Theoretical Considerations

We begin by describing how the market attains equilibrium using the demand for and supply of insurance contracts in a well-functioning competitive environment. Consider an individual who purchases an insurance contract to smooth the flow of his/her income across different states of nature. For simplicity, we assume two states of nature, *no loss* and *loss*. We also assume that the insured individual maximizes his/her expected utility. In the absence of insurance, an individual's preference for income in these two states of nature is given by:

(1) $V(m, p) = (1-p)\,U(m) + p\,U(m - d)$

where m is income, p is the probability of loss, and d is the reduction in income or the amount of loss. U(•) represents the utility of money income, while (1-p) indicates the probability of not incurring a loss. When an individual purchases an insurance contract, the function describing his or her preference for income in the two states of nature is:

(2) $V(\alpha_1, \alpha_2; p) = (1-p)\,U(m-\alpha_1) + p\,U(m-d-\alpha_1+\alpha_2)$

where α_1 is the premium cost, α_2 is the payoff (indemnity) from the insurance contract in the case of loss, and V is the expected utility. An insurance contract may be viewed as a promise by the insured to pay an amount α_1 to the insurer, in return for a promise by the insurer to pay indemnities α_2 if a loss occurs. We assume that individuals are risk averse ($U' < 0$) and, thus, that V is quasi-concave. From all the contracts offered, the individual will choose the one that maximizes his/her expected utility, V.

Assuming that insurance companies are risk neutral (concerned only with expected profits) and that returns from insurance contracts are random, an insurance contract sold to an individual who has the probability of incurring a loss of p, is worth:

(3) $\pi(\alpha_1, \alpha_2; p) = (1-p)\alpha_1 - p(\alpha_2-\alpha_1)$.

If insurance contracts are sold in a full information-competitive market, then the expected profits are zero:

(4) $(1-p)\alpha_1 - p(\alpha_2-\alpha_1) = 0$.

Equation 4 ensures that the expected benefit, $(1-p)\alpha_1$, is equal to the expected cost, $p(\alpha_2-\alpha_1)$, of the firm, assuming no administrative costs.[1] In other words, equation 4 represents the set of contracts that have actuarially fair premium rates.

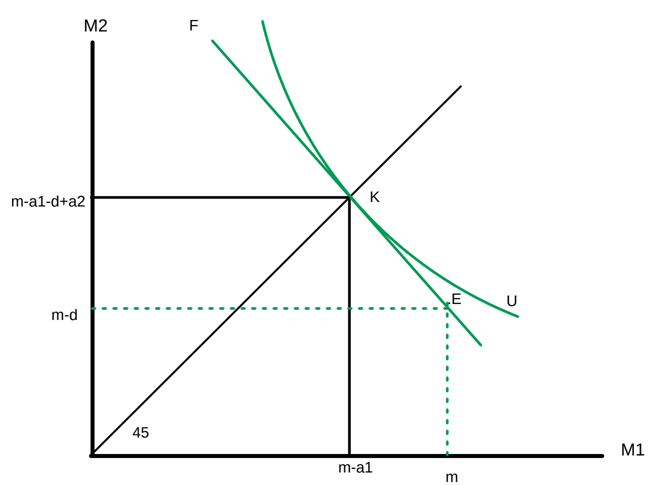
Market Equilibria in Insurance Markets

In insurance markets, unlike other markets, the state of information available to consumers and suppliers of insurance, as well as the nature of the insurance markets' equilibria, matters in understanding how the market functions. Next, we describe in detail the nature of market equilibria under different information conditions in insurance markets.

Market Equilibrium with Full Information

Figure 1A illustrates the equilibrium of a competitive insurance market with identical individuals and *full information* conditions. The horizontal (M_1) and vertical (M_2) axes represent income in the two states: *no loss* and *loss*, respectively. U is the indifference curve representing an individual's preference set. The 45° line represents equal income in both states of nature. The line EF, which is referred to as the fair-odds line, represents the supply of insurance (see equation 4). Policies break even (zero profit for the insurance company, assuming no administrative costs) along the fair-odds line. The slope of the fair-odds line (the supply of insurance) is given by the ratio of the probability of not having a loss to the probability of having a loss, (1-p)/p, while the slope of the indifference curve (the demand for insurance) is given by the marginal rate of substitution of incomes in the two states of nature $\{U'(m_1)\}/\{U'(m_2)\}$. In equilibrium, the

