Mutual Risk Sharing and Fintech: The Case of Xiang Hu Bao*

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Abstract

Xiang Hu Bao (*XHB*), meaning 'mutual treasury' in Chinese, is a novel online mutual aid platform operated by Alibaba's Ant Financial to facilitate risk sharing of critical illness exposures. *XHB* reached nearly 100 million members in less than one year since its launch and offered its members critical illness protections at significantly lower cost than traditional critical illness insurance. There are three major distinctions between *XHB* and traditional insurance products. First, *XHB* leverages the tech giant's platform and digital technology to lower enrollment and claim processing costs. Second, different from insurance applying sophisticated actuarial pricing models, *XHB* collects no premiums ex ante from members, but instead equally allocates indemnities and administrative costs among participants after each claims period. Third, *XHB* limits coverage amount, often below critical illness insurance products, particularly for older participants. We show this restriction potentially leads to separating equilibrium, a la Rothschild-Stiglitz, where low-risk individuals enroll in *XHB* while high-risk individuals purchase critical illness insurance. Data shows that the incidence rate of the covered illness among *XHB* members is well below that of comparable critical illness insurance. Our findings further suggest the role of advantageous selection in explaining the cost advantages of the Fintech-based mutual aid programs.

Keywords: Mutual risk sharing; Fintech; Separating equilibrium; Critical illness

JEL codes: G22; G23; I14; I15

1 Introduction

Borch's theorem (Borch, 1962), also known as the *mutuality principle*, applies Arrow (1953)'s general equilibrium framework to characterize the optimal risk sharing in the insurance market. It shows that participants mutually insure each other to share diversifiable risks while transferring the non-diversifiable risks to the more risk-tolerant parties. While the mutuality principle is viewed as the cornerstone of the insurance theory, it is barely applied in practice. A major hurdle is the difficulty to reach a sufficiently large pool to diversity the idiosyncratic risks given the presence of the myriad of regulatory interventions and significant information costs. In the marketplace, instead of having participants pool their risks and mutually insuring each other, insurance companies take on a central role and set insurance premiums with a goal to maximize their own values (Marshall, 1974).[1]

The significant progress in information technologies promotes new venues in risk sharing and risk management practices (OECD, 2017). Just as peer-to-peer (P2P) lending platforms connected un- or under-financed borrowers to lenders, emerging fintech platforms can also be leveraged to reach traditionally un-insured or under-insured customers.[2] This is exemplified by Xiang Hu Bao (*XHB*, meaning "mutual treasure" or "protecting each other"), an online mutual aid platform operated by the Chinese fintech giant Ant Financial. Launched in late 2018, *XHB* provides indemnity payments to members who are confirmed to have contracted one of the 100 types of covered critical illnesses, such as thyroid cancer, breast cancer, lung cancer, critical brain injury, among others.[3] 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 the traditional critical illness insurance policies in China. The mutual aid practice of *XHB* differs from traditional insurance business, making it difficult to

[1] Notably, 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 [that] has resulted in the use of an inefficient sales technique, supply shortage, and overcapitalization." More recently Zanjani (2002), Koijen and Yogo (2015) and Koijen and Yogo (2016), among others, offer further evidence on the inefficiency and 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.

[2] See Thakor (2020) for a review of the related literature.

[3] See Appendix C for details of the covered critical illnesses.

be regulated. *XHB*, unfortunately, was stopped on January 28, 2022.

In practice, during each claim period *XHB* participants equally share aggregate medical claim payments plus a 8% markup to cover operating expenses; in exchange they receive a fixed indemnity – CNY300,000 for individuals under 40 years old and CNY100,000 for participants of 40 and older – if they are confirmed to have been diagnosed with one of the covered critical illnesses. So far, *XHB*'s cost sharing per member is far below the premium of the corresponding critical illness insurance (*CII*) that provides the same level of coverage. *XHB* charges between CNY3 and CNY6 for a coverage of over 100 illnesses in a biweekly claim period; in contrast, the comparable one-year term *CII* for a 30-year old female charges an annual premium between CNY300 and CNY 600, i.e., between CNY12.5 and CNY 25 biweekly. What accounts for the substantial difference between *XHB*'s sharing cost and the premium of traditional critical illness insurance?

A key advantage of *XHB* is its large pool, which is clearly attributable to its affiliation with Ant Financial whose Alipay is one of the market leaders in mobile payment industry in China. The large member base allows *XGB* to operate at a low cost, making it largely resembles index funds in asset management designed to attract investors for diversification benefits. Nevertheless, on a first glance, *XHB*'s arrangement that all members equally share the cost, which is akin to uniform pricing, makes it prone to the classical adverse selection problem that attracts more higher risk individuals (Rothschild and Stiglitz, 1976). Surprisingly, we find that the incidence rate of the covered critical illnesses among *XHB* members are *not* higher than that of policyholders of the traditional critical illness insurers. In fact, our data suggests that the incidence rates of *XHB*, both for the overall members and within members in different age groups, are substantially lower than those of the commercial critical illness insurance. A main goal of our paper is to understand *XHB*'s seeming success under its business model.

Our main insight is to argue that the relatively rigid indemnity amount structure plays a key role in *XHB*'s ability to overcome the adverse selection problem. First, *XHB*'s indemnity amount for members who are confirmed with one of the covered critical illnesses is below the typical medical costs to treat the critical illnesses, particularly for members who are older than 40. In a simple Rothschild & Stiglitz model, we show the existence of a separating equilibrium in which low-risk individuals choose *XHB* while high-risk individuals purchase traditional critical illness insurance. High-risk individuals value the more flexible choice of coverage amount offered by the traditional insurance relative to the rigid indemnity level under *XHB*, thus they are more likely to favor traditional insurance to *XHB*. The preference of traditional insurance over *XHB* is more likely to occur among the relatively aged population for two reasons: first, *XHB*'s indemnity level to members aged 40 and above is only 1/3 the level for members with age below 40; second, the fraction of individuals who are high-risk tends to be higher in older age groups.

Empirically, 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 joins *XHB* while the participation rate for people above 40 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 the China Association of Actuaries (*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) than that of the young participants below 40.

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. Besides, as a side benefit the incentive to stay with Alipay lowers users' propensity to engage in fraudulent activities. Allen and Gale (1999) suggest that the incentive of financial institutions to stay connected between intermediaries and their customers can be an effective substitute for costly investigations ex-ante and ex-post. Second, *XHB* adopts an artificial intelligence (*AI*) based platform for claim handling. The system substantially lowers human involvement, not only lowering labor costs, but also standardizing claim processing. It contributes significantly to the system's low operational costs (reflected in its 8% administrative cost charge, far below that of insurance firms). Third, *XHB* has a public notification and appeal panel systems – all the critical illness claims confirmed by *XHB* professionals must be publicly announced among participants; disputes are handled by the appeal panel which involves million of qualified *XHB* members (detailed in Section 2) who voluntarily participate in the process. This becomes an additional advantage of large number of participants – in a seminal article titled *Vox Populi*, a Latin phrase that literally means 'voice of the people', published in *Nature*, Galton (1907) demonstrates the surprising accuracy of a group's aggregated judgments, namely the "wisdom of crowds".

Our framework accommodates the coexistence of *XHB* and traditional critical illness insurance. *XHB* is ideal to three types of participants – i) young people, ii) healthy people, and iii) people with relatively low income. Insurance which typically charges a higher premium 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.

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 applies 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 vanishes, 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, who 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 its appeal panel system serve important roles to deter frauds and achieve a relatively high efficiency in claim processing.

The relevance of mutual risk sharing to the financial risk management practice resembles DeFi (acronym for decentralized finance) to financial markets. As noted in Harvey et al. (2021), "For centuries, we have lived in a world of centralized finance. Central banks control money supply. Financial trading is largely done via intermediaries. Borrowing and lending are conducted through traditional banking institutions. In last few years, however, considerable progress has been made on a much different model: decentralized finance. In this framework, peers interact with peers via a common ledger not controlled by any centralized organization." Like DeFi going back to the primitive peer to peer form of market exchange, mutual risk sharing – letting individuals access to the common risk pool, sharing losses and applying fintech to lower production costs, is likely to reshape the insurance practice.

The remainder of the paper is structured as follows. In Section 2 we describe the institutional background of *XHB*; in Section 3, we present a simple model that contrasts mutual aid against critical illness insurance, and demonstrate the existence of separating equilibrium; in Section 4 we describe the data sets used in our empirical analysis; in Section 5 we present our empirical findings; finally, in Section 6 we conclude.

2 Overview of Xiang Hu Bao and Its Fintech Applications

2.1 An Introduction of Xiang Hu Bao

Xiang Hu Bao was initially launched as a peer-to-peer insurance product by Ant Financial, partnering with Trust Mutual Life Insurance, in October 2018. The life insurance partner quitted shortly after the launch, making *XHB* a pure online mutual aid platform.[4] Unfornately, owing to regulatory pressure, *XHB* was halted on January 28, 2022, signifying the end of the largest Fintech based mutual risk sharing platform

XHB hosts two plans: the Critical Illness Plan, abbreviated as *CIP*, for young and middle-aged participants between 30 days and 59 years and the Senior Plan, abbreviated as *SP*, for senior participants 60 to 70.[5] Accordingly, participants of *CIP* stay in a pool where sick members below 40 years old receive CNY300,000 while those at and above 40 receive CNY100,000. Moreover, senior participants between 60 and 70 stay in a different pool and they receive CNY10,000 once confirmed to have a malignant tumor. The size of *CIP* is far larger than that of *SP* – at the end of 2020, the number of participants to *SP* is merely 4% of the number to *CIP*.

