambda_1)k_1,\ \pi_t^2 = p(1+\lambda_2)k_2 \tag{15}$$

$\lambda_1 < \lambda_2$ and $k_1 < k_2$. p_t is time varying and p is a constant. For simplicity, we no longer include the pool identifier "i".

We express the agent's expected utility after participating the mutual protection plan (z=1) and insurance purchase (z=2) as below while the expected utility for the case of having no protection is provided in Eq. (10).

$$E[u(w_{st}^z)] = u(w_{st} - \pi_t^z) + \beta[(1 - p_{s,t+1})u(w_{s,t+1}) + p_{st}u(w_{s,t+1} - o + k_z)] \tag{16}$$

where k_1 and k_2 are indemnities offered by MP and critical illness insurance.

Figure 3 the three cases in the wealth space. The slope of insurance budget line is

$$\frac{\Delta W_2}{\Delta W_1} = \frac{\pi_2 - k}{\pi_2} = 1 - \frac{k}{\pi_2} \tag{17}$$

Following Proposition 1 that $\pi_2 > E(\pi_1)$, we expect the insurance budget line is less steep than the budget line of mutual protection. This is shown in Figure 3. There exists an I driving a Rothschild and Stiglitz (1976) type of separating equilibrium for agents' choices. Individuals with high risk (private information) choose I and individuals with low risk choose X.

Proposition 3 (Choice between Mutual Protection versus Insurance) *Given different coverages of mutual protection and insurance, individuals with high risk (private information) choose* I *and individuals with low risk choose* X.

Noted earlier, the coverage for old individuals is lower than that of young individuals, we expect the separation effect to be greater among old participants. This results in the final proposition stated below.

Proposition 4 (Mutual Protection Participation: Young versus Old) *Old individuals are less likely to participate in* XHB *than young individual.*

4 Data

Our *XHB* data include i) aggregate enrollment per age group and ii) claims in each payment period from January 2019 to August 2020. Despite *XHB* was established in October 2018, owing to the restriction of the three-month waiting period, the first time that *XHB* announced claimant information as well as the aggregate number of enrollment in its public bulletin board, is January 28 2019, i.e., 201901#2. We accordingly begin our sample from the second payment period of January 2019 and end the sample by the end of August 2020.

Participant information includes the number of participants in each payment period and their genders. The data for *XHB* participants across six age groups, i) 0-9, ii) 10-19, iii) 20-29, iv) 30-39, v) 40-49, and vi) 50-59, comes from Alipay. Our hand-collected claim data include detailed information of each claim such as the illness name and indemnity amount as well as claimant information such as the paid participant's name and the city of residence. The data source is *XHB* the public announcement bulletin released on the 7th and 21st of each month, noted in Figure 1.

XHB claim data are collected in the following two steps. First, we take screenshots of all claim cases published on Alipay app and convert them to editable format. Second, we crawl data from these editable files, including payment time, payee's names, names of illness, identifiers for mild critical illnesses, patient age, gender, province, payment amount, among others. To ensure data quality, we identify suspicious cases that i) non-mild illness participants below 40 years old receiving CNY100,000 or CNY100,000 or 50,000 and ii) participants who are 40 years or older receiving

CNY300,000. We find there are altogether 149 such cases and correct errors. Subsequently, we collect random samples of claim data in three different payment time (202003#2, 202006#1, and 202009#1) and compare the information with initial screenshots. We remove 5 additional erroneous cases (in terms of age/payment amount) out of 5,558 cases of the randomly selected samples, which is within acceptable error rate range, and correct them accordingly.

Our data for participation and claims of critical illness insurance come from the 2020 Historical Critical Illness Incidence Rate Table (Henceforth "CI Table" in short) report published by the China Association of Actuaries (*CAA*). The table reports the incidence rates for i) the 6 leading critical illnesses and ii) the 25 leading illnesses (names of illnesses covered under both categories are provided in the Appendix). As noted in China Actuary Association Report (2013), the incidence rate is calculated based on a group of most popular critical illness insurance policies[7] The incidence rate covered in the *CI Table* is the rate paid by insurance companies – to avoid the contamination effect from the waiting period, the table excludes first-year policies issued by an insurer. In addition, though, as noted in the Background Section, critical illness insurance often allows multiple payments, only the first payment is included to construct the insurance incidence rate table.

Our analysis is supplemented by data from the survey of internet mutual production products conducted by Ant Financial in 2019. The survey is exclusively distributed to members of Alipay, Ant Financial's online payment product. The key questions are their i) participation in mutual protection platforms, ii) purchase of commercial medial insurance (including critical illness insurance), and iii) purchase of social security. Other information collected by the survey include participants's ages, gender, city tier of the residence, and their income levels. The total number of survey respondents is 58,721, including 24,117 participating in at least one type of mutual protection products, 51,128 enrolled in the social security program, 33,329 purchasing commercial health insurance. Apparently, among survey respondents, medical social security sponsored by the government has the largest coverage, followed by commercial medical insurance and mutual protection plans. Moreover, the report shows that 11,111 survey respondents participate in mutual protection but do not commercial health insurance; 20,323 survey takers purchase commercial health insurance but do not participate in any mutual protection plans; 13,006 survey participants both join mutual protection

[7]Namely "pre-paid" critical illness insurance policies. It is a mix of life and critical illness insurance. In China, 85% of critical illness insurance policies belong to this category.

plans and buy commercial health insurance. More commercial insurance buyers do not participate in mutual protections plans than the other way around.

In Table 3, we report the number of enrollments, claim payment and shared payment per capita in each period from January 2019 to August 2020. The first reported aggregate enrollment is 23,307,300 on January 28, 2019. The total amount of claim payment is CNY600,000 (awarded to 2 *XHB* members as reported in Table 4). The "premium" (membership due) charged by *XHB*, i.e., the claim cost allocated to each *XHB* member plus the 8% administrative fee, is merely CNY0.03. The table also shows that enrollments grow rapidly in 2019. At the end of 2019, the number of *XHB* participants reaches 97,942,100. After the fast growth in the first year, the enrollment to *XHB* significantly slow down in 2020, which is clearly demonstrated in Figure 4. There was a mild negative growth rate for the first time in May 2020, and occurs again in June and July 2020.

Attributed to the 3-month-waiting-period policy, *XHB*'s claim payments are extremely low in the first half year of 2019. The aggregate claim payment is CNY33 million at the end of June 2019 (i.e., 201906#2), corresponding to a bi-weekly premium of CNY0.51. It increases subsequently and then stays around CNY4 per payment period in our sample period, accumulating to an annual payment of close to CNY100. We consider the sample period from September 2019 is a "stable" claim period as the enrollment no longer grows afterwards. Our main analysis uses data of this period.

A noticeable change is that claim payments dropped significantly over the period from 202002#2 to 202004#1 when China was shut down to contain COVID-19 pandemic.

5 Results

In this section, we first investigate whether *XHB* satisfies the important condition associated with a potential diversification effect. Then we examine the potential separation across different types of participants by contrasting the incidence rates between *XHB* and critical illness insurance. Finally, we extend the analysis to individual choices in mutual protection programs and traditional insurance using the survey data from Ant Financial.

5.1 Effect of Diversification

XHB's critical illness program pools people below 40 years old and those at and above 40 years old with the same participation costs. Participants below 40 years old receive CNY300,000 while participants whose ages are 40 years and above receive CNY100,000 once confirmed to be affected critical illness – the arrangement offers relative aging people, with each group, greater incentive to participate while discouraging young people from participating in *XHB*. We address this by testing the first hypothesis to check whether pooling lowers the variance of the pool thus offering incentives to young people to mix with relative older people.

To see the diversification is indeed a concern, we express the incidence rate and model the CI incidence with a binomial distribution.

$$p_{it} = \frac{M_{it}}{N_{it}} \tag{18}$$

where M_{it} denotes the numbers of participants receiving payments in group i of period t and N_{it} denotes the number of participants in group i of period t.

Considering that M_{it} follows a binomial distribution: $p(M_{it} = m_t) = \begin{pmatrix} N_{it} \\ m_t \end{pmatrix} p_{it}^{m_t}(1-p_{it})^{(N_{it}-m_t)}$, where m_t is reported number of illness cases.

The expected value and variance of M_{it} are expressed as below:

$$E(M_{it}) = N_{it}p_{it} \ \text{ and, } \ \sigma^2(M_{it}) = N_{it}p_{it}(1 - p_{it}) \tag{19}$$

We have

$$\begin{aligned} \sigma_i^2 &= \sigma^2(p_{it}) = \sigma^2(\frac{M_{it}}{N_{it}}) \\ &= \frac{p_{it}(1 - p_{it})}{N_{it}} \end{aligned} \tag{20}$$

Following Eq. (20), σ_i increases in p_{it} when p_{it} is below 1/2, which is applicable for the incidence rate. In other words, a high incidence rate for a larger pool also applies to the variance effect. It is an empirical question whether pooling different age groups together reduces the platform's pricing uncertainty. We address this problem by breaking down *XHB* participants into six age groups (<10; 10∼19; 20∼29; 30∼39; 40∼49; and 50∼60) and evaluate the variance of incidence rates (*IR*) of the first 5 age groups and compare them with the IR variance of wider age groups (<19; 10∼29; 20∼39; 30∼49; 40∼59; and 50∼60).