Figure 1A
Market equilibrium with full information and identical risk types

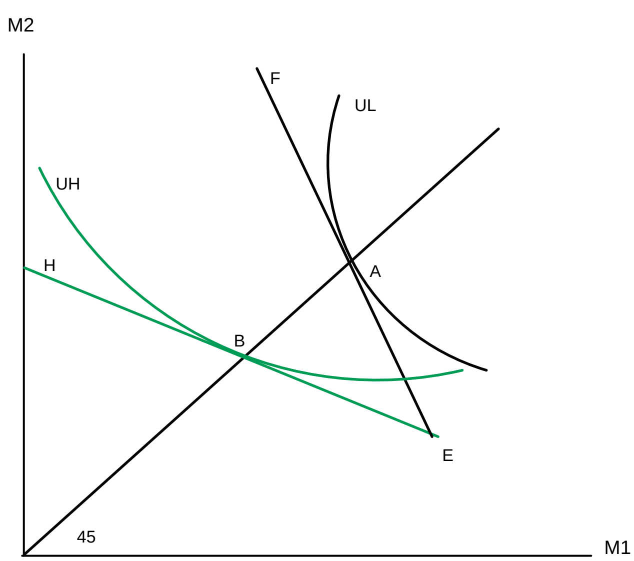


slope of the fair-odds line is equal to the slope of the indifference curve.

An individual starts at an initial endowment E, where income is equal to m if no loss occurs or m-d if a loss occurs. Individuals may reduce their exposure to the risk of loss by trading insurance contracts along the fair-odds line, EF. The equilibrium contract, K, maximizes an individual's expected utility, and it represents *full insurance* coverage, equalizing income in both states of nature. That is, in equilibrium, individuals buy full insurance coverage at an actuarially fair rate resulting, in what is known as, a *full information equilibrium*. Since the contract, K, is on the fair-odds line, the insurer just breaks even.

Figure 1B illustrates the equilibrium of a competitive insurance market with *full information* but individuals representing different levels of risk. Consider a market structure similar to the one discussed above, except that there are low- and high-risk individuals whose probability of loss is known to the insurer. We assume, for simplicity, that there are only two types of individuals ("low-risk" and "high-risk") in the market who differ in their probability of suffering a loss. Let the probability of loss occurrence for high- and low-risk individuals be p^H and p^L, respectively, which implies that p^H is greater than p^L. The low-risk contracts are represented along the line EF, with a slope given by $(1-p^L)/p^L$, while the high-risk contracts are represented along the line EH, with a slope given by $(1-p^H)/p^H$. In this case, the slopes and shapes of indifference curves

Figure 1B
Market equilibrium with full information and different risk types



differ among risk types and depend on the individuals' risk attitudes. Let UL and UH represent indifference curves for low-risk and high-risk individuals, respectively. When the individuals' probability of loss is known, the insurer will offer different contracts commensurate with the various risk types. At equilibrium, both risk types are fully insured at actuarially fair rates at points A and B, where the marginal rate of substitution (the slope of the indifference curve) along the 45º line is just equal to the ratio of the probability of not having a loss to that of having a loss (the slope of the fair-odds line).

Market Equilibrium with Asymmetric Information

Akerlof (1970), in his pioneering work on asymmetric market information, demonstrates the problems that arise in health insurance markets when an applicant for insurance has full information about his/her health, while insurers have no such information. He uses the example of an insurer who is unable to distinguish between high- and low-risk insurance applicants, and values contracts at an average premium for all applicants. In this case, only those individuals whose risk is above average are likely to buy insurance. This will result in losses for the insurer and, thus, premiums would have to be raised for the insurer to break even. Of the group which purchased insurance in the first place, only the worse-than-average risks would purchase insurance again at the higher premium. Premiums would again need to be raised to cover losses and, eventually, only the very high-risk individuals would purchase insurance at extremely high premiums and the entire market for insurance would collapse.

In their seminal work, Rothschild and Stiglitz (1976) explain the existence of equilibrium in an insurance market in which asymmetric information exists between insurer and insurance applicant. In the absence of full information, this market can have two kinds of equilibria: *a pooling equilibrium* or a s*eparating equilibrium*. In a pooling equilibrium, high- and low-risk insurance applicants are not differentiated by the insurer and, therefore, contracts are priced at an average premium. Contracts are offered to both groups at the same premium, and hence, applicants buy i*dentical contracts*. This situation leads to the type of market described above in the Akerlof model. In a separating equilibrium, on the other hand, different risk types purchase different contracts that are associated with different premium rates and contract characteristics. In a separating equilibrium, individuals of different risk characteristics separate themselves by contract selection, with the insurer offering *different contracts* commensurate with different risk types.