Table 1 offers details of the coverage of *XHB* at different stages. The first version was effective

[4] 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 its insurance partner, Trust Mutual Life, left *XHB*.

[5] *XHB* is not the only mutual aid network in China while it is the biggest. Other mutual aid platforms include Water Drop Mutual (closed on March 31, 2021), Meituan Mutual (closed on January 18, 2021), and Qingsong Mutual (closed on March 25, 2021), among others.

from October 2018 to April 2019, which 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. In the second version, *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 starting in January 2020 and ending in May 2020, *XHB* additionally covers 5 rare illnesses while it stops mild illness coverage. The latest program offers reduced indemnity plans, CNY100,000 for participants below 40 and CNY50,000 for participants 40 and older. Sharing costs are charged on a proportional basis.

Panel A of Figure 1 presents *XHB*'s enrollment procedure. The first step is to file an online application (through mobile phone) with an authentic identity. In order to be a qualified member, an applicant needs to be free of any listed critical illness (see Appendix C) and maintains a clean medical record. Individuals with more than 30 days of continuous medication or over 15 days of hospitalization in the past 2 years are not allowed to join *XHB*. When one is diagnosed with a critical illness within the first 90-day trial period, his or her membership would be terminated. Moreover, *XHB* members are required to have an account with Alipay, making *XHB* participants younger than the population. Based on the statistics provided iimedia (data.iimedia.cn), over 2/3 of Alipay users are below 30 while this young age group accounts for slightly over 40 percent of the population at the end of 2019. To be an *XHB* member, an individual needs to have a good credit score, having a minimum of 600 sesame points out of the maximum of 800 points. This makes *XHB* subscribers potentially more healthy.

Panel B of Figure 1 illustrates *XHB*'s claim process. When an *XHB* participant submits a critical illness claim, all the documents must be submitted through an artificial intelligence and blockchain integrated system designed to improve claim processing efficiency and accuracy (this is detailed in the next subsection) and prevent from potential frauds. The entire claim process is also recorded on the temper-proofed blockchain based system. Once *XHB* receives a claim application, it performs a preliminary review involving virtual face-to-face interviewer with the applicant and field investigation to hospitals and other related parties. Once the investigations are completed, the case would be notified to all members on scheduled announcement days – 7th and 21st of each month. If a case receives no disputes from participants, the claim payment is scheduled and notified to all members seven days afterwards on the 14th and 28th of each month. The payment will be made to the claimant within seven days after the payment announcement day.

When an applicant disputes an unfavorable decision, he/she can request a second review by a panel of qualified *XHB* members.[6] 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.

Different from *XHB* offering a short-term (bi-weekly) coverage, coverages offered by traditional critical illness insurance has a much longer horizon, e.g., one year or multiple years, known as term critical illness policies and even whole-life critical illness policies.[7] In 2019, critical illness insurance covers around 100 million people, in a comparable size to the *XHB* participants. A similar 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 aid programs are comparable, critical illness insurance offers more options and better coverages than those of *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.

2.2 *XHB*'s Fintech-based Claim Process

Figure 2 shows how Fintech is involved in the four key steps of *XHB* claim process: i) claim submission and preparation, ii) preliminary claim screening analysis, iii) formal investigation, and

[6] 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 within 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.

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

iv) claim adjustments. In the first step, claimers upload their claim materials into the *XHB* claim system through an Alipay mobile application. All documents are converted to digital data through an optical character recognition (*OCR*) program. The system sends automatic messages to claim submitters for file replacements when submissions are not legible (either due to a poor image quality or an inappropriate file format). Sorting information based on keywords, the system generates over 100 reports that will be used in subsequent steps. This results in a more standardized and efficient claim process.

In the second step, the platform applies textual analysis on submitted files to perform a preliminary critical illness claim analysis. A claim is rejected if it does not meet the payment standards, such as a claim for an illness not on the covered illness list, pre-existing condition, or an illness occurring during the first 3-month trial period. According to Ant Financial, 50% of submitted claims are rejected in the pre-screening stage – 100,000 cases out of 200,000 submitted claims were declined in this step in 2020. As this step is purely handled by the artificial intelligence based system, it involves zero human input. This design substantially lowers *XHB*'s claim adjustment costs.

The third step is to investigate claims passing the initial screening stage. Considered to be labor intensive, the main tasks of this step includes interviewing claimants and collecting documents and witness reports from hospitals and other related parties. To improve efficiency (e.g., tracing investigators and assign one in the nearest location for a hospital visit), *XHB* has a dispatching system building on artificial intelligence (AI) to arrange tasks to third-party investigators. Investigators are required to constantly update their progress and communicate with the system in case they encounter any issues; the entire process is recorded in a digital form. The standardized procedure helps *XHB* to optimize human involvement, cut its labor costs, and make claim processing more stringent.

The final step is to settle claims. *XHB* settles undisputed cases instantly – either accepting the claim and making payments or rejecting the claim. It refers disputable claims to medical experts within its network. There experts are typically accessable online and they provide recommendations to the system. This procedure substantially improves accuracy of *XHB* claim handling. In 2020, *XHB* made payments to 52,682 claims, which is comparable to the total number of critical illness claims processed by the largest insurance company in China.

3 Simple Model

3.1 Risk Sharing in a Large Pool

A primary feature of *XHB* is its large pool of participants coming from Alipay. This motivates us to look at the effect of pool size on participants' incentives. A larger pool achieves a higher level of diversification. On the other hand, an increase in the pool size potentially pool together heterogeneous age groups with different incident rates, resulting in wealth transfer from high-risk individuals to low-risk participants. To understand this mechanism, we use x to denote *XHB* and express the price of *XHB*, π_t^x, as:

$$\pi_t^x = p_t^x K(1 + \lambda^x) \tag{1}$$

where p_t^x is the realized incidence rate for *XHB*; K is the amount of fixed indemnity to an *XHB* participant; λ^x is the management fee (or called loading or markup) charged to *XHB* participants proportional to its indemnity cost.

Ex-post incidence rate is involved in *XHB* price. We thus model p_t^x as the sum of an expected incidence rate p^x and a random error u_t^x, with a mean 0 and a standard deviation of σ_x.

$$p_t^x = E(p_t^x) + u_t^x = p^x + u_t^x \tag{2}$$

An *XHB* participant has an endowed wealth stream of w_{st} at time t and $w_{s,t+1}$ at time $t+1$. Participating in *XHB* qualifies the individual to receive the indemnity K in the subsequent period if diagnosed to be critically ill, and in the same time subjects her to *XHB* pricing uncertainty. Denoting the incidence rate for agent s is p_s and the loss amount is O, her expected utility to join the pool can be written as below:

$$E[u^x] = \underbrace{E[u(w_{st} - \pi_t^x)]}_{EU_t} + \underbrace{\beta[(1 - p_s)u(w_{s,t+1}) + p_s u(w_{s,t+1} - O + K)]}_{EU_{t+1}} \tag{3}$$

Applying the Arrow-Pratt approximation, we may express the expected utility of *XHB* participants from his wealth at t as below:

$$\begin{aligned} E[u(w_{st} - \pi_t^x)] &= u[w_{st} - p^x K(1 + \lambda^x) - \Pi_t^x] \\ &= u[v_{st}^x - \Pi_t^x] \end{aligned} \tag{4}$$

where

$$v^x_{st} = w_{st} - p^x K(1+\lambda^x)$$
$$\Pi^x_t = 1/2A_s[K(1+\lambda^x)]^2\sigma^2_x \quad (5)$$

A_s is the individual's risk aversion. Π^x_t is the compensation for the pricing risk taken by *XHB* participants.

We take derivatives of the expected utility specified in Eq. (4) with respect to the size of pool. Using N to denote the aggregate number of participants of *XHB*, we have the following expression jointly considering the pooling effects on *XHB* expected incidence rates and its volatility.

$$\frac{\partial Eu^x}{\partial N} \propto (\frac{\partial p^x}{\partial N} + \gamma\frac{\partial \sigma}{\partial N}) \quad (6)$$

where $\gamma = A_s K(1+\lambda^x)\sigma$.

For a low-risk participant, staying a larger pool may force them to share risk with other individuals with a higher risk – young participants mixing with old participants, inferring $\frac{\partial p^x}{\partial N} > 0$. For the holding of the optimal condition Eq. (B1), the standard deviation of incidence rate must be inversely related to the pool size; i.e., $\frac{\partial \sigma}{\partial N} < 0$. This results in the following proposition:

Proposition 1 *A necessary condition for an expected utility maximizer to participate in a mutual aid program is* $\frac{\partial \sigma}{\partial N} < 0$.

A large pool has a stable incidence rate but it invites high-risk individuals when the same price is charged to all participants. A practical implication of Proposition 1 is that mutual aid programs may restrict their pool size to prevent adverse selection. In practice, *XHB* handles the issue in a smart way, it restricts the coverage to high-risk participants – offering individuals 40 and above 1/3 coverage of individuals younger than 40 and putting senior individuals who are 60 and above in a different pool.

3.2 Price Difference in *XHB* and *CII*

Now we contrast *XHB* with *CII* and explore channels driving their price differences. Consistent with the notation used for the *XHB* price expressed in Eq. (1), we express the insurance price as π^i_t where i denotes critical illness insurance. Insurance price can be expressed below:

$$\pi_t^i = p_t^i K(1+\lambda^i) \tag{7}$$

where p_t^i is the expected incidence rate of *CII* and λ^i is the insurance loading.