Corresponding to our data, p_{it} is the incidence rate of the i-th group at time t. N_{it} and M_{it} respectively represent the number of enrollments and paid claims of the i-th group associated with the incidence rate at time t.

To closely match incidence rates between *XHB* and insurance, we define three incidence rates for *XHB* respectively for the 6 leading critical illness ($IR6^1_{i,t}$), 25 leading critical illness ($IR25^1_{i,t}$), and all critical illnesses ($IR100^1_{i,t}$, including both severe critical illnesses and non severe critical illnesses). Using the incidence rate of 6 leading illnesses, $IR6^1_{i,t}$, as an example,

$$IR6^1_{i,t} = \frac{c6_{i,t}}{e_{i,t-6}} \tag{21}$$

where $c6_{i,t}$ and $e_{i,t-6}$ are the number of paid claims of the 6 leading critical illnesses at time t and the number of enrollment at $t-6$.

The variance of an individual age group is estimated using Eq. (20).

In Table 4, we report the results of the paired analysis on the diversification effects when comparing a single age group with the combined age-group pooling arrangement. Panel A reports the results using all stable periods from 2019#2. Panel B reports the result when the COVID-19 lockdown period (202002#2-202004#1) is excluded. The variance of the large group is lower than that of the small group. For example, for the 6 leading illnesses, the reported variance of the incidence rate is 14.8% for the 30-39 age group and it is reduced to 12.8% when we mix the 30-39 and 40-49 age groups. The result holds for the 25 leading illness and all critical illnesses. The evidence suggests that combining different age groups lower the variance of the group's incidence rate.

Is it always good to add more age groups to risk pool? Figure 5 addresses this question. As we can see, the effect of diversification stops after having the 20-29 age group in the pool. Using *CI6* as an example, the average variance in the stable non-COVID periods is 13.46% for the 0-9 group, and significantly dropped to 6.23% (0-19) and 3.5% (0-29). The variance increases to 4.53% and 5.32% for the 0-49 and 0-59 groups. The same pattern holds for all illness groups and stays the same for the last payment period.

5.2 Incidence Rates: *XHB* versus Insurance

In this subsection, we analyze the incidence rates of different age group and compare them with the incidence rates of CI insurance for corresponding age groups. The results are reported in Table 5. The first column of the table reports the the total number of claims paid in each payment period (including both paid severe critical illness claims and mild critical illness claims) from January 2019 to August 2020. The first two critical illness claims were paid on on January 28th, 2019. At the end of 2019, the number of paid claims is 1,931 and it is 2,344 at the end of August 2020. In the subsequent three columns, we break down critical illness into i) severe critical illness for young participants (participants below 40 years old, denoted as "sy"), ii) severe critical illness for middle aged participants (participants at or above 40 years old, denoted as "sm"), and iii) non severe critical illness (denoted as "ns") for all eligible participants between 3-month and 59 years old and report the number of cases of each type. Table 5 clearly shows that there are more claims for the middle-aged than for the young and severe critical illness cases significantly outnumber mild critical illness cases. The total number of severe illness claims for the middled-age group in the sample period is 21,998, almost doubles the number of the below-40 group (11,902).

We subsequently report the incidence rates of i) severe critical illnesses and ii) all critical illnesses (additionally including non-severe critical illnesses) of *XHB* in each payment period. Continuing to use "1" to denote *XHB*, we have

$$IR_t^1 = \frac{c_t}{e_{t-6}} \text{ and } IR_t^{1s} = \frac{c_t^s}{e_{t-6}} \tag{22}$$

where IR_t^1 and IR_t^{1s} represent *XHB* incidence rates at time t of all critical illnesses and of severe critical illnesses respectively; c_t and c_t^s represent the numbers of paid claims at time t of all critical illnesses and of severe critical illnesses respectively; e_{t-6} denotes the trailing 3-month (6-period) aggregate enrollment.

The incidence rates for severe critical illness participants, IR_t^{1s}, and for all participants including both severe critical illness and non-severe critical illness participants, IR_t^{1s}, are reported in the last two columns of Table 5. The incidence rate is fairly low in early periods of the sample and there is a jump in the infection from the first to the second payment period in September 2019 (from 7.68 per million to 15.51 per million for incidence rates of severe critical illness, and from 9.41 per million participants to 22.51 per million participants). The incidence rate becomes stable after that, with an overall incidence rates from 22 to 25 per million participant each payment period. As reported, the number of claims and incidence rates are notably lower over the COVID lockdown period from 202002#2 to 202004#1 which is consistent with the number of payments reported in Table 3.

For comparison purpose, we also estimate an implied insurance incidence rate using *CAA* incidence rates and assume participants following a standard population distribution. Different from the incidence rate covering over 100 critical illness, the *CAA* incidence rate report only covers rates for the 6 leading critical illnesses and 25 leading critical illnesses at different ages. We therefore estimate incidence rates of 6 (25) leading illness using the 2018 population distribution published by China Statistics Bureau for participants' distribution across ages. We find the average incidence rates are 100 and 146 per million in these categories. *XHB*'s incidence rates reported here, e.g., 23.31 per million participants as of the the average of stable periods, are far below those of CI insurance.

Next, we compare the incidence rates of *XHB* with insurance within each of the different age groups. Like we did in Table 4, six age groups are created: i) below 10 years old, ii) between 10 and 19, iii) between 20 and 29, iv) between 30 and 39, v) between 40 and 49, and vi) between 50 and 59 and we compare the incidence rates of individual age groups between *XHB* and insurance.

Like we did in Table 4, we trace incidence rates of illness groups including the 6 leading critical illnesses, 25 leading critical illnesses, and all critical illnesses (covering both severe critical illnesses and non severe critical illnesses): $IR6^1_{i,t}$, $IR25^1_{i,t}$, and $IR100^1_{i,t}$.

We further estimate the incidence rate of a given age group for critical illness insurance as the weighted average of incidence rate across different ages using the population distribution. Specifically, the insurance incidence rate of the age group i, for the 6 leading critical illness ($IR6^2_i$) and 25 leading critical illness ($IR25^2_i$), is

$$IR6^2_i = \sum_{j \in i} w_j * IR6^{CAA}_j \text{ and } IR25^2_i \ = \textstyle\sum_{j \in i} w_j * IR25^{CAA}_j \tag{23}$$

where j is a specific age; i is a certain age group; w_j denotes the population weights; and $IR6^{CAA}_j$ and $IR25^{CAA}_j$ denote *CAA* incidence rates, respectively for the 6 leading critical illness and 25 leading critical illness.[8]

The results are reported in Table 6, with Panel A for the average results for all stable periods from 201909#2 to 202008#2 and Panel B for the average results for all stable periods excluding the COVID pandemic lockdown period from 202002#2 to 202004#1. Without any surprise, incidence rates, for both *XHB* and insurance, are the lowest in the 10-19 age group and the highest in the 50-59 age group. In the average results, the incidence rates are 43, 50 and 72 per million participants respectively for CI6, CI25 and CI100 in age group 10-19, while they are respectively 1,278, 1,321 and 1,465 per million participants in age group 50-59.

More importantly, the table shows a clear pattern that *XHB* participants are " healthier" than traditional CI insurance buyers – with a lower incidence rate than that reported by *CAA* in each age group. In the table, we report the ratios of *CAA* and *XHB* incidence rates (calculated in each payment period and averaged over time) which shows that combining all age groups, the incidence rate of CAA is 7.43 times of that of *XHB* for the 6 critical illnesses, and 7.79 times of that of *XHB* for the 25 critical illnesses. The result suggests that the average incidence rate is significant lower than that of insurance in every age group and every way we categorize illnesses - both CI6 and CI25. Interestingly, the incidence ratio between the CAA and *XHB* is the lowest for the youngest group (<10). Consistent result are obtained for the results excluding COVID periods, though the incidence rates become larger in all age groups after we exclude the COVID periods. One may attribute the much lower average incidence rate of *XHB* than that of *CAA* to the fact that internet users are younger than the population. While *XHB* participants are younger, the difference cannot be explained away by the age affect, considering that the incidence rate is much lower for *XHB* in every age group.

In Figure 6, we plot the enrollment distributions of *XHB* and critical illness insurance and compare them with the population distribution across ages. Inspecting the enrollment distributions, we find *XHB* is lower in the low age groups (below 20 years old) and among the participants above 39 years old. The 30-39 group having the highest participation rate. Another interesting point is that *XHB*'s enrollment rate declines significantly from the 30-39 group (33%) to the 40-49 group. This is consistent with the significant drop of indemnity from CNY 300,000 to CNY 100,000 from 39

[8] Note that the original table reports incidence rate respectively for female and male. We create a combined table based on the sex ratio in 2018 population distribution.

years old to 40 years old. A smoother transition potentially helps *XHB* to attract more participants in the 40-49 age range.

When contrasting the enrollment distributions of *XHB* and insurance, we find they share similar traits. For example, the insurance participation rate also peaks in the 30-39 years age range and it drops in the 40-49 years age range. Interestingly, the fractional enrollment *XHB* exceeds that of insurance in the 20-29 group and the 50-59 group. The lower participation cost of *XHB* makes it appealing to both young and old people who are not willing or not affordable to conventional critical illness insurance.