Figure 1C illustrates an example of *pooling equilibrium* under asymmetric information. As in the previous example, we assume that there are two types of individuals in the market: “low-risk” and “high-risk,” who differ in their probability of suffering a loss. Let the probability of loss occurrence for high- and low-risk individuals be p^H and p^L , respectively, which implies that p^H is greater than p^L. The low-risk contracts are represented along the line EF, with a slope given by $(1-p^L)/p^L$, while the high-risk contracts are represented along the line EH, with a slope given by $(1-p^H)/p^H$. In this case, the slopes and shapes of indifference curves differ among risk types and depend on the individuals’ risk attitudes. Let UL and UH represent indifference curves for low-risk and high-risk individuals, respectively. When an individual’s probability of loss is hidden knowledge, the full-information equilibrium (A, B), in which both risk types are optimally insured, is *unattainable*. This is because insurers cannot prevent high-risk individuals from purchasing the contract A, which assures higher utility in each state.

Furthermore, the nature of asymmetric information implies that insurance companies are unable to distinguish among their customers and, therefore, charge an average premium (represented by line EG). In the resulting pooling equilibrium, the high-risk individual will buy contract B′ and the low-risk individual will buy contract A′. At these levels of coverage, high-risk individuals pay less and low-risk individuals pay more relative to their respective full insurance contracts. In this case, the high-risk individual is over-insured (undercharged), while the low-risk individual is under-insured (overcharged).

Figure 1D illustrates an example of a *separating equilibrium* under asymmetric information, as described by Rothschild and Stiglitz (1976). Consider a market structure similar to the one discussed in figure 1C, except that the insurer offers two contracts at two different prices. The low-price contracts are represented along the line EF, with a slope given by $(1-p^L)/p^L$, while the high-price contracts are represented along the line EH, with a slope given by $(1-p^H)/p^H$. Let UL and UH represent indifference curves for low- and high-risk individuals, respectively. As in the previous case, when an individual’s probability of loss is unknown, the full-information equilibrium (A, B), in which both risk types are optimally insured, is *unattainable*. The full information equilibrium (represented by contracts A and B in this example) is where the insureds’ expected utilities are maximized (UL and UH) and the insurer breaks even. This full information equilibrium is unattainable because high-risk individuals prefer the contract A over B, as A assures higher utility (consumption) in each state. In this case, however, the insurer can offer two contracts (represented

Figure 1C
Pool equilibrium under asymmetric information and different risk types

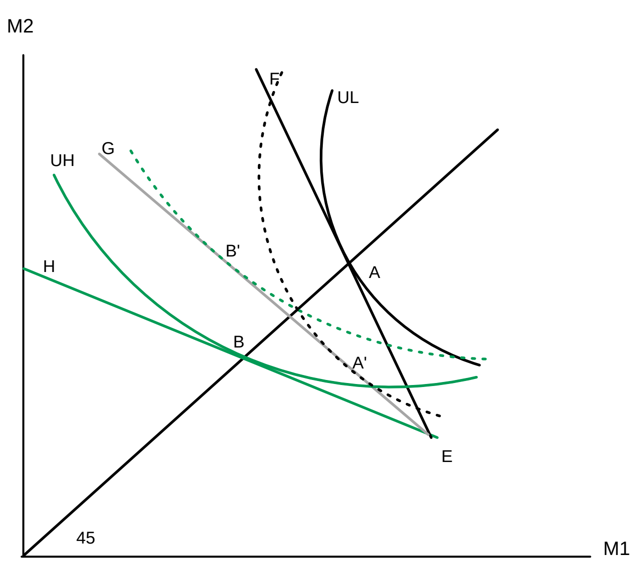
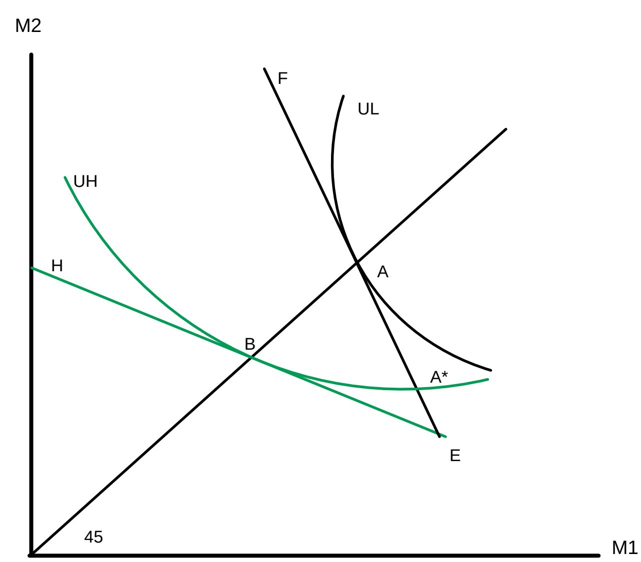


Figure 1D
Separating equilibrium under asymmetric information and different risk types



by fair-odds lines EF and EH) suitable for the two different risk types.