We further decompose the price difference *XHB* and *CII* ($\Delta\pi_t = \pi_t^x - \pi_t^i$) as:

$$\Delta\pi_t = \underbrace{[p_t^x - p_t^i]K(1+\lambda^x)}_{\text{IR difference}} + \underbrace{p_t^x K(\lambda^x - \lambda^i)}_{\text{Loading difference}} \tag{8}$$

Based on Eq. (8), the price difference is attributable to i) the difference in their incidence rates (*IR*s) and ii) the difference in their respective loadings. In the following, we look into specific drivers to these two differences. As noted in Section 2.2, the Fintech application in *XHB* cuts its operational cost, driving λ^x to be lower than λ^i. Thus, the second term of Eq. (8) is expected to be negative.

Now we work on the first term. The incidence rate for *CII* is set ex-ante, different from *XHB*'s incidence rate which is set ex-post. Let us consider the insurance incidence rate is same as the expected incidence rate.

$$p_t^i = p^i \tag{9}$$

Then the individual's expected utility with insurance is

$$E[u^i] = u(w_{st} - \pi_t^i) + E[\beta[(1-p_s)u(w_{s,t+1}) + p_s u(w_{s,t+1} - O + K)] \tag{10}$$

Taking the difference between $E[u^x]$ and $E[u^i]$, the expected utility associated with wealth at $t+1$ cancels out. We have

$$\Delta Eu = E[u^x(w_{st}, w_{s,t+1})] - u_i(w_{st}, w_{s,t+1}) = E[u(w_{st} - \pi_t^x)] - u(w_{st} - \pi_t^i) \tag{11}$$

Denoting $v_{st}^i = w_{st} - \pi_t^i$, we simplify the difference between $E[u^x]$ and $E[u^i]$ as,

$$\Delta Eu = u[v_{st}^x - \Pi_t^x] - u(v_{st}^i) \tag{12}$$

In equilibrium, one would expect the expected utility from participating in mutual aid equates the expected utility of having insurance – $\Delta Eu = 0$, implying that $v_{st}^x - \Pi_t^x = v_{st}^i$. That is,

$$E(\pi_t^x) = \pi_t^i - \Pi_t^x \tag{13}$$

where $\Pi_t^x = 1/2A_s[K(1+\lambda^x)]^2\sigma^2$.

Since $\sigma^2 > 0$, we have $\pi_t^i > E(\pi_t^x)$ suggesting that *XHB* is expected to be less expensive than *CII* in general, except the special case that when the size of *XHB* goes to infinitely large, $\sigma^2 = 0$. This gives rise to $\pi_t^x = \pi_t^i$.

The above discussions result in an important condition for relative pricing of *XHB* and *CII*.

Proposition 2 *In equilibrium,* $E(\pi_t^x) = \pi_t^i - \Pi_t^x$*, where* $\Pi_t^x = 1/2A_s[K(1+\lambda^x)\sigma]^2$*. XHB is expected to be less expensive than CII. However, when all risks can be diversified away,* XHB *and* CII *is expected to have the same price.*

In principle, this proposition is equivalent to the mutuality principle (presented in the Appendix A) that i) individuals are willing to pay a risk premium to transfer their risks and ii) such risk premium goes to zero when the risk can be diversified away.

3.3 Choice between *XHB* and *CII*

Relative to *CII*, *XHB* is less flexible as it offers less indemnity to participants, particularly aged individuals. Here we demonstrate that the difference between *XHB* and *CII* potentially leads to à la Rothschild-Stiglitz separating equilibrium.

In an analysis similar to Rothschild and Stiglitz (1976), we graphically present individual choices in a two-state space – either the individual experiences no loss (W_1) or has loss (W_2). As we can see from Figure 3, there are three points involved: E represents the individual's respective wealth without any protection; X represents the individual's payoffs after participating in *XHB*; I represents the individual's payoffs with insurance purchase. The respective coordinators are presented below:

Point	Protection Type	$\mathbf{W}_1$	$\mathbf{W}_2$
E	No protection	$w_t + w_{t+1}$	$w_t + w_{t+1} - O$
X	with *XHB*	$w_t - \pi^x + w_{t+1}$	$w_t - \pi^x + w_{t+1} - O + K^x$
I	with *CII*	$w_t - \pi^i + w_{t+1}$	$w_t - \pi^i + w_{t+1} - O + K^i$

Specifically, at E, the individual's aggregate payoff at time t and $t+1$ is $w_t + w_{t+1}$ in the no-loss state and and the payoff is $w_t + (w_{t+1} - O)$ in the loss state. By joining *XHB*, the individual's aggregate payoff is $w_t - \pi_t^x + w_{t+1}$ in the no-loss state while it is $w_t + (w_{t+1} - O + K^x)$ in the loss state. Alternatively, by purchasing insurance, the individual's aggregate payoff is $w_t - \pi_t^i + w_{t+1}$ in the no-loss state and it is $w_t + (w_{t+1} - O + K^i)$ in the loss state. Here we further distinguish the amount of fixed indemnity to an *XHB* participant and a *CII* participant, respectively denoted as K^x and K^i.

With information about *E* and *X*, the slope of the budget line, *EX*, for individuals to participate in *XHB* is expressed as below:

$$\frac{\partial W_2}{\partial W_1}|_X = \frac{\pi_t^x - K^x}{\pi_t^x} = 1 - \frac{1}{p_t^x(1+\lambda^x)} \tag{14}$$

where p_t^x is the incidence rate of *XHB*.

And given the coordinates of *E* and *I*, the slope of the budget line, *EI*, for insurance purchase is:

$$\frac{\partial W_2}{\partial W_1}|_I = \frac{\pi_t^i - K^i}{\pi_t^i} = 1 - \frac{1}{p^i(1+\lambda^i)} \tag{15}$$

we have $\frac{\partial W_2}{\partial W_1}|_X$ and $\frac{\partial W_2}{\partial W_1}|_I$ are negative because $\frac{1}{p_t^x(1+\lambda^x)}$ and $\frac{1}{p^i(1+\lambda^i}$) are greater than 1. If we continue to take the assumption that the expected incidence rate of *XHB*, p_t^x, is the same as insurance incidence rate, p^i, then *XHB*'s budget line is expected to be steeper than *CII* since $\lambda^x < \lambda^i$.

Accordingly, the utility gain from participating in *XHB* is the difference in expected utilities between an *XHB* participant and an individual without any protection.

$$\begin{aligned} \Delta E u^x &= E[u^x] - E[u^n] \\ &= E[u(w_{st} - \pi_t^x)] - u(w_{st}) + \beta p_s[u(w_{s,t+1} - O + K^x) - u(w_{s,t+1} - O)] \end{aligned} \tag{16}$$

The individual's expected utility gain between having insurance and not having a protection can be expressed as:

$$\begin{aligned} \Delta E u^i &= E[u^i] - E[u^n] \\ &= E[u(w_{st} - \pi_t^i)] - u(w_{st}) + \beta p_s[u(w_{s,t+1} - O + K^i) - u(w_{s,t+1} - O)] \end{aligned} \tag{17}$$

Now we consider heterogeneity in incident rates across individuals – a high-risk individual with a high incidence rate and a low-risk individual with a low incidence rate. It can be easily show that the indifference curve (*IC*) for the low-risk individual is steeper than that of the high-risk individual. Therefore, as shown in Figure 3, the coverage *I*, offering greater coverage than *X*, delivers a higher expected utility than X to the high-risk individual. By intuition, the high-risk individual prefers more coverage thus they are willing to pay a higher cost to purchase insurance. Alternatively, low-risk individuals would rationally choose the low-coverage X. This results in 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. We summarize the separating equilibrium in the following proposition.

Proposition 3 *Given different coverages of mutual aid and insurance, individuals with high risk (private information) choose I and individuals with low risk choose X.*

It should be noted that the above proposition holds when mutual aid participation and insurance purchase are mutual exclusive. However, this condition does not hold in practice where participants can access mutual aid products and insurance simultaneously. As a result, high risk individuals have incentives to choose X as a supplement to traditional insurance coverage, thus increasing *XHB*'s participation costs. Following Eq. (14), a high p^x leads to a less negative slope of the budget line. Consequently, *XHB* becomes less attractive to low-risk individuals. They may rationally quit the program When they are perfectly price elastic. Nevertheless, there are several reasons to believe *XHB* participants may not be fully price elastic. One is that, as pointed out in Rothschild and Stiglitz (1976) and other works, e.g., Doherty and Thistle (1996) and Doherty and Posey (1998), insurance buyers may not be fully informed of their own risk types. This potentially leads to a lower price sensitivity for *XHB* and other *MA* participants and low-risk individuals would stay when they are not highly price sensitive. Alternatively, relatively young and healthy individuals are likely to stay in the pool due to altruism incentives (Bourlès et al., 2021; Say et al., 2014).

4 Data

Our *XHB* data include i) total number of enrollment, ii) shared cost per participant, and ii) claims in each payment period since the October of 2018 (the inception of*XHB*) to August 2020. Since *XHB* has the three-month waiting period for new members, the first claim payment made by *XHB* was in January 28 2019, i.e., 201901#2, as shown in Table 2. For this reason, we 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 reports published on the 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 CI 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 C). As noted in China Actuary Association Report (2013), the incidence rate is calculated based on a group of most popular critical illness insurance policies.[8] 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

[8] 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.

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 aid 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 aid 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 aid plans. Moreover, the report shows that 11,111 survey respondents participate in mutual aid but do not commercial health insurance; 20,323 survey takers purchase commercial health insurance but do not participate in any mutual aid plans; 13,006 survey participants both join mutual aid plans and buy commercial health insurance. More commercial insurance buyers do not participate in mutual aids plans than the other way around.

In Table 2, 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 2). 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 modest 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 the country was shut down to contain the COVID-19 pandemic.

5 Empirical Results

In this section, we first investigate whether *XHB* is designed properly to balance the cost and benefit associated with a large platform. 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 aid programs and traditional insurance with the mutual aid survey conducted by Ant Financial.

