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Samofal Yevhen
Master in Finance
Taras Shevchenko National University of Kyiv
Самофал Євген Володимирович
магістр з фінансів
Київського національного університету імені Тараса Шевченка

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THE USE OF DERIVATIVES IN ASSET-LIABILITY MANAGEMENT OF INSURANCE COMPANIES

ВИКОРИСТАННЯ ДЕРИВАТИВІВ В УПРАВЛІННІ АКТИВАМИ ТА ЗОБОВ'ЯЗАННЯМИ СТРАХОВИХ КОМПАНІЙ

Summary. *Introduction. Asset-Liability Management (ALM) is a crucial aspect of insurance companies' operations aimed at ensuring their financial stability and solvency. However, traditional methods like duration matching (portfolio immunization) often prove not flexible enough in volatile interest rate environments and unstable financial markets. The growing complexity of regulatory requirements, such as Solvency II, pose new challenges for effective ALM. These circumstances necessitate the search for new approaches and tools that would allow insurance companies to better manage their assets and liabilities, reduce risks, and ensure stability.*

Purpose. The main purpose of this study is to assess the effectiveness of advanced Asset-Liability Management techniques for insurance companies, particularly the use of derivatives to manage duration gaps and mitigate interest rate risks. The paper investigates how these tools can be integrated into existing ALM approaches to ensure better alignment of assets and liabilities and enhance the resilience of insurance companies to changing market conditions.

Materials and methods. The materials of this study include: 1) academic works by foreign authors focused on asset-liability management (ALM) within the insurance industry; 2) regulatory documents (namely, Solvency II) which outline the requirements for risk management and financial stability of European insurance companies.

In the course of this study, the following scientific methods were utilized: theoretical analysis and synthesis (to evaluate the existing ALM strategies and their effectiveness in managing duration gaps); comparative analysis (to compare traditional ALM techniques with more flexible approaches incorporating derivatives); and the logical generalization method (to formulate conclusions regarding the application of derivative instruments in ALM for insurance companies).

Results. The study's findings indicate that the integration of derivatives, such as government bond futures, interest rate swaps, and government bond options, can significantly improve the management of duration gaps and portfolio optimization for insurance companies. The use of these financial instruments allows for a flexible and effective response to changing market conditions, ensuring the stability and solvency of insurance companies.

Discussion. Further research can be directed towards a deeper study of the effectiveness of derivatives in the context of risk management in property & casualty insurance companies versus life insurance companies. Modelling performance of specific portfolios of different types of insurers will contribute to improving ALM efficiency.

Key words: *Asset-Liability Management, duration, immunization, insurance, derivatives, interest rate risk, portfolio optimization.*

Анотація. *Вступ. Управління активами і зобов'язаннями (Asset-Liability Management, ALM) є важливим аспектом діяльності страхових компаній, спрямованим на забезпечення їх фінансової стабільності та платоспроможності. Однак традиційні методи, такі як узгодження дюрації активів з дюрацією зобов'язань (імунізація портфоліо), часто виявляються недостатньо гнучкими в умовах змінних процентних ставок і нестабільних фінансових ринків. Зростаюча складність нормативних вимог, таких як Solvency II, створює нові виклики для ефективного ALM. Ці обставини зумовлюють необхідність пошуку нових підходів та інструментів, які б дозволили страховим компаніям краще управляти своїми активами та зобов'язаннями, зменшуючи ризики та забезпечуючи стабільність.*

Мета. Головною метою даного дослідження є оцінка ефективності сучасних методів управління активами та зобов'язаннями у страхових компаніях, зокрема використання деривативів для управління дюраційним розривом та зменшення процентних ризиків. У роботі досліджується, як ці інструменти можуть бути інтегровані в існуючі підходи до ALM, щоб забезпечити краще узгодження активів і зобов'язань, а також підвищити стійкість страхових компаній до змін ринкових умов.

Матеріали і методи. Матеріалами цього дослідження є: 1) наукові праці іноземних авторів, присвячені управлінню активами та зобов'язаннями (ALM) у страховій галузі; 2) регуляторні документи (зокрема, Solvency II), які визначають вимоги до управління ризиками та фінансової стабільності європейських страхових компаній.