We show that the price of insurance is far higher than *XHB* in the early sections. Here in Figure 7, we further compare incidence rates of *XHB* and conventional critical illness insurance in different age groups. Panels A and B respectively depict the contrasts in the incidence rates between two programs for the 6 leading critical illnesses and 25 leading illnesses across different age groups. We can see that insurance incidence rates are higher in every age group than that of *XHB*. The most striking finding is that the incidence rate of insurance exceeds *XHB* most in the 50 to 59 age group. Jointly considering the relatively higher participation rates of *XHB* in this age range, the lower claim rate indicates that *XHB* can attract healthier older participants.

5.3 Evidence from Mutual Protection Survey

It is interesting to investigate what determines people's willingness to join *XHB*, or more generally internet-based mutual protection programs, and whether determinants are different for people with different risks, for example, different age groups. It is also interesting to check the relationship between mutual protection programs with traditional protection plans, such as social security and commercial insurance. Therefore, we carry out a regression analysis based on the survey conducted by Ant Financial distributed to Alipay users in 2019, and report the findings of logistic regression models in Table 7.

In Panel A, we report the baseline regression. The dependent variable of the Logistic regression is an indicator whether or not an agent participates in an internet mutual protection programs. Independent variables include age (*Age*), gender (*Female*), city tier (*CityTier*), income group (*Inc1*-*Inc5*), indicators for whether they have social security (*SS*) and whether they have commercial insurance coverage (*Ins*). CityTier takes a number from 1 to 6; the higher the number is, the worse economic development the city is. Income is grouped into five groups, with annual income $\leq$ 50,000 (*Inc1*), (50,000, 100,000] (*Inc2*), (100,000, 200,000] (*Inc3*), (200,000, 500,000) (*Inc4*) and $\geq$ 500,000) (*Inc5*). We perform three sets of regressions for i) the entire sample (i.e., all ages), ii) the young participants (<40 years old) and iii) the middle-age participants ($\geq$40 years old). The sample size is 45,031 and 13,691, respectively for two sub-groups.

The results can be briefly summarized as below. First, shown in Column 1, across participants of all ages, the willingness to join a mutual protection program is inversely associated with both *Age* and *CityTier*, albeit insignificantly. That is, the older a participant is, or the less developed region (a higher *CityTier*), the less likely for the survey participant to join an internet mutual protection program. Interestingly, the parameters are opposite for the young group (Column 2) and middle-age group (Column 3). In the young group, the older is more willing to participate in such programs, while in the middle-age group, the older is less willing to participate. In the young group, people from less developed region is less willing to participate, while in the middle-age group, people from less developed region is more willing to participate. Second, as income grows, the probability of purchasing an internet mutual protection product also grows, indicated by positive parameters increasing from *Inc2* to *Inc4*. From *Inc4* (the second richest group with an annual income between 200,000 CNY and 500,000 CNY) to *Inc5* (the richest group with an annual income more than 500,000 CNY), the middle-age group is still more willing to buy an internet mutual protection product, while the young group is less willing to buy. Third, there is no evidence that male and female survey participants exhibit different preferences for mutual protection products, for both all ages and two subgroups. Taken together, our evidence is not in favor of the presence of widespread incentive problems among mutual protection participants.

Most interestingly, our findings show opposite signs for coefficient on *SS* and *Ins*. In the all-age regression, the coefficient on *SS* is 0.56 an the coefficient on *Ins* is -0.29, both statistically significant at the 1 percent level. The finding suggests a complementary effect for participating the social security program and mutual protection while mutual protection programs appear to be supplementary to commercial critical illness insurance. The results remains for two subgroups, i.e., the young and the middle-age.

In Panel B, we perform three sets of regressions exploring the effect of i) having social security ii) having a commercial insurance and iii) the regional economic development on aged people's incentive to participate in mutual protection programs. We investigate this by adding interaction terms to the baseline regression model, i.e.,*Age*SS*, *Age*Ins*, and *Age*CityTier*. We find both significantly negative parameters on the interaction terms of *Age*SS* and *Age*Ins* for all ages. This suggests that for people with social security coverage or commercial insurance coverage, the marginal effect of age on the willingness to buy mutual protection products intensifies. In other words, for people with social security or commercial insurance, the aged people are more unwilling to buy such mutual protection products. However, the parameter on the interaction terms of *Age*CityTier* is significantly positive, suggesting that in poor cities, the marginal effect of age on the probability to buy mutual protection products mitigate, compared with that in rich cities. In other words, in a poor city, as age grows, people may also be willing to buy such a product, and this is quite different in a rich city. Besides, for people with no coverage of social security or commercial insurance, more aged people are more willing to participate in mutual protection programs. For people from richest cities (*CityTier*=1), more aged people are less willing to buy mutual protection products, while for people from the poorest cities (*CityTier*=6), more aged people are more willing to buy mutual protection products.

6 Conclusions

Xiang Hu Bao (*XHB*) is a novel online platform facilitating mutual risk sharing of critical illness exposures. It leverages the tech giant's platform and digital technology to lower the cost of participants enrollment and claim processing. Different from insurance products applying sophisticated actuarial pricing models, *XHB*, letting participants equally share losses and costs, is highly transparent and easy to implement. In addition, *XHB* restricts coverage amount, which is less than typical critical illness insurance products, particularly for older participants. Using a simple model, we show that the combination of lower price and indemnity of *XHB* can lead to separating equilibrium where low-risk individuals enroll in *XHB* while high-risk individuals purchase critical illness insurance. Our empirical evidence shows that the covered illness among *XHB* members is indeed far below that of comparable critical illness insurance across different age groups. Our findings suggest the role of advantageous selection in explaining the cost advantages of the FinTech-based mutual protection programs.

References

Arrow, K. (1953). The role of securities in the optimal allocation of risk-bearing. *Econometrie*, 41–47.

Borch, K. (1962). Equilbrium in a reinsurance market. *Econometrica 30*(3), 424–444.

Carbrales, A., A. Calvo-Armengol, and M. Jackson (2003). La crema: A case study of mutual fire insurance. *Journal of Political Economy 111*(2), 425–458.

China Actuary Association Report (2013). Critical illness historial incidence rate (2006-2010) report.

Fang, H., M. Keane, and D. Silverman (2008). Sources of advantageous selection: Evidence from medigap insurance market. *Journal of Political Economy 116*(2), 303–350.

Joskow, P. (1973). Cartels, competition and regulation in the property liability insurance industry. *Bell Journal of Economics and Management Science 4*, 327–427.

Koijen, R. and M. Yogo (2015). The cost of financial frictions for life insurers. *American Economic Review 105*, 445–475.

Koijen, R. and M. Yogo (2016). Shadow insurance. *Econometrica 84*(3), 1265–1287.

Marshall, J. (1974). Insurance theory: Reserves versus mutuality. *Economic Inquiry 12*, 476–492.

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

Schwarcz, D. (2014). Transparently opaque: Understanding the lack of transaparency insurance consumer protection. *UCLA Law Review 61*, 394–462.

Zanjani, G. (2002). Pricing and capital allocation in catastrophe insurance. *Journal of Financial Economics 65*, 283–305.

Table 1: Summary Statistics

This table summarizes the key coverage and major changes of the Xiang Hu Bao (*XHB*) program.

Panel A: Program V1 from October 2018 to April 2019

Plan Name	Age	Indemnity (CNY)	Coverage
Critical Illness Plan (CIP)	30 days to 39 years	300,000	99 Critical illnesses Critical malignant tumors*
	40 to 59 years	100,000	Same as above

Panel B: Program V2 from May 2019 to December 2019

Plan Name	Age	Indemnity (CNY)	Coverage
Critical Illness Plan (CIP)	30 days to 39 years	300,000	99 Critical illnesses plus critical malignant tumors**
	40 to 59 years	100,000	Same as above
	30 days to 59 years	50,000	2 Mild critical illnesses**
Senior Cancer Plan (SP)	60 to 70 years	100,000	Critical malignant tumors
		50,000	2 Mild critical illnesses

Panel C: Program V3 from January 2020 to May 2020

Plan Name	Age	Indemnity (CNY)	Coverage
Critical Illness Plan (CIP)	30 days to 39 years	300,000	Same as V2 plus 5 rare illnesses
	40 to 59 years	100,000	Same as V2 plus 5 rare illnesses
Senior Cancer Plan (SP)	60 to 70 years	100,000	Critical malignant tumors only

Panel D: Program V4 since June 2020

Plan Name	Age	Indemnity (CNY)	Coverage
Critical Illness Plan (CIP)	30 days to 39 years	300,000 (Standard) 100,000 (Reduced)	Same as V3
	40 to 59 years	100,000 (Standard) 50,000 (Reduced)	Same as V3
Senior Cancer Plan (SP)	60 to 70 years	100,000	Critical malignant tumors only

* For the full list of malignant tumors, see xxx for names in Chinese or refer to https://www.cancer.gov/types for the conventional list in English. ** Two types of illness originally categorized as malignant tumors in *XHB* V1, including i) Papillary thyroid cancer (PTC) or follicular thyroid cancer (FTC) without distal metastases and ii) $T2N_0M_0$ prostatic cancer, are no longer included. They are reclassified as mild critical illnesses.

Table 2: Payoffs in No-loss and Loss States under Mutual Protection and Insurance

This table shows payoff to an agent with mutual protection and without it in the i) loss and ii) no loss state.