5.1 Effect of Diversification

XHB's critical illness program pools together people of different ages in the same platform – participants below 40 years old receive CNY300,000 while participants whose ages are 40 years and above receive CNY100,000. This setup has the benefit to achieve a high level of diversification while it has two potential weaknesses. First, as all participants below 40 and those above 40, respectively, pay the same price to access the coverage pool, it is unclear whether the diversification benefit can offset the potential cost due to relatively high incentive for old people to join *XHB*. Second, whether it is reasonable to set 40 years old as the threshold for the two different price groups. We address these questions 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.

We express the critical illness incidence with a binomial distribution.

$$p_t = \frac{M_t}{N_t} \tag{18}$$

where M_t denotes the numbers of participants receiving payments at time t and N_t denotes the number of participants in *XHB* in period t.

Considering that M_{it} follows a binomial distribution: $p(M_t = m_t) = \left(\begin{array}{c} N_t \\ m_t \end{array} \right) p_t^{m_t}(1-p_t)^{(N_t-m_t)}$, where m_t is reported number of illness cases.

The expected value and variance of M_t are expressed as below:

$$E(M_t) = N_t p_t \text{ and, } \sigma^2(M_t) = N_t p_t(1-p_t) \tag{19}$$

We have

$$\sigma^2 = \sigma^2(p_t) = \sigma^2(\frac{M_t}{N_t}) \quad (20)$$
$$= \frac{p_t(1-p_t)}{N_t}$$

Following Eq. (20), σ increases in p_t when p_t is below 1/2, applicable to 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 the data, we use p_{it} to refer to the incidence rate of a specific age group i at time t. Considering different age groups, N_{it} and M_{it} respectively represent the number of enrollments and paid claims associated with the incidence rate of age group k 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 ($IR6^x_{k,t}$), 25 leading critical illness ($IR25^x_{k,t}$), and all critical illnesses ($IR100^x_{k,t}$, including both severe critical illnesses and non severe critical illnesses). Using the incidence rate of 6 leading illnesses, $IR6^x_{k,t}$, as an example,

$$IR6^x_{k,t} = \frac{c6_{k,t}}{e_{k,t-6}} \quad (21)$$

where $c6_{k,t}$ and $e_{k,t-6}$ are the number of paid claims of the 6 leading critical illnesses at time t and the number of enrollment at $t-6$, as a result of the 3-month (equivalently 6 payment periods) waiting period; in other words, an *XHB* member is not eligible for claim payments till he has been with the platform for 3 months.

We estimate the variance of incidence rates for a given age group using Eq. (20). In Table 3, we report the comparison results for the effect of diversification when pairing a single age group (e.g., 10∼19) with the corresponding combined age-group (10∼29). Panel A reports the results using all stable periods from 201909#2. Panel B reports the result when the COVID-19 lockdown period (202002#2-202004#1) is excluded. Among all pairs, 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 14.43 for the 30-39 age group and it is reduced to 12.41 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.

Next, we answer the question whether it is beneficial to add more age groups to the risk pool from the perspective of diversification. Figure 5 addresses this question by comparing the variance of six age groups: 0-9, 0-19, 0-29, 0-39, 0-49, and 0-59. 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 13.10 for the 0-9 group, and significantly drops to 6.16 for the 0-19 group and 3.31 for the 0-29 group. The variance increases to 3.85, 4.42 and 5.31 for the 0-39, 0-49 and 0-59 groups. The same pattern holds for all illness groups and stays the same for the last payment period.

Taken together, our empirical findings render support to the first hypothesis that there exists an optimal level of diversification. They are also suggestive that optimal cutoff of age for reduced indemnities may be a point between 30 and 40.

5.2 Incidence Rates: *XHB* versus *CII*

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. We report the statistics of claim payments in Table 4. The first column of the table shows the the total number of claims paid in each payment period from January 2019 to December 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 1,953 and it is 2,810 at the end of December 2020. In the subsequent two columns, we break down critical illness into for young participants (participants below 40 years old) and middle aged participants (participants at or above 40 years old) and report the number of cases of each type. Table 4 clearly shows that there are more claims for the middle-aged than for the young. The total number of critical illness claims for the middle-age group in the sample period is 30,978, almost doubles the number of the young group (21,271).

We further report the incidence rates of critical illnesses of *XHB* in each payment period. Denoted as IR^x, the annual incidence rate of *XHB* is 24*IR100^x.

The annualized incidence rates per million for severe critical illness participants are reported in the last column of Table 4. The incidence rate is fairly low in early periods of the sample and there is a jump from the first to the second payment period in September 2019 (from 226 per million to 540 per million). The incidence rate becomes stable after that, with an overall incidence rates from 529 to 670 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 2.

For comparison, we 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 3,085 and 3,347 per million in these categories. *XHB*'s incidence rates reported here, e.g., 442 and 458 per million as of the the average of stable periods, are far below those of CI insurance.

Next, we compare the incidence rates of *XHB* with *CII* within each of the different age groups. The same six age groups are created which allow us to compare the incidence rates of between *XHB* and *CII*.

Like we did in Table 4, we trace incidence rates of illness groups including the 6 leading critical illnesses and 25 leading critical illnesses: $IR6^x_{k,t}$, $IR25^x_{k,t}$, and $IR100^x_{k,t}$.

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 k, for the 6 leading critical illness ($IR6^i_i$) and 25 leading critical illness ($IR25^i_k$), is

$$IR6^i_k = \sum_{j\in k} w_{jk} * IR6^{CAA}_j \quad \text{and} \quad IR25^i_k \quad = \textstyle\sum_{j\in k} w_{jk} * IR25^{CAA}_k \tag{22}$$

Note that j is a specific age reported in CAA, e.g., 35 years old. $IR6^{CAA}_j$ and $IR25^{CAA}_j$ denote *CAA* incidence rates respectively for the 6 leading critical illness and 25 leading critical illness. w_{jk} is the proportion of participants at age j in the age group k.[9]

The results are reported in Table 5, with Panel A for the average results for all stable periods

[9] The CAA table separately reports incidence rate for female and male. We create a combined table based on the sex ratio in 2018 population distribution.

from 201909#2 to 202012#2 and Panel B for the average results for all stable periods excluding the COVID pandemic lockdown period from 202002#2 to 202004#1. Note that the reported incidence rates for *XHB* are annualized per million Without any surprise, incidence rates, for both *XHB* and insurance, are the highest in the 50-59 age group. However, the lowest is in the 10-19 age group for *XHB*, while 0-10 for CI insurance. In the average results, the incidence rates are 43 and 50 per million participants respectively for CI6 and CI25 in age group 10-19, while they are respectively 1,278 and 1,321 per million 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 much 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 the COVID period, though the incidence rates become larger in all age groups after we exclude the COVID lock-down period. 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* in November 2020 and critical illness insurance reported by *CAA* and compare them with the 2018 population distribution across ages. Inspecting the enrollment distributions, we find *XHB* is lower in the young 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 years old to 40 years old. A smoother transition may potentially help *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 age group and drops in the 40-49 age group. 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.

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.

Evidently, the results reported in Table 5 and Figures 6 and 7 suggests that *XHB* has a much lower incidence rate than traditional critial illness insurance. This echos the third hypothesis that the restricted coverage offered by *XHB* leads to a separating equilibrium that healthy individuals participate in *XHB* while less healthy individuals prefer traditional insurance coverages. In practice, Fintech facilites the separation between these types by efficiently declining claims from high-risk participants. This is documented in Section 2.2 – in 2020, Fintech rejects 50% of claim requests during the preliminary screening stage and pre-existing conditions are one of major reasons causing claim rejections.

5.3 Age Gradients of Incidence Rates of *XHB* and *CII*

An important question remaining unanswered is the fairness of *XHB* pricing. We address this question by studying the age gradient of incidence rates for *XHB* and compare it with *CII*. participants below 40 years old and the 40 and above group. As noted earlier, the ratio of indemnity amounts two these two age groups is 3:1 designed by *XHB*, implying that the incidence rate of the mid-aged group is three times of the young-individual group, i.e., an age gradient of incidence rates of 3, if *XHB* is fairly priced.

With the results reported in Panel A of Table 6, we estimate the age gradient of incidence rates above and below 40 for *XHB* and *CII*. We find that, in the stable period, the ratios of incidence rates for 6, 25 and 100 illnesses between the middle-aged and young groups are respectively 4.53, 4.47 and 4.24, all statistically significantly exceeding the indemnity ratio of 3 based on incidence rates in payment periods. For the comparison purpose, we also report the ratios of *CII* incidence rates between the middle-aged and young groups – they are 5.21 and 5.12 for the 6 and 25 leading illnesses, higher than the ratios for *XHB*. We obtain consistent results when excluding COVID lockdown periods.

Taken together, our finding shows that *XHB* is not fairly priced – young participants subsidize the elder group even the shared cost of the young group is one-third of the mid-aged group. Moreover, we find that the magnitude of "mispricing" is smaller for *XHB*. It appears the adverse selection problem is less severe among *XHB* participants.

5.4 Evidence on Advantageous Selection from Mutual Aid Survey

Under the mutuality principle, mutual risk sharing (mutual aid) and risk transfer (insurance) are two non-mutual exclusive mechanisms in risk management. Mutual risk sharing is effective in spreading diversifable risk while the strength of insurance is in handling risks of high information costs. Following this idea, we expect mutual aid products to supplement the insurance market. In this section, we primarily focus on the relationship between mutual aid and insurance, whether it is supplementary or substituting, and test it using a survey distributed to Ant Financial members.