У процесі цього дослідження були використані такі наукові методи: теоретичний аналіз і синтез (для оцінки існуючих стратегій ALM та їхньої ефективності в управлінні дюраційними розривами); порівняльний аналіз (для порівняння традиційних методів ALM із більш гнучкими підходами, які включають використання деривативів); метод логічного узагальнення (для формулювання висновків щодо застосування деривативів в ALM для страхових компаній).

Результати. Результати дослідження показують, що інтеграція деривативів, таких як ф'ючерси на державні облігації, процентні свопи та опціони на державні облігації, може значно покращити управління дюраційним розривом і оптимізацію портфеля страхових компаній. Використання цих фінансових інструментів дозволяє гнучко та ефективно реагувати на зміну ринкових умов, забезпечуючи стабільність та платоспроможність страхових компаній.

Перспективи. Подальші дослідження можуть бути спрямовані на глибше вивчення ефективності деривативів у контексті управління ризиками в компаніях зі страхування майна та від нещасних випадків у порівнянні з компаніями зі страхування життя. Моделювання ефективності конкретних портфелів різних типів страховиків сприятиме підвищенню ефективності ALM.

Ключові слова: *управління активами та зобов'язаннями, дюрація, імунізація, страхування, деривативи, процентний ризик, оптимізація портфеля.*

Problem statement. Insurance companies face the challenge of managing the duration gap between assets and liabilities to maintain financial stability. Traditional methods of asset-liability matching, such as duration matching and immunization, often prove not flexible enough in volatile interest rate environments. The issue is further complicated by stringent regulatory requirements, such as those imposed by Solvency II, which mandate a market-consistent valuation of assets and liabilities. A possible solution is to develop ALM strategies that are more flexible and allow to optimize portfolio performance while ensuring regulatory compliance and mitigating interest rate risks through the use of derivatives and other financial instruments.

Analysis of existing research and publications. The first ideas related to asset liability management were developed by Macaulay who introduced the concept of duration. Redington linked this concept to assets and liabilities of insurance companies and suggested that they should think about underwriting risks and investments simultaneously. Also, he developed the immunization theory. Ferguson discusses how the concept of duration can be applied to immunize insurance portfolios in the elevated interest rate volatility environment to minimize the reinvestment risk. Leibowitz analyzes how the traditional (mean-variance) approach to portfolio optimization could be adapted to the asset allocation process of an insurer. Van der Meer and Smink classify approaches to asset liability management into three categories: static (cashflow calendar, gap analysis, segmentation, cashflow matching), valuedriven (immunization, portfolio insurance, constant proportion portfolio insurance), and return driven (spread management, required rate of return analysis). Santomero and Babbel come up with an extensive list of risks that an insurance company faces and suggest two analytical approaches to evaluation of the aggregate risk exposure. Ahlgrim, D'Arcy and Gorvett try to overcome the drawbacks of modified duration and convexity (assumptions of a flat yield curve with parallel shifts and independence of cash flows from interest rate movements) by using effective duration and convexity. They conclude that once the abovementioned unrealistic assumptions are dropped, the effective duration and convexity are more relevant indicators to use in the process of immunization. Gajek, Ostaszewski and explain how the concepts of duration and convexity viewed from a theoretical perspective (as derivatives of a bond price to interest rate) are connected to the same concepts seen from a practical point of view as weighted average time to maturity (duration) and weighted average square of time to maturity (convexity). The authors criticize classical immunization as it violates the principle of no-arbitrage pricing and implies several unrealistic assumptions (flat yield curve; parallel and infinitely small shifts in the yield curve; continuous portfolio rebalancing). Then they summarize more advanced concepts such as key rate immunization and multivariate immunization.

More recently, the research on asset liability management has been increasingly focused on the topics of asset allocation and portfolio optimization under regulatory constraints. Regarding the regulatory constraints, it is important to mention that European insurers operate under the Solvency II regime since 2016. This regime requires insurance companies to provide a market-based view on their solvency by marking to market their assets and liabilities, thus setting up a specific framework for the asset liability management process [4].

To sum up, in the light of the discussed above literature, asset liability management for an insurance company can be defined as a process of development of an asset allocation taking into account the combined impact of financial risks on both assets and liabilities, as well as on the ability to meet the relevant regulatory requirements.

The purpose of this paper is to explore and evaluate the effectiveness of advanced Asset-Liability Management techniques in the insurance industry. Specifically, it aims to assess the utility of derivatives, such as interest rate swaps and bond futures, in managing the duration gap and mitigating interest rate risks.