Since the insurer cannot separate low-risk applicants from high-risk applicants, the contract offered to low-risk types must not be more attractive to high-risk types than their best contract. In the resulting equilibrium, the high-risk individual will buy contract B and the low-risk individual will buy contract A*. Thus, for a separating equilibrium to exist, the low-risk contract must lie on the high-risk indifference curve, U^H, or lower. This establishes the contract set (A*, B) as the attainable equilibrium for a market with low- and high-risk individuals. At the equilibrium, high-risk individuals buy the full insurance contract, B (where the high-risk fair-odds line is tangent to the high-risk indifference curve), while low-risk individuals will buy the partial insurance contract, A* (where the low-risk fair-odds line intersects the high-risk indifference curve).

Since individuals may not have any incentive to divulge information on their level of risk, the insurer is better off by offering a menu of contracts such that high-risk and low-risk types purchase different contracts commensurate with their level of risk. Studies in automobile and health insurance demonstrate that offering a selection of contracts with different prices and coverage levels is more efficient than offering a single contract at an average price (Hoy, 1982).

Wilson (1977) and Miyazaki (1977) extended the Rothschild and Stiglitz model further to show the *transfer of income* from low-risk individuals to high-risk individuals under both pooling and separating equilibria. The Wilson model demonstrates the transfer of income from low-risk to high-risk individuals as both individuals purchase *identical contracts* for the same price. A low- to high-risk subsidization results as the high-risk individuals have a greater incidence of loss for the identical contracts than the low-risk individuals.

In the Miyazaki model, high-risk and low-risk individuals purchase *different contracts*. The contracts purchased by high-risk individuals generate losses for the insurer, while contracts purchased by the low-risk individuals generate profits. Therefore, the low-risk to high-risk subsidization in the Miyazaki model occurs across individuals buying different contracts. In the Wilson model, the subsidization is across individuals buying identical contracts.

Market signaling. The theory of market signaling suggests that in insurance markets with asymmetric information, agents signal their hidden knowledge through their choice of insurance contracts (Cho and Kreps, 1987; Spence, 1978). Studies in automobile and health insurance markets have shown that low-risk individuals have an incentive to signal their risk characteristics by selecting high deductibles in the presence of hidden knowledge and unobservable heterogeneity of risk types among the insurance applicants (Riley, 1985; Browne, 1992; Puelz and Snow, 1994).

Rothschild and Stiglitz (1976) and Spence (1978) have shown that when insurance firms offer a menu of contracts, high-risk individuals are more likely to purchase the high coverage contracts, while low-risk individuals are more likely to choose the low-coverage contracts. This is a self-revealing mechanism widely used in automobile and health insurance markets to identify risk types. When an individual chooses an insurance contract among the menu of contracts offered, the individual reveals some information about himself/herself, or sends a “signal” to the insurer. For example, if an individual purchases a health insurance contract with a high deductible, the individual sends a “signal” which could mean that he/she represents lower risk than the one who opted for a lower deductible contract.

It is possible that signaling could also be influenced by other characteristics such as the degree of risk aversion. When individuals vary in risk averseness as well as in their likelihood of expected loss, the choice of an insurance contract is no longer influenced by the probability of loss alone. For example, an individual may purchase an insurance contract with high coverage either because his/her probability of loss is high, or because he/she is highly risk-averse. However, if we assume independence of the distribution of probabilities of loss and the distribution of attitudes towards risk, individuals who buy insurance with higher coverage will tend, on average, to have larger expected losses than those with insurance with lower coverage (Pauly, 1974).

Adverse selection. Adverse selection has long been recognized as a problem in insurance markets, including crop insurance. Empirical studies in automobile and health insurance markets have found that adverse selection reduces the consumption of insurance by low-risk individuals and results in the transfer of income from low-risk to high-risk insureds (Browne and Doerpinghaus, 1993; Dionne and Doherty, 1994; Puelz and Snow, 1994).