Ant Financial conducted a survey distributed to Alipay users in March 2020. This resulted in 58,719 valid responses. Among the completed surveys, 24,117 respondents participate in least one type of mutual aid products (41.07%); the supermajority of them (51,128) are invovled in the government sponsored social security program involving medical protection; Slightly more than half of the respondents (29,823) purchased commercial medical insurance products, including critical illness insurance, Further, 21,867 had both mutual aid and social security coverage (37.2%) and 12,011 had bought both mutual aid product and commercial insurance (20.5%). The number of participants that only have mutual aid but no insurance or social security is 1,255, while the number of participants that only have have insurance but not mutual aid or social security is 2,512.

The rich questionaire lends us the ability to answer additional questions. We are interested in the heterogeneity across individuals in their participations and examine the relationship between mutual aid programs with traditional commercial health insurance programs. We carry out a logistic regression based on the survey conducted by Ant Financial distributed to Alipay users, and report the findings in Table 7.

The dependent variable is an indicator of a survey participant participates in an mutual aid program including *XHB*. In Table 7, we first report the baseline regression Explanatory variables include participant ages (*Age*), their gender (*Female*), income group (*Inc1-Inc5*), city tier (*CityTier*), and whether they have commercial insurance coverage (*Ins*). Participants' 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*). *CityTier* takes a number from 1 to 6; the higher the number is, the worse economic development the city is. 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.

Shown in Column 1, across participants of all ages, the willingness to join a mutual aid 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 aid 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 aid 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 aid 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 aid 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 aid participants. Interestingly, in the all-age regression and two grouped regressions, we find the coefficient on *Ins* is -0.29, -0.28 and -0.34, all statistically significant at the 1 percent level, suggesting mutual aid programs to be supplementary to commercial critical illness insurance in all age groups. Early works show that the existence of advantageous selection that wealthy and healthy individuals are more likely to purchase insurance and other medical coverage (see, e.g., Cutler, Finkelstein, and McGarry, 2008; Fang, Keane, and Silverman, 2008). The analysis based on Alipay survey is aligned with this line of argument.

6 Conclusion

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 actuarial models to price products, *XHB*, letting participants share medical costs, is far more transparent and easy to implement than traditional critical illness insurance products. *XHB* restricts coverage amount, which is less than typical critical illness insurance products, particularly for relatively older participants. 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.

Strictly enforcing the law of large numbers to diversify idiosyncratic risks, *XHB* and mutual risk sharing works well when there is a large and stable pool of participants. Fintech facilitates decentralized risk pooling by lowering its operational costs and increasing operational efficiency. Together with its restriction on high risk individual participation, the low-cost and low-loading feature of *XHB* makes it appealing among young people, relatively healthy, and low incomers. Our empirical evidence shows that *XHB*'s incidence rates are lower than comparable critical illness insurance. This result holds for different different age groups. Our findings raise doubt about the efficiency of traditional insurance market. Instead, our findings support the presence of advantageous selection in mutual aid programs. The low-cost and efficiency advantage of Fintech of *XHB* make it attractive when competing with traditional insurance.

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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)	Same as V3
		100,000 (Reduced)	
	40 to 59 years	100,000 (Standard)	Same as V3
		50,000 (Reduced)	
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: 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 December 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
202009#1	101,279,021	385,250,000	4.17
202009#2	100,716,367	381,700,000	4.17
202010#1	100,486,662	386,300,000	4.23
202010#2	100,287,800	439,300,000	4.86
202011#1	100,669,825	436,750,000	4.83
202011#2	100,026,526	432,100,000	4.83
202012#1	98,243,639	424,250,000	4.83
202012#2	97,159,970	460,300,000	5.31

Table 3: Effect of Diversification

This table reports the variances of incidence rates (reported as annualized per million *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 202012#2. Panel B reports the average results based on the *XHB* claim data from 201909#2 to 202012#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	5.75	12.25	-6.49	(-12.80)	6.55	13.78	-7.23	(-13.59)	9.51	20.14	-10.63	(-14.43)
10∼19	10∼29	4.02	9.27	-5.25	(-8.12)	4.26	10.86	-6.59	(-8.86)	5.03	15.53	-10.50	(-11.99)
20∼29	20∼39	5.03	5.27	-0.25	(-1.41)	5.23	5.56	-0.32	(-1.82)	5.93	6.47	-0.54	(-2.95)
30∼39	30∼49	12.41	14.43	-2.03	(-6.96)	12.82	14.97	-2.15	(-7.25)	14.19	16.79	-2.60	(-8.57)
40∼49	40∼59	40.19	52.83	-12.64	(-7.12)	41.51	54.39	-12.89	(-7.24)	45.58	59.37	-13.79	(-7.29)
Panel B: Results of Non-COVID19 "Stable" Periods													
<10	0∼19	6.16	13.10	-6.94	(-13.44)	7.02	14.75	-7.73	(-14.59)	10.20	21.65	-11.43	(-16.81)
10∼19	10∼29	4.25	9.98	-5.72	(-8.31)	4.51	11.68	-7.17	(-9.24)	5.33	16.58	-11.25	(-12.60)
20∼29	20∼39	5.32	5.57	-0.25	(-1.22)	5.55	5.88	-0.33	(-1.63)	6.29	6.85	-0.56	(-2.64)
30∼39	30∼49	13.23	15.30	-2.07	(-6.19)	13.68	15.88	-2.21	(-6.49)	15.16	17.84	-2.69	(-7.78)
40∼49	40∼59	43.11	56.69	-13.58	(-6.88)	44.51	58.35	-13.84	(-6.98)	48.90	63.76	-14.85	(-7.08)

Table 4: 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. # total is the total number of paid claims # <40 (≥40) is the number of critical illness program of participants below 40 years old (at or above 40 years old) 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.Then this number is annualized, i.e., multiplied by 24, and converted to per million basis: $IR_t^x = 24 * 1,000,000 * \frac{c_t}{e_{t-6}}$. The last row reports the aggregate numbers of cases for different groups and the average incidence rates.

Period	# (Full sample) (1)	# (<40) (2)	# (≥40) (3)	IR_t^x (per mil) (4)
201901#2	2	2	0	0
201902#1	1	0	0	0
201902#2	3	3	0	0
201903#1	1	1	0	0
201903#2	1	0	0	0
201904#1	3	3	0	0
201904#2	9	8	1	9
201905#1	10	6	4	7
201905#2	32	23	9	22
201906#1	100	53	47	64
201906#2	150	90	60	87
201907#1	286	178	108	141
201907#2	496	301	195	227
201908#1	500	319	181	211
201908#2	615	347	268	235
201909#1	632	377	255	226
201909#2	1,581	862	719	540
201910#1	1,718	904	814	563
201910#2	1,731	863	868	549
201911#1	1,735	857	878	538
201911#2	1,837	811	1,026	552
201912#1	1,931	860	1,071	556
201912#2	1,953	863	1,090	547
202001#1	2,025	882	1,143	553
202001#2	2,279	982	1,297	610
202002#1	2,381	1,056	1,325	609
202002#2	1,045	459	586	264
202003#1	1,047	462	585	260
202003#2	1,003	440	563	247
202004#1	1,753	709	1,044	430
202004#2	2,559	835	1,724	621
202005#1	2,411	833	1,578	582
202005#2	2,234	851	1,383	539
202006#1	2,219	801	1,418	532
202006#2	2,213	768	1,445	529
202007#1	2,291	751	1,540	544
202007#2	2,275	733	1,542	540
202008#1	2,370	776	1,594	563
202008#2	2,344	757	1,587	557
202009#1	2,336	775	1,561	554
202009#2	2,300	770	1,530	547
202010#1	2,303	785	1,518	547
202010#2	2,660	885	1,775	632
202011#1	2,663	873	1,790	631
202011#2	2,607	869	1,738	619
202012#1	2,554	867	1,687	605
202012#2	2,810	917	1,893	670
Total/Avg	52,250	21,272	30,978	430

Table 5: Incidence rates by Age Groups: *XHB* versus Critical Illness Insurance

This table reports the number of 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 202012#2. Panel B reports the results in the "stable" period while excluding COVID-19 lockdown periods. *CI6* and *CI25* respectively represent 6 and 25 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* Cases		IR^x (per million)		IR^i (per million)		IR Ratio CII/XHB	
		CI6	CI25	CI6	CI25	CI6	CI25	CI6 (t-stats)	CI25 (t-stats)
Panel A: Results Based on "Stable" Periods									
<10	6,512,308	22	25	80	90	175	257	2.55 (5.31)	3.32 (6.20)
10∼19	4,728,042	9	10	43	50	249	321	7.16 (5.91)	8.23 (5.27)
20∼29	26,926,729	163	171	146	153	995	1,102	7.65 (9.64)	8.02 (9.59)
30∼39	28,091,886	457	473	391	404	2,391	2,558	6.50 (10.53)	6.71 (10.47)
40∼49	14,515,814	461	474	763	784	4,933	5,297	6.96 (8.42)	7.26 (8.63)
50∼59	10,814,477	576	595	1,278	1,321	8,100	8,780	7.40 (8.17)	7.77 (8.35)
Total	91,589,257	1,689	1,748	442	458	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	88	99	175	257	2.15 (6.73)	2.80 (7.99)
10∼19	4,671,539	9	11	48	55	249	321	6.01 (4.47)	6.72 (4.02)
20∼29	26,604,940	175	183	157	166	995	1,102	6.93 (7.42)	7.21 (7.20)
30∼39	27,756,173	489	505	422	437	2,391	2,558	5.80 (8.46)	5.98 (8.43)
40∼49	14,342,342	502	515	840	862	4,933	5,297	5.88 (6.82)	6.14 (6.93)
50∼59	10,685,238	624	644	1,401	1,446	8,100	8,780	6.40 (6.61)	6.74 (6.76)
Total	90,494,716	1,822	1,885	483	500	3,085	3,347	6.39 (7.32)	6.70 (7.39)

Table 6: Incidence rates of Age Groups and Cost Sharing

This table shows the incidence rates of *XHB* and critical illness insurance as well as ratios between these two for people below 40 years old and those of 40 years old and above. Panel A reports the results in the "stable" claim period from 201909#2 to 202012#2. Panel B reports the results in "stable" periods excluding the COVID lockdown period. *IR6* and *IR25* represent incidence rates for 6, 25 leading critical illnesses of *XHB* and *CII* and and *IR100* is for the incidence rate of all illness. The *t*-statistics of ratios for the relative incidence rates between the 40-59 group and the below 40 group minus 3 are reported in the parentheses.