	No Loss	Loss
without protection *XHB*	$E(w_t + w_{t+1})$	$E(w_t + w_{t+1} - l)$
with *MP*	$E(w_t - \pi^1 + w_{t+1})$	$E(w_t - \pi^1 + w_{t+1} - l + k)$
with Insurance	$E(w_t - \pi^2 + w_{t+1})$	$E(w_t - \pi^2 + w_{t+1} - l + k)$

Table 3: Xiang Hu Bao Aggregate Enrollment and Claims over Time

This table presents i) the number of enrollment to Xiang Hu Bao, ii) aggregate claim payments, and iii) allocated cost per member from January 2019 to August 2020.

Period	Enrollment	Aggregate Claim Payment (CNY)	Allocated Cost Per Member (CNY)
201901#2	23,307,500	600,000	0.03
201902#1	32,407,600	0	0
201902#2	34,684,900	900,000	0.03
201903#1	37,537,000	300,000	0.01
201903#2	41,185,700	0	0
201904#1	48,624,500	900,000	0.02
201904#2	52,426,700	2,500,000	0.05
201905#1	56,824,200	2,200,000	0.05
201905#2	62,896,200	7,800,000	0.13
201906#1	67,186,700	20,600,000	0.33
201906#2	70,224,600	33,000,000	0.51
201907#1	73,234,000	63,400,000	0.94
201907#2	75,621,800	103,550,000	1.48
201908#1	77,327,200	105,100,000	1.47
201908#2	79,920,300	107,200,000	1.44
201909#1	83,391,000	115,000,000	1.49
201909#2	85,756,600	235,300,000	2.96
201910#1	87,904,100	245,200,000	3.01
201910#2	89,682,000	254,100,000	3.06
201911#1	93,883,800	263,450,000	3.03
201911#2	95,145,600	266,700,000	3.02
201912#1	96,718,200	274,700,000	3.06
201912#2	97,347,400	274,650,000	3.05
202001#1	97,942,100	284,400,000	3.13
202001#2	98,927,100	317,950,000	3.47
202002#1	99,461,300	318,350,000	3.45
202002#2	99,531,100	139,700,000	1.51
202003#1	100,071,800	142,000,000	1.53
202003#2	100,433,700	144,500,000	1.55
202004#1	100,992,000	264,100,000	2.83
202004#2	101,035,200	369,650,000	3.95
202005#1	101,049,100	368,350,000	3.93
202005#2	100,952,900	367,000,000	3.92
202006#1	101,165,600	400,625,776	3.96
202006#2	100,944,200	396,710,705	3.93
202007#1	101,070,800	400,240,368	3.96
202007#2	101,056,300	397,151,259	3.93
202008#1	101,305,000	387,150,000	4.17
202008#2	101,129,000	380,900,000	4.11

Table 4: Effect of Diversifications

This table reports the variances of incidence rates (*IR*s) of different age groups and their differences. Panel A reports the average results based on the *XHB* claim data from 201909#2 to 202008#2. Panel B reports the average results based on the *XHB* claim data from 201909#2 to 202008#2 (excl. 202002#2-202004#1, the COVID-19 lockdown period. *CI6*, *CI25*, and *CI100* respectively represent 6, 25, and all leading critical illnesses. σ_i^2 and σ_j^2 in each period are calculated based on Eq. (20) and then average over time. t-statistics for the differences in are reported in the parentheses.

		CI6				CI25				CI100			
Group i	Group j	σ_j^2	σ_i^2	$\sigma_j^2 - \sigma_i^2$	(t-stats)	σ_j^2	σ_i^2	$\sigma_j^2 - \sigma_i^2$	(t-stats)	σ_j^2	σ_i^2	$\sigma_j^2 - \sigma_i^2$	(t-stats)
Panel A: Results of "Stable" Periods													
<10	0∼19	0.058	0.125	-0.067	(-10.811)	0.066	0.140	-0.075	(-11.467)	0.094	0.200	-0.107	(-11.472)
10∼19	10∼29	0.045	0.090	-0.046	(-5.865)	0.047	0.104	-0.057	(-6.414)	0.055	0.150	-0.095	(-9.212)
20∼29	20∼39	0.053	0.059	-0.006	(-3.317)	0.055	0.062	-0.007	(-3.733)	0.061	0.071	-0.010	(-4.753)
30∼39	30∼49	0.128	0.148	-0.021	(-5.803)	0.131	0.153	-0.022	(-5.939)	0.144	0.170	-0.026	(-6.846)
40∼49	40∼59	0.388	0.545	-0.156	(-6.973)	0.400	0.559	-0.159	(-7.066)	0.439	0.608	-0.169	(-7.008)
Panel B: Results of Non-COVID19 "Stable" Periods													
<10	0∼19	0.064	0.138	-0.074	(-11.804)	0.072	0.155	-0.082	(-12.965)	0.103	0.222	-0.118	(-14.027)
10∼19	10∼29	0.049	0.100	-0.051	(-5.753)	0.052	0.115	-0.063	(-6.417)	0.060	0.163	-0.103	(-9.333)
20∼29	20∼39	0.058	0.065	-0.007	(-3.092)	0.060	0.068	-0.008	(-3.531)	0.067	0.078	-0.011	(-4.442)
30∼39	30∼49	0.140	0.162	-0.022	(-5.050)	0.144	0.167	-0.023	(-5.212)	0.159	0.186	-0.027	(-6.084)
40∼49	40∼59	0.426	0.602	-0.175	(-7.001)	0.439	0.617	-0.178	(-7.076)	0.482	0.672	-0.190	(-7.066)

Table 5: Number of Paid Claims and Incidence Rates of Xiang Hu Bao

This table reports the numbers of claims of different groups and incidence rates of *XHB* in each payment period. # tot is the total number of paid claims # sy (sm) is the number of severe critical illness program young (middle-aged) participants below 40 years old (at or above 40 years old) receiving claim payments. # ns is the number of non-severe critical illness program participants receiving claim payments. The incidence rates (IR) of a given group is the number of paid claims of a group and scaled by the number of enrollment of 3-month lagged enrollments: $IR^1_t = \frac{c_t}{e_{t-6}}$ and $IR^{1s}_t = \frac{c^s_t}{e_{t-6}}$ where "1" stands for the critical illness program available covering severe critical illnesses and non-severe critical illnesses and "1s" stands for the severe critical illness program. The last row reports the aggregate numbers of cases for different groups and the average incidence rates.

Period	# tot (1)	# sy (2)	# sm (3)	# ns (4)	IR^{1s}_t (per mil) (5)	IR^1_t (per mil) (6)
201901#2	2	2	0	0	0.00	0.00
201902#1	0	0	0	0	0.00	0.00
201902#2	3	3	0	0	0.00	0.00
201903#1	1	1	0	0	0.00	0.00
201903#2	0	0	0	0	0.00	0.00
201904#1	3	3	0	0	0.00	0.00
201904#2	9	8	1	0	0.39	0.39
201905#1	10	6	4	0	0.31	0.31
201905#2	32	23	9	0	0.92	0.92
201906#1	100	53	47	0	2.66	2.66
201906#2	150	90	60	0	3.64	3.64
201907#1	286	175	107	4	5.80	5.88
201907#2	496	277	190	29	8.91	9.46
201908#1	500	286	172	42	8.06	8.80
201908#2	615	261	224	130	7.71	9.78
201909#1	632	288	228	116	7.68	9.41
201909#2	1,581	509	580	492	15.51	22.51
201910#1	1,718	514	616	588	15.43	23.46
201910#2	1,731	525	726	480	16.54	22.89
201911#1	1,735	565	709	461	16.48	22.44
201911#2	1,837	527	862	448	17.38	22.99
201912#1	1,931	531	908	492	17.26	23.16
201912#2	1,953	523	925	505	16.88	22.77
202001#1	2,025	537	978	510	17.23	23.04
202001#2	2,279	597	1,095	587	18.87	25.41
202002#1	2,381	580	1,086	715	17.75	25.36
202002#2	1,045	252	489	304	7.79	10.98
202003#1	1,047	260	493	294	7.79	10.83
202003#2	1,003	282	477	244	7.80	10.30
202004#1	1,753	516	961	276	15.08	17.90
202004#2	2,559	642	1,624	293	22.91	25.87
202005#1	2,411	689	1,511	211	22.12	24.24
202005#2	2,234	754	1,336	144	21.00	22.45
202006#1	2,219	760	1,394	65	21.52	22.17
202006#2	2,213	739	1,432	42	21.62	22.03
202007#1	2,291	710	1,524	57	22.12	22.68
202007#2	2,275	704	1,525	46	22.06	22.52
202008#1	2,370	757	1,588	25	23.21	23.45
202008#2	2,344	739	1,579	26	22.96	23.22
Total/Avg	40,087	11,902	21,998	6,187	19.72	23.31

Table 6: Incidence rates by Age Groups: *XHB* versus Insurance

This table reports the number of *XHB* claims, incidence rates of *XHB* and critical illness insurance of six age groups: <10, 10∼19, 20∼29, 30∼39, 40∼49, and 50∼59. Panel A reports the results in the "stable" claim period from 201909#2 to 202008#2. Panel B reports the results in the "stable" period excluding the COVID-19 lockdown. *CI6*, *CI25*, and *CI100* respectively represent 6, 25, and all leading critical illnesses. The reported number of *XHB* enrollment is the averaged 3-month trailing number of enrollments. The number of paid claims is the average number of claims reported in the current payment period. *XHB* incidence rates (*IR*) are estimated as the number of paid claims and scaled by the aggregate *XHB* enrollment in the lagged 3-months. The *CAA* incidence rates (*IR*s are the critical illness incidence rates published by the China Association of Actuaries (*CAA*) weighted by the 2018 population distribution. Both incidence rates reported in the table are first estimated in each payment period and then average over time. Ratios of *CAA* and *XHB* incidence rates are calculated in each payment period and averaged over time. The t-statistics of the ratio of incidence rate ratios of CI insurance and *XHB* minus 1 are reported in the parentheses.