Figures 1C and 1D illustrate the adverse selection problem in the case of two risk types, low-risk and high-risk. When an insured's probability of loss is unknown to the insurer, the full information equilibrium (A, B) is unattainable. Under asymmetric information, those with high risk are over-insured and under-priced (B′) and those with low risk are under-insured and over- priced (A′ or A*).

The Crop Insurance Market

To analyze the crop insurance market, where different products and coverage levels are offered to farmers, we apply the asymmetric information equilibrium framework developed in automobile and health insurance markets. Consider a farmer with an initial income, m, who is exposed to a risk, which can cause a loss, d, with a probability of insuring a loss, p, while (1-p) is the probability of not insuring a loss. The farmer can pay a premium, π, to an insurance firm, which in return pays some compensation or indemnity (I) if the loss occurs. The farmer chooses a contract that maximizes expected utility:

$$(5) \quad U(\bullet) = (1-p)\,U(m - \pi) + p\,U(m - \pi - d + I)$$

where U(•) is the von Neumann-Morgenstern utility function, assumed to be increasing, strictly concave (reflecting risk aversion), and differentiable. The indemnity paid by the insurance company to the farmer when the actual yield (revenue) falls below the guaranteed yield (revenue) depends on the insurance contract (α):

$$(6) \quad I = I(\alpha).$$

The insurance contract is defined as a yield or revenue insurance product with a coverage level that specifies the yield or revenue guarantee. To derive an equilibrium condition, we assume that α is a continuous choice variable. Assuming there are no transaction costs, the premium can be expressed as a function of α and other observable characteristics (z) indicative of risk type[2]:

$$(7) \quad \pi = \pi(\alpha, z).$$

When risk type is *not observable* and insurance is *not costless*, equations 6 and 7 imply that equilibrium insurance contracts depend on the manner in which insurers and insureds interact in the market.

Differentiating (5) with respect to α, we obtain the optimal choice of an insurance contract that satisfies the following first order condition:

$$(8) \quad \frac{U'(m - \pi)}{U'(m - \pi - d + I)} = \frac{p\{I'(\alpha) - \pi'(\alpha, z)\}}{(1-p)\,\pi'(\alpha, z)}$$

where $U'(\bullet) > 0$ is the marginal utility of income. The ratio p/(1-p), which gives the odds of incurring a loss, is a measure of risk associated with the insurance contract. $I'(\alpha)$ and $\pi'(\alpha, z)$ represent the indemnity and the premium at the margin, respectively. Equation 8 implies that, in equilibrium, the demand for insurance is equal to the supply of insurance.

If the price of insurance is actuarially fair, individuals would buy full insurance resulting in equalization of incomes in the two states of nature.[3] This is *full-insurance* in the sense that the individual would be indifferent between the two states of nature such that:

$$(9) \quad U'(m - \pi) = U'(m - \pi - d + I(\alpha)).$$

Individuals would trade income from one state of nature to another through a payment of premium (π) to the insurer, in return for a promise by the insurer to pay indemnities (I) if a loss occurs. Such trading will continue until the incomes are equalized. The ratio of marginal utilities of expected incomes explains why risk-averse individuals are willing to purchase insurance (Ehrlich and Becker, 1972).[4] Substituting 9 in 8 yields the optimal condition for the supply of insurance:

$$(10) \quad (1-p)\,\pi'(\alpha, z) = p\{I'(\alpha) - \pi'(\alpha, z)\}$$

which indicates that expected benefits are equal to expected costs for the insurer. Solving equation 10 for premium rate yields:

$$(11) \quad \pi'(\alpha, z) = p\,I'(\alpha)$$

which means that the fair premium is equal to the expected indemnity payment.

We derive the reduced-form solutions by applying the implicit function theorem to equation 8 (see Puelz and Snow). That is, the choice of α is expressed as a function of risk type (τ), willingness to pay for insurance (ρ), and cost of insurance or premium (π):

$$(12) \quad \alpha = \alpha(\tau, \rho, \pi).$$

An empirical finding that risk type is statistically significant ($\alpha_\tau \neq 0$) supports the presence of a *separating equilibrium* in the crop insurance market. Conversely, if risk type is not significant ($\alpha_\tau = 0$), the evidence is consistent with a *pooling equilibrium*.

When it is impossible or prohibitively expensive for the insurer to differentiate applicants according to risk types, insurance premiums may not accurately reflect the risk of loss (Borch, 1990; Browne, 1992; Puelz and Snow, 1994). Under such circumstances, the insurer sets premiums based on the average risk of the insured pool. As argued by Rothschild and Stiglitz, average premium rates are more attractive to high-risk individuals, potentially leading to adverse selection in the insurance markets.