Panel A: Results Based on "Stable" Periods

	XHB			*CII*	
	IR6	IR25	IR100	IR6	IR25
<39	233	244	283	1,183	1,300
40∼59	1,055	1,091	1,200	6,167	6,656
40∼59/<39	4.53	4.47	4.24	5.21	5.12
(*t*-stats)	(6.54)	(6.52)	(6.26)		

Panel B: Results Based on Non-COVID "Stable" Periods

Group	*XHB*			*CII*	
	IR6	IR25	IR100	IR6	IR25
<39	245	258	299	1,183	1,300
40∼59	1,132	1,171	1,288	6,167	6,656
40∼59/<39	4.61	4.54	4.31	5.21	5.12
(*t*-stats)	(6.56)	(6.48)	(6.20)		

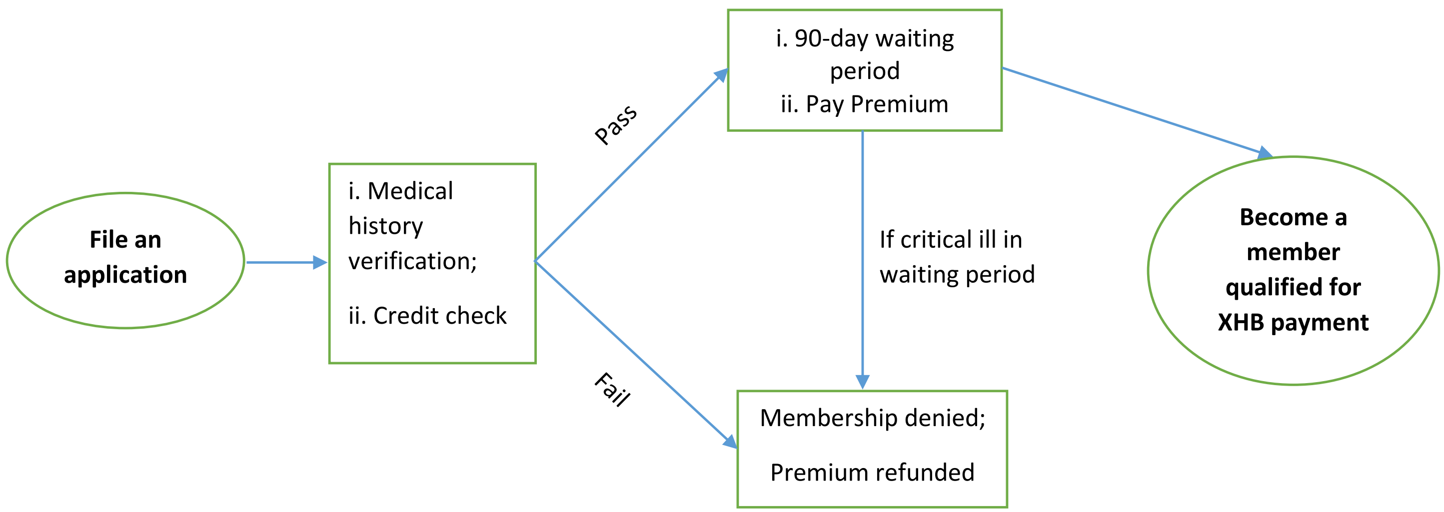
Table 7: Logistic Regressions of Mutual Aid Participation Data

This table presents the logistic regression results based on a survey on mutual aid 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 aid program. Panel A reports a baseline regression examining the determinants of mutual aid 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), and whether they have commercial insurance coverage (Ins=1 if they have; Ins=0 if not).

Panel A: Baseline Regression

	(1) All ages	(2) <40 years	(3) ≥40 years
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)
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 A: Procedure to Enroll in XHB