Group	# *XHB* (3-month lag)	# *XHB Claims* Cases			*XHB IR* (per million)			CAA IR (per million)		IR Ratio CAA/XHB	
		CI6	CI25	CI100	CI6	CI25	CI100	CI6	CI25	CI6 (t-stats)	CI25 (t-stats)
Panel A: Results Based on "Stable" Periods											
<10	6,512,308	22	25	35	80	90	130	175	257	2.55 (5.31)	3.32 (6.20)
10∼19	4,728,042	9	10	14	43	50	72	249	321	7.16 (5.91)	8.23 (5.27)
20∼29	26,926,729	163	171	198	146	153	177	995	1,102	7.65 (9.64)	8.02 (9.59)
30∼39	28,091,886	457	473	528	391	404	451	2,391	2,558	6.50 (10.53)	6.71 (10.47)
40∼49	14,515,814	461	474	517	763	784	855	4,933	5,297	6.96 (8.42)	7.26 (8.63)
50∼59	10,814,477	576	595	660	1,278	1,321	1,465	8,100	8,780	7.40 (8.17)	7.77 (8.35)
Total	91,589,257	1,689	1,748	1,954	442	458	512	3,085	3,347	7.43 (9.12)	7.79 (9.23)
Panel B: Results Based on Non-COVID19 "Stable" Periods											
<10	6,434,483	24	27	39	88	99	144	175	257	2.15 (6.73)	2.80 (7.99)
10∼19	4,671,539	9	11	15	48	55	78	249	321	6.01 (4.47)	6.72 (4.02)
20∼29	26,604,940	175	183	212	157	166	191	995	1,102	6.93 (7.42)	7.21 (7.20)
30∼39	27,756,173	489	505	566	422	437	489	2,391	2,558	5.80 (8.46)	5.98 (8.43)
40∼49	14,342,342	502	515	563	840	862	942	4,933	5,297	5.88 (6.82)	6.14 (6.93)
50∼59	10,685,238	624	644	715	1,401	1,446	1,605	8,100	8,780	6.40 (6.61)	6.74 (6.76)
Total	90,494,716	1,822	1,885	2,110	483	500	560	3,085	3,347	6.39 (7.32)	6.70 (7.39)

Table 7: Logistic Analysis on Participating Mutual Protection Programs

This table provides the logistic regression results based on a survey on mutual protection program participation conducted by Ant Financial in 2019. The dependent variable of the logistic regression is an indicator on whether a survey participant joins an internet mutual protection program. Panel A reports a baseline regression examining the determinants of mutual protection participation including the following independent variables: age (Age), gender (Gender=1 if it is a female and 0 otherwise), city tier (CityTier takes a number from 1 to 6; the higher the number is, the worse economic development the city is), dummy variables for income group (Inc is grouped into five groups, with annual income $\leq$ 50,000 (Inc1), (50,000, 100,000] (Inc2), (100,000, 200,000] (Inc3), (200,000, 500,000) (Inc4) and $\geq$ 500,000) (Inc5), whether they have social security (SS=1 if they have social security and 0 otherwise) and whether they have commercial insurance coverage (Ins=1 if they have; Ins=0 if not). Panel B reports extended panel regressions examining the impact of commercial insurance purchase and regional economic development on the age effect on the incentive to participate in mutual protection programs. Besides the independent variables included in Panel A, we include the interactions between Age and Ins and Age and *CityTier*.

Panel A: Baseline Regression

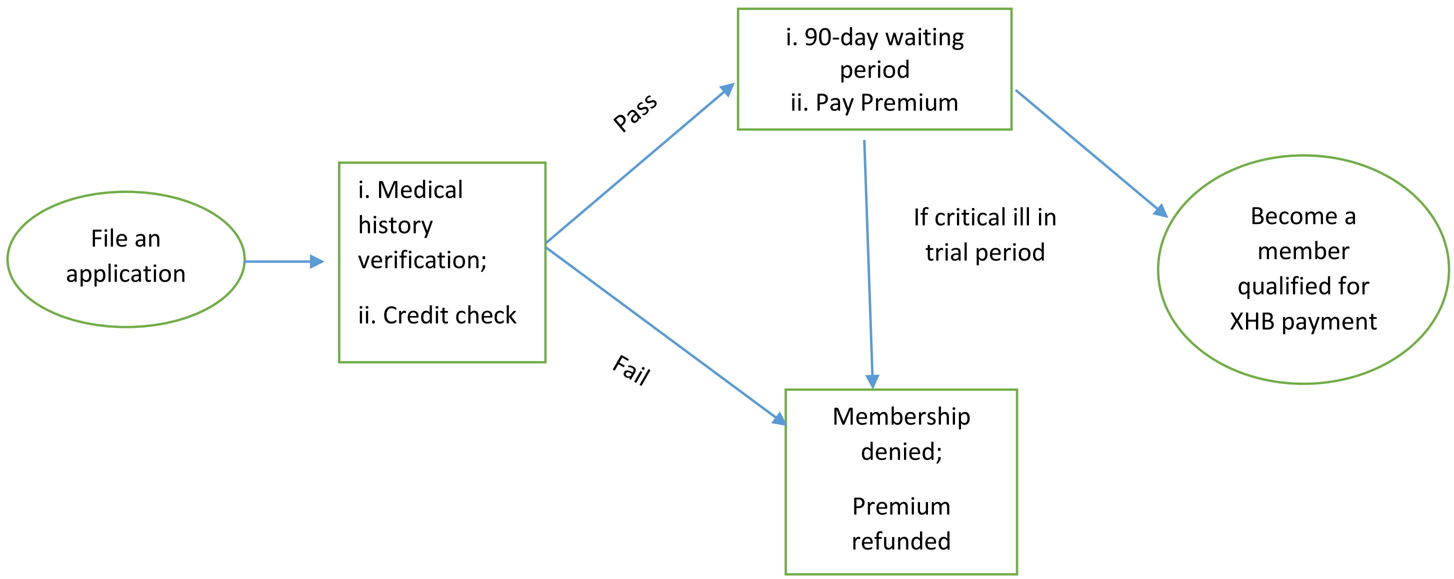
	(1) All ages	(2) <40	(3) ≥40
Age	-0.0001	0.01***	-0.01**
	(-0.06)	(6.81)	(-2.50)
Female	0.01	-0.004	0.06
	(0.39)	(-0.18)	(1.47)
SS	0.56***	0.57***	0.49***
	(20.90)	(19.30)	(7.62)
Ins	-0.29***	-0.28***	-0.34***
	(-16.56)	(-14.07)	(-9.47)
CityTier	-0.01	-0.01***	0.03***
	(-1.02)	(-2.77)	(3.02)
Inc2	0.28***	0.30***	0.15***
	(14.40)	(13.26)	(3.68)
Inc3	0.37***	0.38***	0.21***
	(14.32)	(12.83)	(3.92)
Inc4	0.43***	0.46***	0.22**
	(9.27)	(8.47)	(2.38)
Inc5	0.24***	0.17	0.42**
	(2.67)	(1.63)	(2.22)
Const	-0.88***	-1.00***	-0.65***
	(-23.53)	(-22.93)	(-5.05)
N	58,722	45,031	13,691
R^2	0.01	0.02	0.01