Panel B: Claim Process

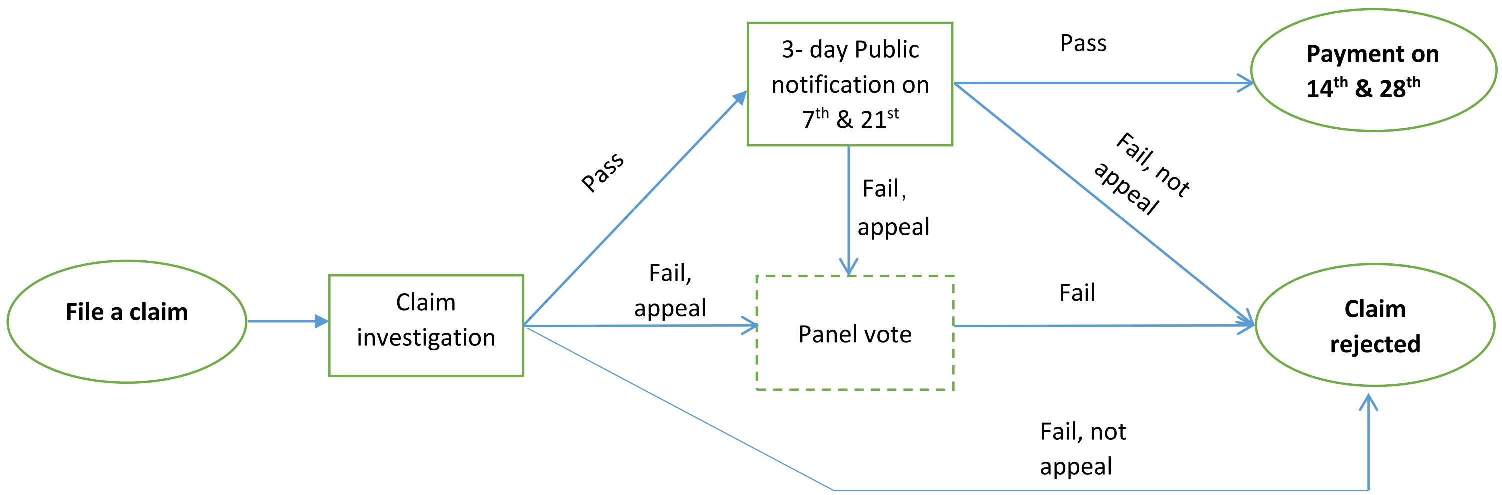


Figure 1: Enrollment and Claim Procedures

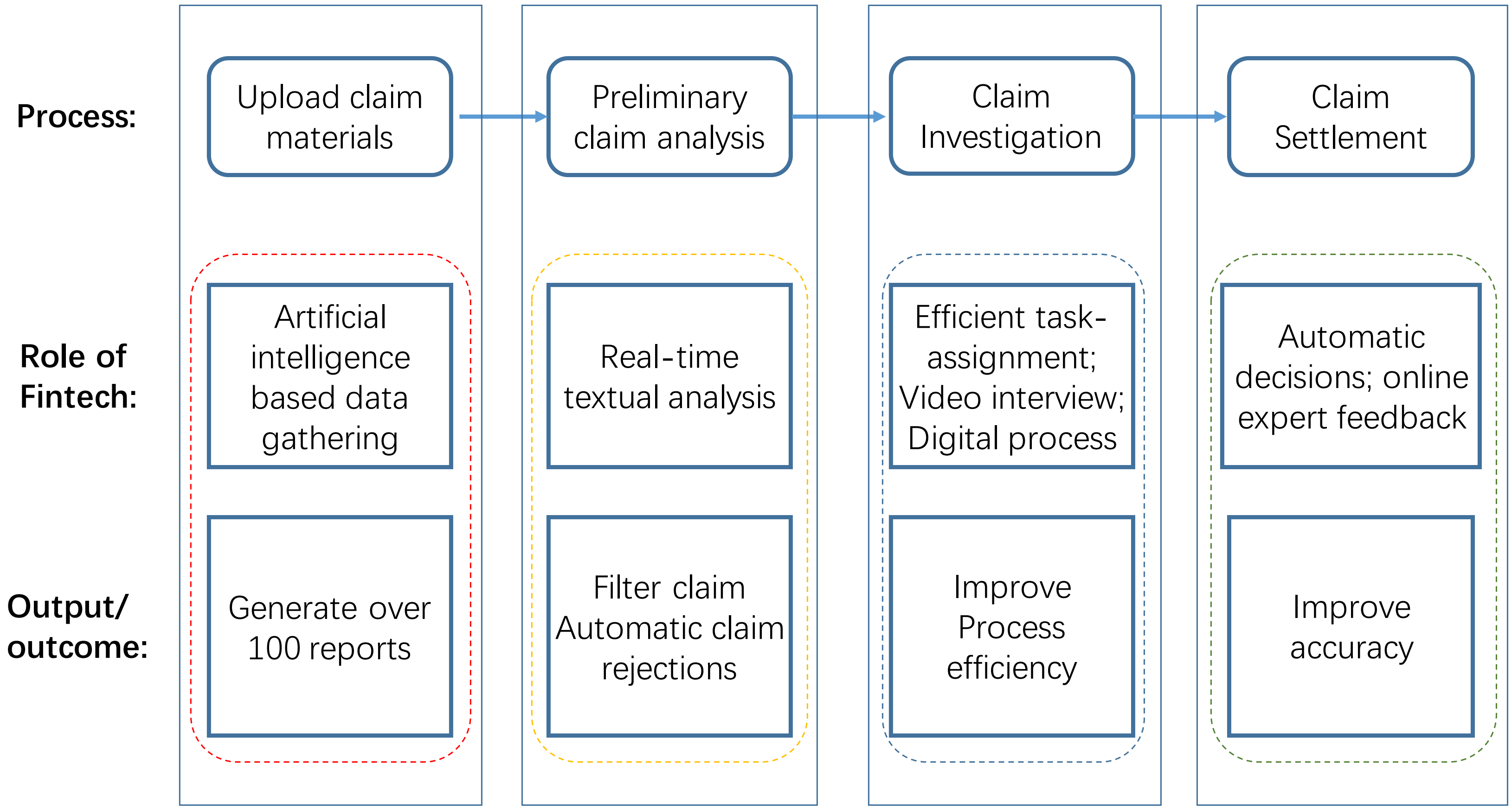


Figure 2: Fintech in XHB Claim Process

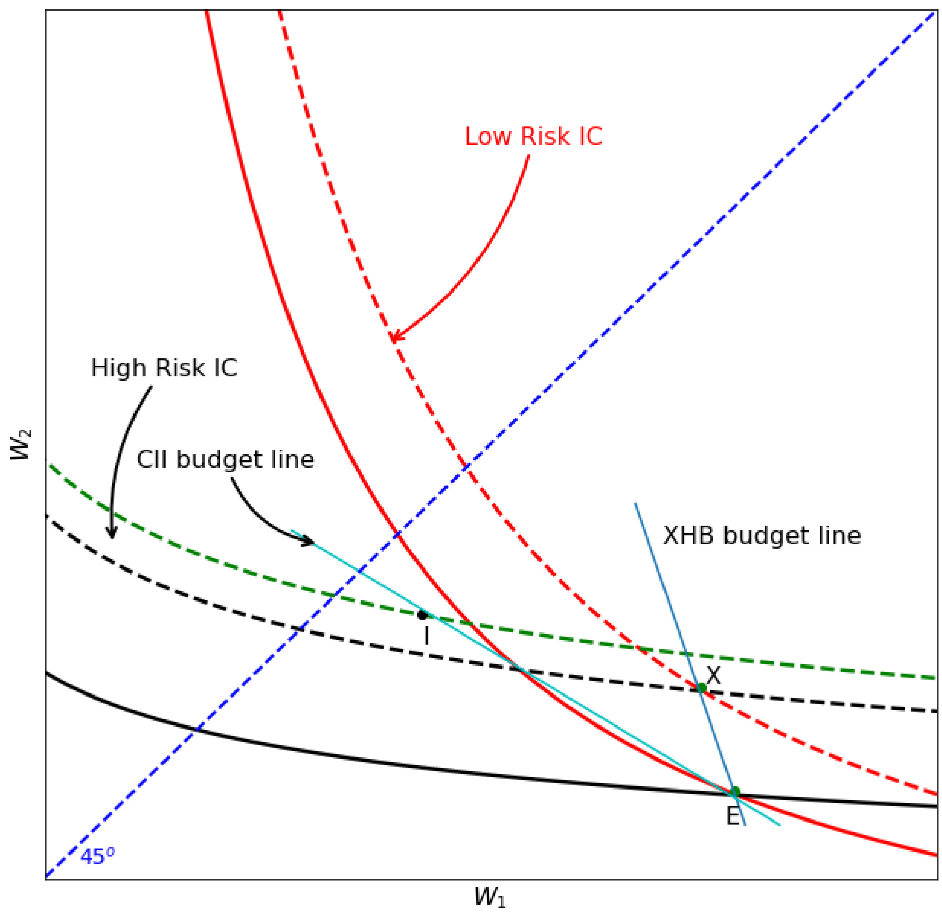


Figure 3: Mutual Aid versus Critical Illness Insurance
W_1 represents an individual's aggregate payoff at t and $t+1$ in the no-loss state. W_2 represents the individual's aggregate payoff at t and $t+1$ in the loss state.

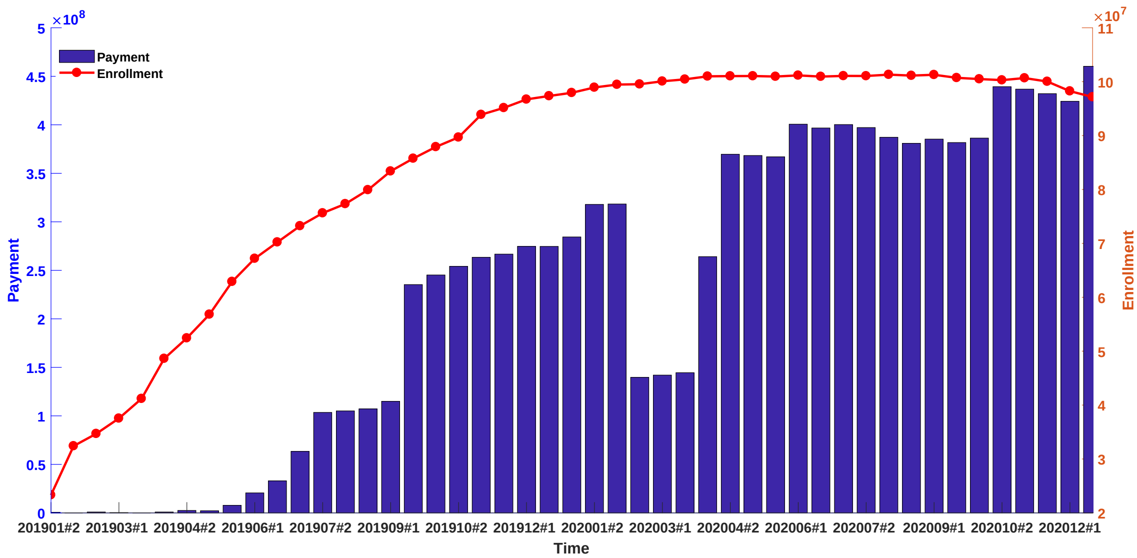


Figure 4: *XHB* Enrollment and Aggregate Claim Payout

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

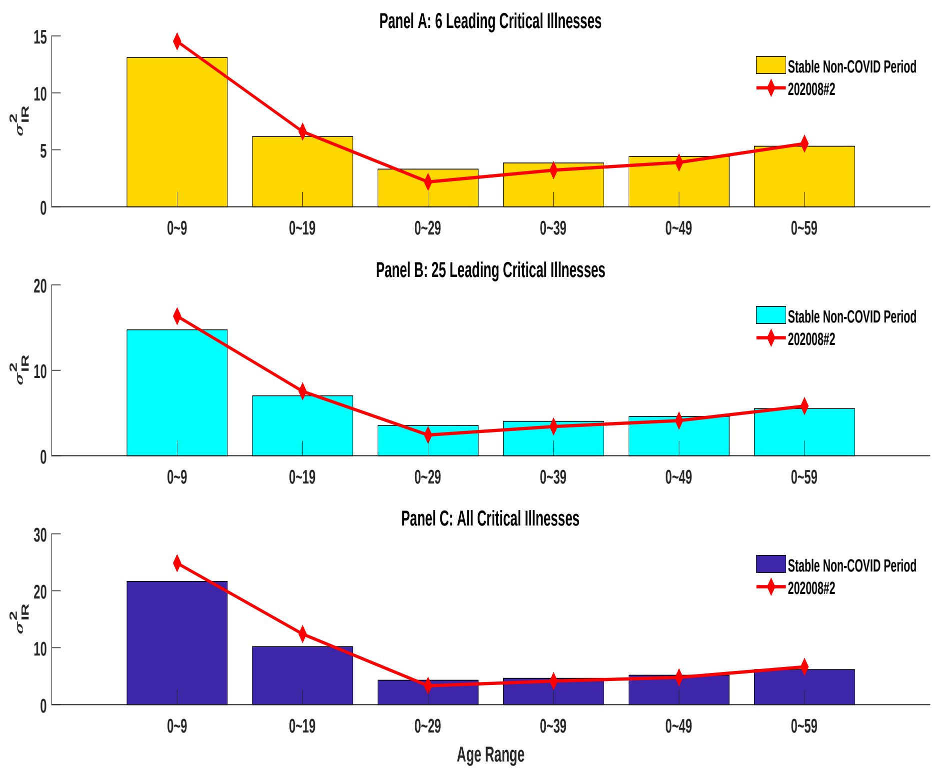


Figure 5: Diversification across Age Groups

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: 202012#2.

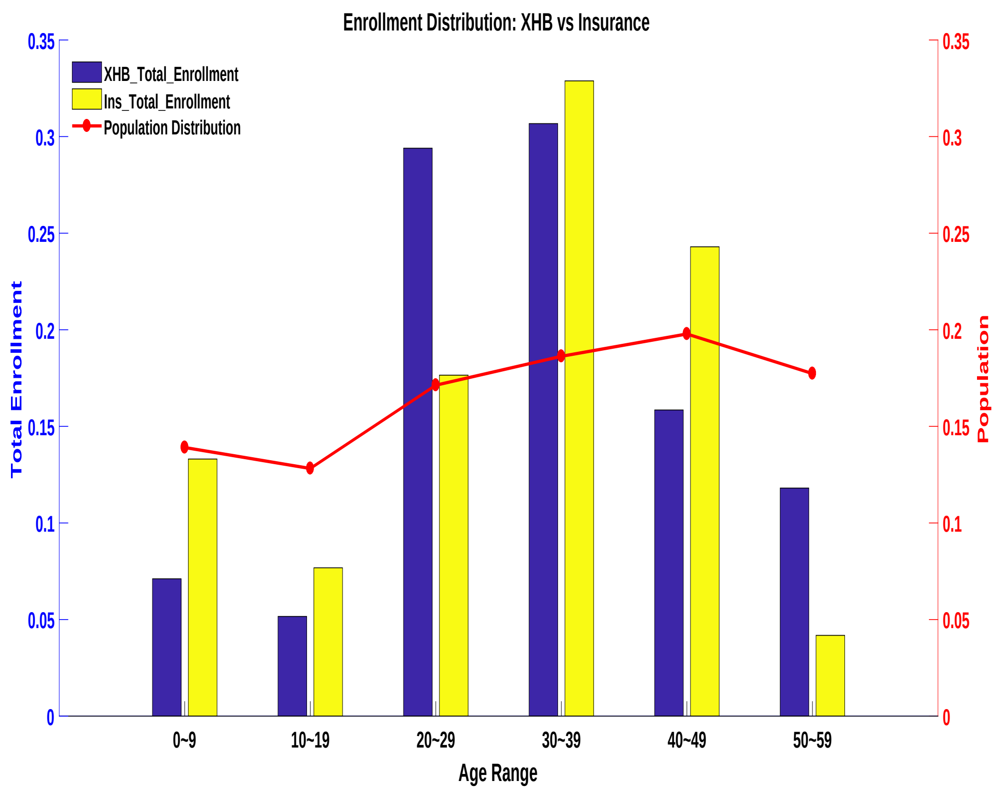


Figure 6: Enrollment Distribution across Different Age Groups

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

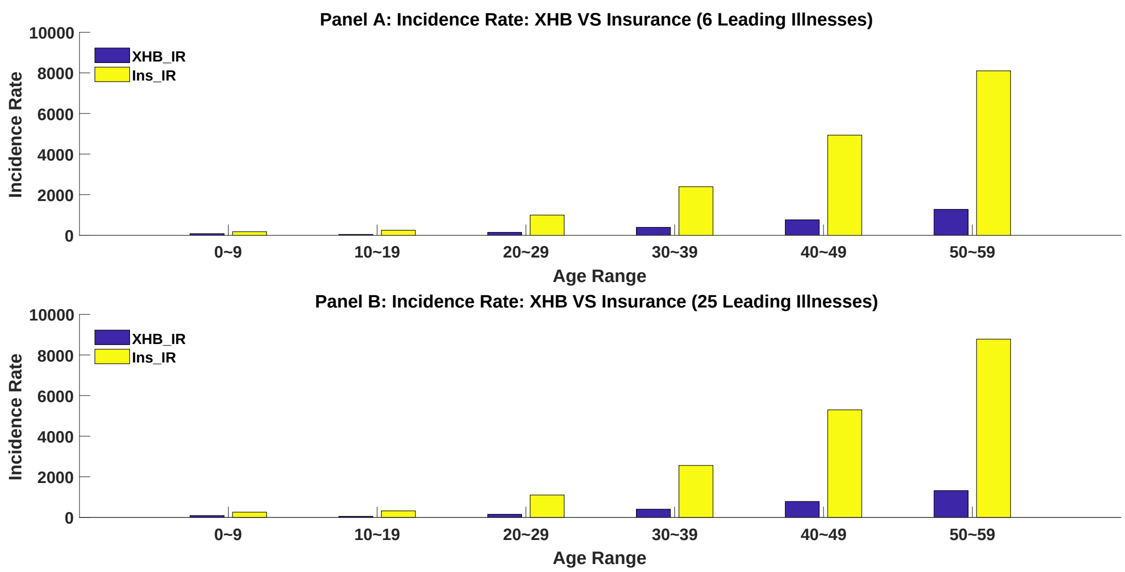


Figure 7: Incidence Rates of *XHB* and Critical Illness Insurance across Age Groups
This figure shows the incidence rates of age groups for *XHB* and critical illness insurance.

Appendix

A Optimal Risk Sharing: A Review

This appendix summarizes the Borch (1962)'s theorem which derives 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. While which state prevails in the future is unknown, there is a probability p^s attached to the realization of state s. Use w_i^s to denote the uncertain wealth to individual i in state s and use Π_s to 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:

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

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 $\pi^s = \frac{\Pi^s}{p^s}$ (the price of state s per unit of state and η_i is the shadow cost of violating the wealth constraint, Eq. (A2).

The above expression describes the market participant's tradeoff at the equilibrium point. $u_i^{'}[c_i^s]$ is the marginal utility of consumption for agent i in state s; i.e., the gain in the agent's utility given a change in her consumption in state s. $\pi^s \eta_i$ represents the shadow cost for agent i when its consumption deviates from the optimal consumption, $\hat{c}_i^s$.

In equilibrium, an individual agent i's wealth change in state s is $\hat{c}_i^s - w_i^s$, which can be denoted as $\hat{z}_i^s$.

Summing up across individuals in each state s, we have that in each state the aggregate net wealth change is 0 when the market is cleared: $\sum_{i=1}^n \hat{z}_i^s = 0$.

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

Intuitively, in absence of transaction costs, risk sharing does not alter the aggregate wealth in any state even it makes changes to individual agents' consumption plan in individual states.

Now let us consider the simple case of idiosyncratic uncertainty – i.e., the aggregate wealth is constant even though individual wealth varies across states. Since the risk can be diversified away when an individual pools her risk with other participants, she would have the same consumption regardless of the state. In other words, agents hold a risk-free portfolio. It can be easily shown that $\pi^s = \frac{1}{1+r}$ where r is the risk free rate of return. Accordingly, the state price Π^s is fully determined by p^s:

$$\Pi^s = \frac{p^s}{1+r} \tag{A5}$$

It states that when the aggregate risk can be fully diversified away, the state contingent price does not depend on individual agents' risk tolerance, but fully depends on their probability of having state s. An individual is willing to pay a higher price for state t when she has a greater likelihood to have the state. Take *XHB* as an example. A greater critical illness likelihood results in a higher participation cost for *XHB*.

Next we consider the general case that the aggregate wealth is not expected to be the same across states. 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:

$$\frac{d\hat{c}_i^s}{dw_s} = \frac{t_i}{\sum_i^n t_i}. \tag{A6}$$

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

In other words, any increment in an agent's wealth should be shared in proportion to individual risk tolerances. Details of the derivations can be found in Wilson (1968). Under the specific setting of critical illness risk sharing, when the aggregate cost of critical illness is uncertain, we expect less risk averse agents to take more risks.

B Proofs

B.1 Proof of Equation (6): $\frac{\partial Eu^x}{\partial N} \propto (\frac{\partial p^x}{\partial N} + \gamma \frac{\partial \sigma}{\partial N})$

We take derivatives of the expected utility specified in Eq. (3) (in the sense that pool size would only affect the participant's expected utility in period t). Using N to denote the aggregate number of participants for *XHB*, we have:

$$\begin{aligned}\frac{\partial E[u^x]}{\partial N} &= \frac{\partial E[u(w_{st} - \pi_t^x)]}{\partial N} \\ &= \frac{\partial u(w_{st} - p^x K(1+\lambda^x) - \Pi_t^x)}{\partial N}\end{aligned}$$

We know that $\Pi_t^x = 1/2A_s[K(1+\lambda^x)]^2\sigma_x^2$. Inserting both to Eq. (B1), we have

$$\frac{\partial Eu^x}{\partial N} \propto (\frac{\partial p^x}{\partial N} + \gamma \frac{\partial \sigma}{\partial N}) \tag{B1}$$

where $\gamma = A_s K(1+\lambda^x)\sigma$.

B.2 Proof of Equations (14): $\frac{\partial W_2}{\partial W_1}|_X = \frac{\pi_t^x - K^x}{\pi_t^x} = 1 - \frac{1}{p_t^x(1+\lambda^x)}$

The line EX is the *XHB*'s breakeven line. As plotted in Figure 3, the coordinators of E and X are respectively $(w_t + w_{t+1},\ w_t + w_{t+1} - O)$ and $(w_t - \pi^x + w_{t+1},\ w_t - \pi^x + w_{t+1} - O + K^x)$. Scaling the difference between the payoffs in loss states (W_2) by the difference between payoffs in no-loss states (W_1), we have the slope of EX to be $\frac{\pi_t^x - K^x}{\pi_t^x}$.

Recall that $\pi_t^x = p_t^x K(1+\lambda^x)$ (Eq. 1 and insert it in the expression for the slope of EX. This gives us

$$\frac{\partial W_2}{\partial W_1}|_X = 1 - \frac{1}{p_t^x(1+\lambda^x)} \tag{B2}$$

Thus, we prove Eq. (15).

Eq. (15) can be proved in the same way.

B.3 Proof of Eq. (16)

Following Eq. (3), we have $E[u^x] = E[u(w_{st} - \pi_t^x)] + \beta[(1-p_s)u(w_{s,t+1}) + p_s u(w_{s,t+1} - O + K^x)]$

Similarly, $E[u^e] = E[u(w_{st})] + \beta[(1-p_s)u(w_{s,t+1}) + p_s u(w_{s,t+1} - O)]$

Taking the difference between $E[u^x]$ and $E[u^e]$, we have Eq. (16).

Eq. (17) can be obtained in the similar way.

C List of Critical Illness

Panel A: Critical Illness

#	Critical illnesses	CBIRC 6	CBIRC 25
1	Malignant tumor/cancer	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