Panel B: Social Security, Insurance and City Development Effects

	Effect of Social Security			Effect of Commercial Insurance			Effect of Economic Development		
	(1)	(2)	(3)	(1)	(2)	(3)	(1)	(2)	(3)
	All ages	<40	≥40	All ages	< 40	≥40	All ages	< 40	≥40
Age	0.01**	0.02***	-0.02	0.01***	0.02***	-0.01	-0.01***	-0.0005	-0.01*
	(2.36)	(3.55)	(-1.47)	(3.51)	(8.08)	(-1.40)	(-5.38)	(-0.12)	(-1.89)
Female	0.01	-0.004	0.06	0.01	-0.001	0.06	0.008	-0.004	0.06
	(0.40)	(-0.19)	(1.47)	(0.58)	(-0.03)	(1.48)	(0.40)	(-0.15)	(1.45)
SS	0.67***	0.64***	0.19	0.57***	0.58***	0.49***	0.57***	0.58***	0.49***
	(13.16)	(9.30)	(0.54)	(20.87)	(19.29)	(7.61)	(20.95)	(19.35)	(7.66)
Ins	-0.29***	-0.28***	-0.35***	-0.14***	-0.07	-0.28	-0.29***	-0.28***	-0.35***
	(-16.56)	(-14.06)	(-9.48)	(-4.09)	(-1.35)	(-1.39)	(-16.60)	(-14.06)	(-9.49)
CityTier	-0.01	-0.02***	0.03***	-0.01	-0.02***	0.03***	-0.06***	-0.06***	-0.02
	(-1.04)	(-2.79)	(3.02)	(-1.03)	(-2.83)	(3.02)	(-5.64)	(-4.13)	(-0.32)
Age*SS	-0.01**	-0.01	0.01						
	(-2.51)	(-1.04)	(0.80)						
Age*Ins				-0.01***	-0.02***	-0.002			
				(-4.83)	(-4.67)	(-0.37)			
Age*CityTier							0.003***	0.004***	0.002
							(5.91)	(3.30)	(0.89)
Inc2	0.29***	0.31***	0.15***	0.29***	0.30***	0.15***	0.29***	0.30***	0.15***
	(14.39)	(13.25)	(3.68)	(14.38)	(13.15)	(3.69)	(14.37)	(13.26)	(3.69)
Inc3	0.38***	0.39***	0.22***	0.38***	0.39***	0.22***	0.38***	0.39***	0.22***
	(14.32)	(12.83)	(3.92)	(14.32)	(12.86)	(3.92)	(14.33)	(12.89)	(3.91)
Inc4	0.43***	0.46***	0.22**	0.44***	0.47***	0.22**	0.44***	0.47***	0.22**
	(9.28)	(8.49)	(2.38)	(9.30)	(8.59)	(2.37)	(9.42)	(8.62)	(2.37)
Inc5	0.25***	0.17	0.42**	0.25***	0.18*	0.42**	0.25***	0.18*	0.42**
	(2.70)	(1.64)	(2.23)	(2.66)	(1.65)	(2.22)	(2.69)	(1.68)	(2.17)
Constant	-0.97***	-1.06***	-0.38	-0.96***	-1.11***	-0.69***	-0.69***	-0.84***	-0.47*
	(-18.24)	(-15.47)	(-1.07)	(-23.53)	(-22.40)	(-4.08)	(-13.89)	(-12.79)	(-1.93)
N	58,722	45,031	13,691	58,722	45,031	13,691	58,722	45,031	13,691
R^2	0.01	0.02	0.01	0.01	0.02	0.01	0.01	0.02	0.01

Figure 1. Enrollment and Claim Procedures

Panel A: Procedure to Enroll in XHB



Panel B: Claim Process

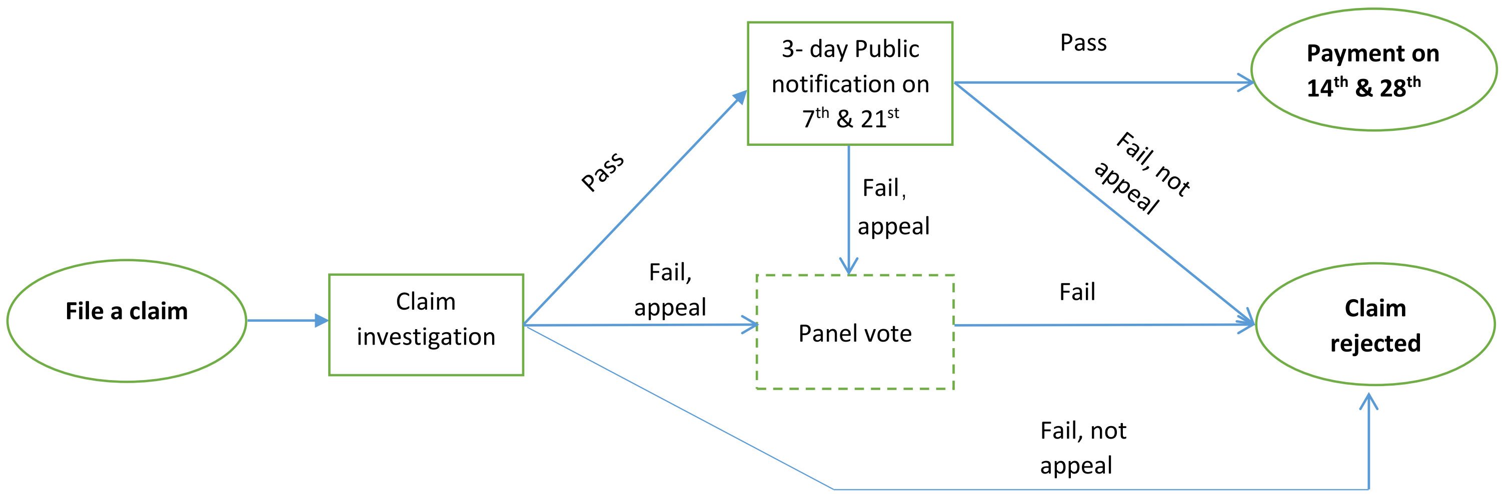


Figure 2. Mutual Protection and Individual Expected Utility

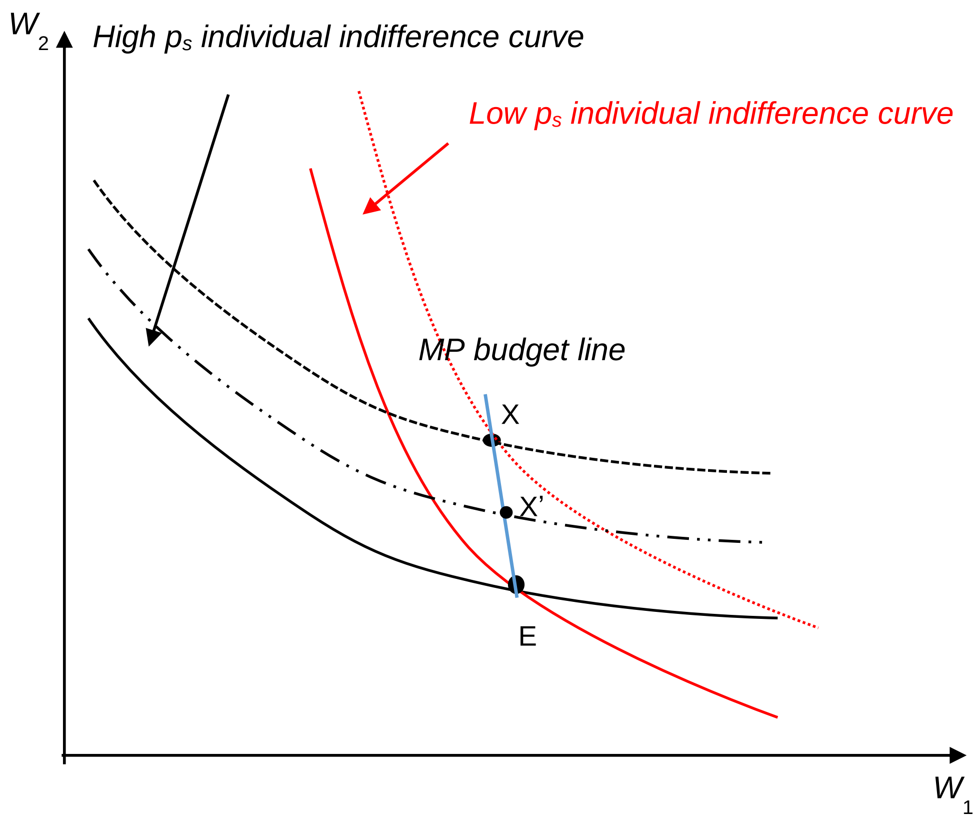


Figure 3. Mutual Protection and Insurance

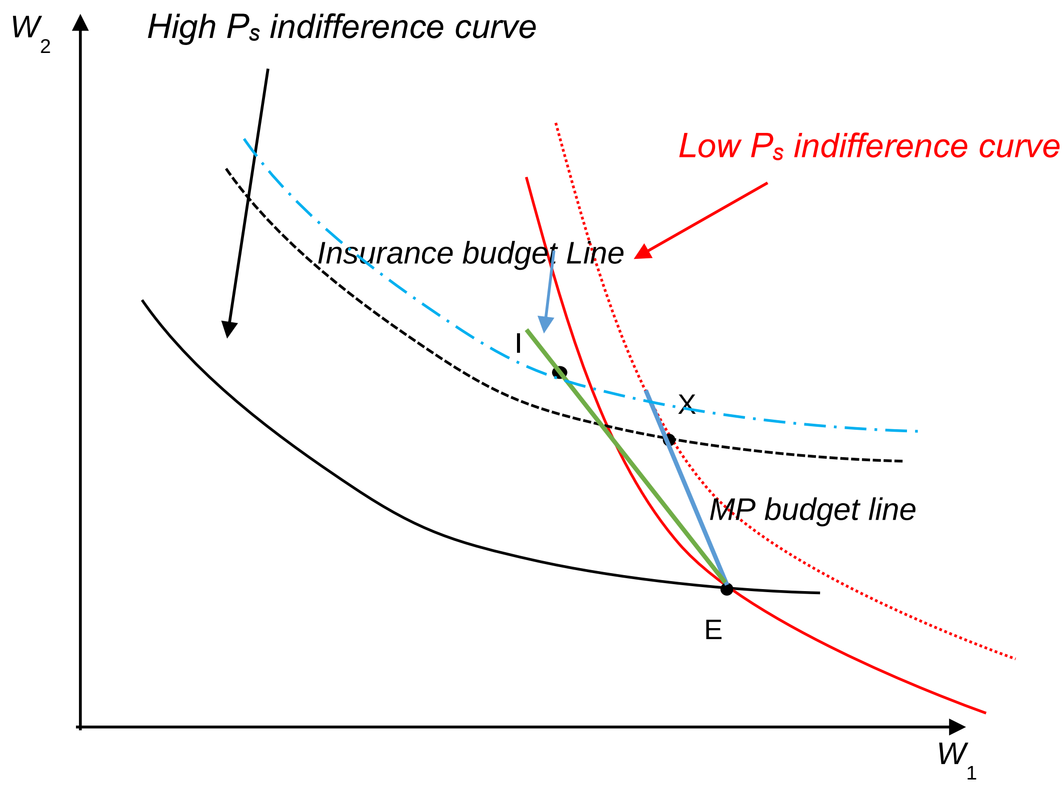
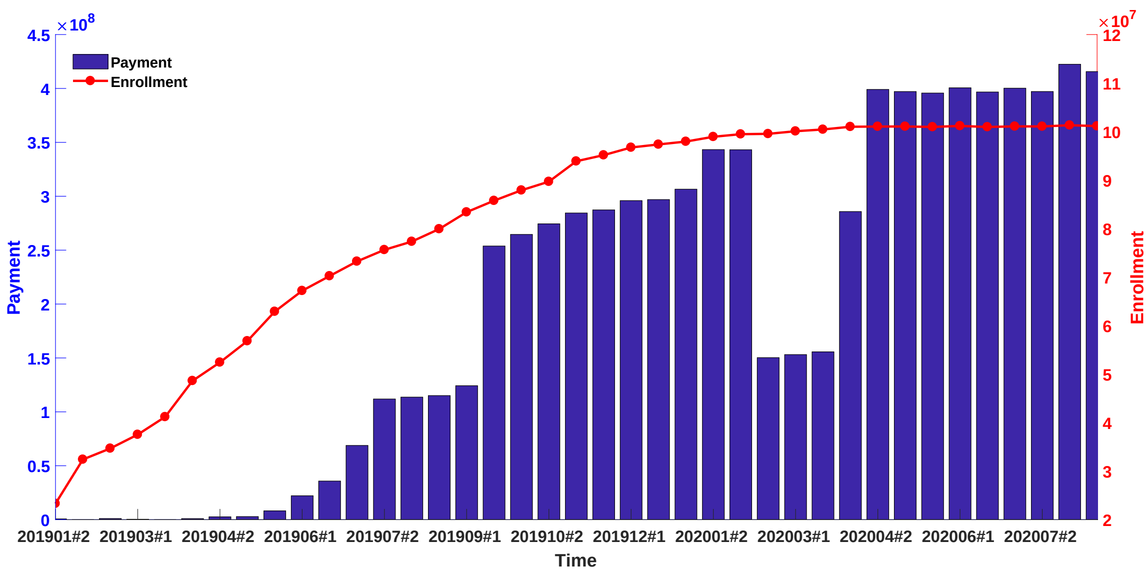
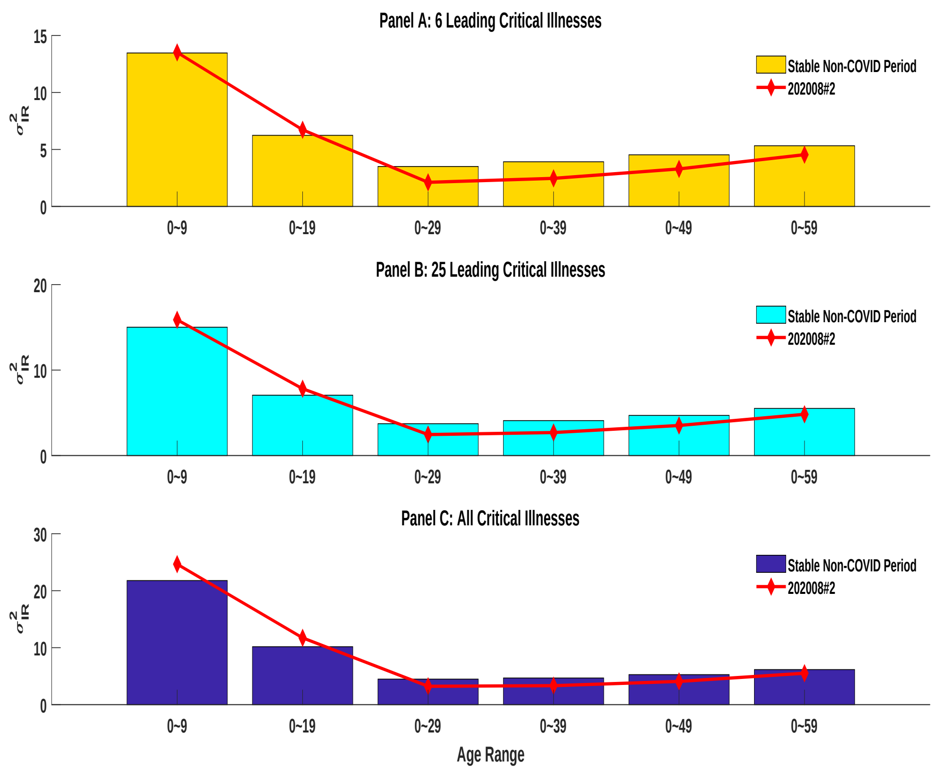


Figure 4. *XHB* Enrollment and Aggregate Payout



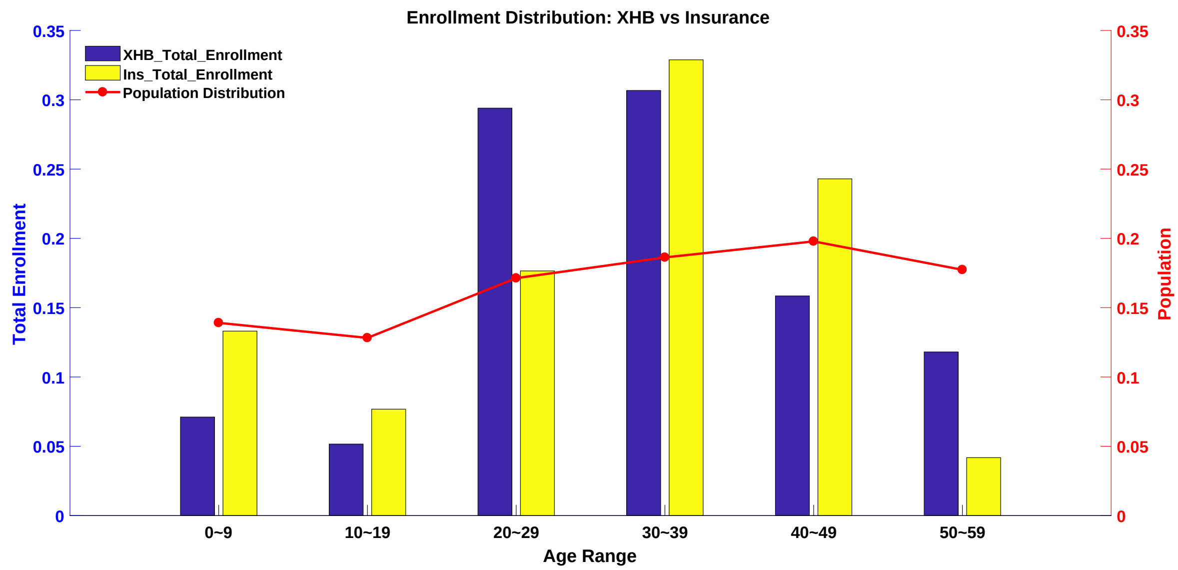
This figure shows the number of Xiang Hu Bao enrollments and aggregate payout over time.

Figure 5. The Effect of Diversification



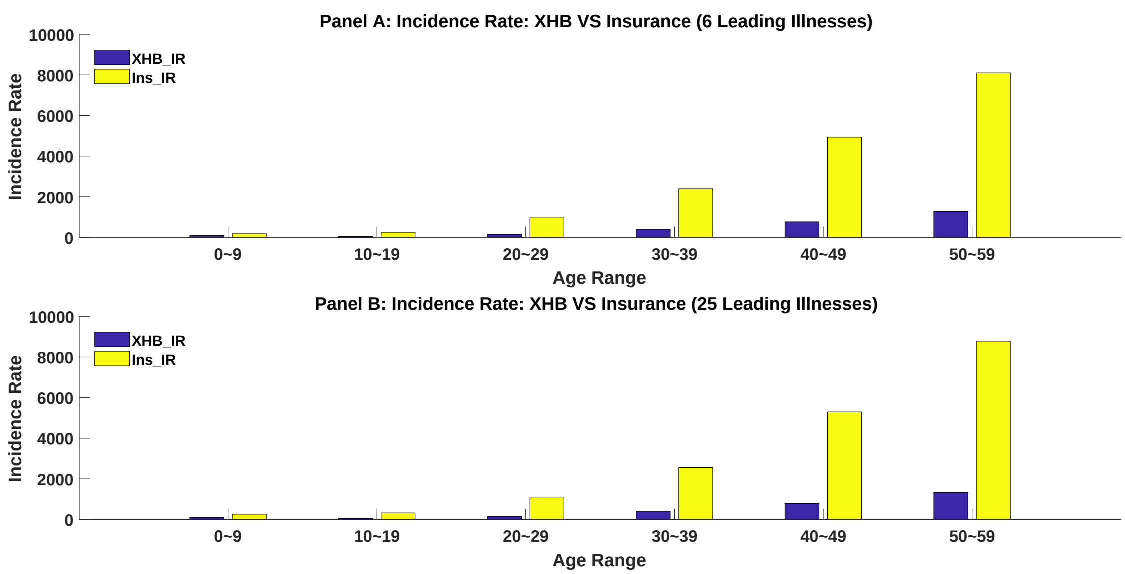
This figure shows variance of *XHB* incidence rates of six age groups: 0-9, 0-19, 0-29, 0-39, 0-49, 0-59 years old. Bars for the stable non-COVID periods; Curves for the last payment period: 202008#2.

Figure 6. Enrollment Distribution across Age Groups



This figure shows enrollment distributions of *XHB* and critical illness insurance across age groups. The age distribution of the population is also plotted.

Figure 7. Incidence Rates of *XHB* and Critical Illness Insurance across Age Groups



This figure shows the incidence rates of age groups for *XHB* and critical illness insurance.

A Optimal Risk Sharing: A Review

We derive conditions for optimal risk sharing under the state contingent framework. Imagine we are in a world with no trading costs. There are n risk averse agents and a finite number of possible future states of nature, s = 0, 1, 2, . . . , S-1. Which state prevails in the future is unknown, but there is a probability p^s attached to the realization of state s. Let w_i^s denote the initial endowment of individual i in state s and π_s denote the price of the Arrow-Debreu asset in state s. Then, agent i chooses a consumption plan in different states, c_i^0, c_i^1, . . . , c_i^s,. . . , c_i^{S-1} to maximize her expected utility:

$$\max_{c_i^0, c_i^1, \ldots, c_i^{S-1}} EU_i[c_i^s] = \max_{c_i^0, c_i^1, \ldots, c_i^{S-1}} \sum_{s=0}^{S-1} p_i u_i[c_i^s] \tag{A1}$$

subject to the wealth constraint for any agent that the value of the agent's new portfolio equates the value of her initial endowment:

$$E[\pi^s(c_i^s - w_i^s)] = 0 \ \ for \ \forall \ i \tag{A2}$$

The first-order conditions for the problem can be expressed as:

$$u_i^{'}[c_i^s] = \pi^s \eta_i \ \ for \ all \ s \tag{A3}$$

where $u_i^{'}[c_i^s]$ is the marginal utility of consumption for agent i in state s, i.e., the change in the agent's utility due to a change in her consumption in state s; η_i is the Lagrange multiplier associated with the wealth constraint, i.e., the shadow price of risk transfer for agent i.

Based on Equation (3), agent i achieves her optimal consumption at $\hat{c}_i^s$ in a given state s, which is chosen concerning the tradeoff between ... In equilibrium, agent i's wealth change in state s is $\hat{c}_i^s - w_i^s$, denoted as $\hat{z}_i^s$.

The market clearance condition suggests that in each state the aggregate net wealth change is 0: $\sum_{i=1}^n \hat{z}_i^s = 0$. That is,

$$\sum_{i=1}^n \hat{c}_i^s = \sum_{i=1}^n w_i^s = w^s \tag{A4}$$

In words, risk sharing does not alter the aggregate wealth in any state though it changes individual agents' consumption plan in a given state.

As shown in Borch (1962), under the assumption that any individual's optimal consumption, c_i^s is equally sensitive to any individual's initial wealth, the rule for efficient risk sharing can be obtained by Equations A3 and A4 – the sensitivity of agent i's consumption to the aggregate wealth, $c_i^{s'}(w_s)$ (w_s represents the aggregate wealth of state s), is proportional to agent i's risk tolerance to the sum of individual risk tolerance:

$$\frac{d\hat{c}_i^s}{dw_s} = \frac{t_i}{\sum_i^n t_i}. \tag{A5}$$

where $t_i = \frac{u^{'}(c_i^s)}{u^{''}(c_i^s)}$ stands for risk tolerance for agent i.

In words, any increment in an agent's wealth should be shared in proportion to individual risk tolerances.

Consider a special case that the sole source of risk comes from the uncertainty of being infected critical illness which is idiosyncratic. By joining a large pool that can fully diversify the idiosyncratic risk, individuals have the same aggregate payoff across all states. According, individual agents have the same consumption in different states, and they hold a risk-free portfolio. Accordingly, *XHB* is potential application of the mutual risk sharing under the following three conditions: the first is the perfect market condition where transaction costs do not exist. The second is critical illness risk is perfectly diversifiable.

Table A1: Appendix: List of Critical Illness

Panel A: Critical Illness

#	Critical illnesses	CBIRC 6	CBIRC 25
1	Malignant tumor	Yes	Yes
2	Acute myocardial infarction	Yes	Yes
3	The sequelae of severe stroke	Yes	Yes
4	Major organ transplantation or hematopoietic stem cell transplantation	Yes	Yes
5	Coronary artery bypass surgery (or coronary artery bypass grafting)	Yes	Yes
6	End-stage renal disease (or chronic renal failure uremia period)	Yes	Yes
7	Multiple limbs are missing		Yes
8	Acute or subacute severe hepatitis		Yes
9	Benign brain tumors		Yes
10	Decompensation period of chronic liver failure		Yes
11	Sequelae of severe encephalitis or sequelae of meningitis		Yes
12	Deep coma		Yes
13	Deafness in both ears (no compensation for illness before 3 years old)		Yes
14	Blindness (no compensation for illness before 3 years old)		Yes
15	Paralysis		Yes
16	Heart valve surgery by thoracotomy		Yes
17	Severe Alzheimer's disease		Yes
18	Severe brain damage caused by external forces		Yes
19	Severe Parkinson's disease		Yes
20	Severe degree burns		Yes
21	Severe primary pulmonary hypertension		Yes
22	Severe motor neuron disease		Yes
23	Loss of language ability (no compensation for illness before 3 years old)		Yes
24	Severe aplastic anemia		Yes
25	Aortic surgery with thoracotomy or laparotomy		Yes
26	Severe infective endocarditis		
27	Severe muscular dystrophy		
28	Open surgery for acute hemorrhagic necrotizing pancreatitis		
29	Paralysis caused by polio		
30	Severe progressive supranuclear palsy		
31	Human immunodeficiency virus (HIV) infection caused by blood transfusion		
32	Craniotomy (including ruptured cerebral aneurysm clipping surgery)		
33	Severe heart failure caused by myocarditis		
34	Severe myasthenia gravis		
35	Severe medullary cystic disease		
36	Resection of pheochromocytoma		
37	Idiopathic chronic adrenal insufficiency		
38	Severe elephantiasis		
39	Ebola virus infection		
40	Severe Crohn's disease		
41	Severe chronic recurrent pancreatitis		
42	Severe chronic constrictive pericarditis		
43	Severe systemic scleroderma		
44	Severe primary cardiomyopathy		
45	The third type of osteogenesis imperfecta		
46	Primary sclerosing cholangitis		
47	Aortic dissection aneurysm		
48	Continued vegetative state		
49	Severe necrotizing fasciitis		
50	Severe hemorrhagic dengue fever		
51	Severe Kawasaki disease with coronary aneurysm		

52	Severe dementia caused by non-Alzheimer's disease
53	Alveolar proteinosis
54	Severe heart failure caused by pulmonary heart disease
55	Severe autoimmune hepatitis
56	Severe hepatolenticular degeneration
57	Multiple root avulsion of brachial plexus
58	Intellectual disability caused by disease or trauma
59	Severe syringomyelia
60	Tumors in the spinal cord
61	Severe spinal cerebellar degeneration
62	Sequelae of severe spinal vascular disease
63	Progressive multifocal leukoencephalopathy
64	End-stage lung disease
65	Systemic juvenile rheumatoid arthritis
66	Biped amputation due to diabetes complications
67	Autologous hematopoietic stem cell transplantation
68	Aggressive hydatidiform mole (or malignant hydatidiform mole)
69	Hemolytic uremic syndrome
70	Severe cranial fissure meninges or meninges bulging
71	Resection of left ventricular aneurysm
72	Permanent nerve damage caused by bacterial meningococcal meningitis
73	Severe lupus nephritis
74	Pancreas transplantation
75	Severe subacute sclerosing panencephalitis
76	Severe type 1 diabetes
77	Complications of severe intestinal diseases
78	Severe Fanconi syndrome (no compensation for illness before 3 years old)
79	Severe myelodysplastic syndrome
80	Severe spina bifida spinal cord meninges or meninges bulging
81	Human immunodeficiency virus (HIV) infection caused by organ transplantation
82	Severe Eisenmenger syndrome
83	Severe coronary heart disease
84	Severe Creutzfeldt-Jakob disease
85	Fulminant ulcerative colitis
86	Permanent irreversible joint dysfunction caused by rheumatoid arthritis
87	Severe ankylosing spondylitis
88	Severe Reye's syndrome
89	Severe pulmonary lymphangioleiomyomatosis
90	Gangrene caused by hemolytic streptococci
91	Severe facial burns caused by accidents
92	Severe multiple sclerosis
93	Severe hand, foot and mouth disease with complications
94	Thoracotomy for cardiac myxoma
95	Severe acute disseminated intravascular coagulation
96	Severe secondary pulmonary hypertension
97	Severe arteritis
98	Severe Brugada syndrome
99	Severe hemophilia A and B
100	Severe infant progressive spinal muscular atrophy

Panel B: Rare Illness

#	Name
1	Gaucher disease
2	Fabry disease

3	Mucopolysaccharidosis
4	Pompe disease
5	Langerhans cell histiocytosis