Materials and methods. The materials of this study include: 1) academic works by foreign authors focused on asset-liability management (ALM) within the insurance industry; 2) regulatory documents (namely, Solvency II) which outline the requirements for risk management and financial stability of European insurance companies.

In the course of this study, the following scientific methods were utilized: theoretical analysis and synthesis (to evaluate the existing ALM strategies and their effectiveness in managing duration gaps); comparative analysis (to compare traditional ALM techniques with more flexible approaches incorporating derivatives); and the logical generalization method (to formulate conclusions regarding the application of derivative instruments in ALM for insurance companies).

Overview of core findings. Duration is a measure of interest risk of a fixed income security. Macaulay duration shows the weighted average time in years until cash flows of a security are received:

$$MacDur = \frac{\sum_{t=1}^{n} CF_t \cdot t \cdot (1+i)^{-t}}{PV} \qquad (1)$$

where *MacDur* — Macaulay duration of a security; CF_t — cash flow in year t; i — market interest rate; PV — present value of the security.

The higher the Macaulay duration of a security, the more time is required to recover the cash flows invested in it.

Modified duration shows the percentage change in price of a security given a unit change in yield:

$$ModDur = -\frac{1}{PV(i)} \cdot \frac{dPV(i)}{di}. \qquad (2)$$

Since

$$\frac{dPV(i)}{di} = -\frac{\sum_{t=1}^{n} CF_t \cdot t \cdot (1+i)^{-t}}{1+i}, \qquad (3)$$

modified duration can be expressed in terms of Macaulay duration as follows:

$$ModDur = \frac{MacDur}{1+i}. \qquad (4)$$

The higher the modified duration of a security, the higher its sensitivity to a unit change in yield.

Duration of a portfolio of securities is calculated by weighting the durations of individual securities by their weight in the total portfolio:

$$ModDur_p = \sum_{i=1}^{n} ModDur_i \cdot W_i, \qquad (5)$$

where W_i — weight of i-th security in the portfolio.

This formula can be applied to compute the weighted average duration of both assets and liabilities [5, p. 100–120].

Convexity (modified convexity) shows how modified duration changes given a unit change in yield:

$$Convexity = \frac{1}{PV(i)} \cdot \frac{d^2PV(i)}{di^2} = \frac{\sum_{t=1}^{n} CF_t \cdot t \cdot (t+1) \cdot (1+i)^{-(t+2)}}{PV}. \qquad (6)$$

Therefore, approximate percentage change in price of a security can be calculated using Taylor's theorem where modified duration is used in place of the first derivative, convexity is used in place of the second derivative, while the third and higher order derivatives are neglected:

$$\frac{\Delta PV}{PV} = -ModDur \cdot \Delta i + \frac{1}{2} \cdot Convexity \cdot (\Delta i)^2. \qquad (7)$$

The concept of the duration gap is based on a less tight approximation that takes into account only the first derivative and an assumption that both assets and liabilities are sensitive to the same interest rate:

$$\frac{\Delta MV_A}{MV_A} = -ModDur_A \cdot \Delta i; \quad \frac{\Delta MV_L}{MV_L} = -ModDur_L \cdot \Delta i \qquad (8)$$

$$\Delta MV_E = \Delta MV_A - \Delta MV_L = -(MV_A \cdot ModDur_A - MV_L \cdot ModDur_L) \cdot \Delta i \qquad (9)$$

$$\Delta MV_E = -\left(ModDur_A - \frac{MV_L}{MV_A} \cdot ModDur_L\right) \cdot MV_A \cdot \Delta i = -Duration\,Gap \cdot MV_A \cdot \Delta i \qquad (10)$$

From the formula, it is obvious that under an increase in the interest rate the market value of equity will decrease if the duration gap is positive, increase if the duration gap is negative, and stay the same if the duration gap is zero. Under a decrease in the interest rate the effects on the market value of equity are the opposite.

Thus, the concept of immunization is based on managing the duration of assets in such a way that the duration gap is set to zero. Ideally, the convexity gap (calculated in the same way but using convexity in place of modified duration) should also be considered. It should be non-negative as convexity links the change in market value of equity to squared change in the interest rate, which is always positive. Therefore, if convexity of assets is higher than that of liabilities, convexity effect on equity is net positive for any direction of the interest rate change [7].

One case when a non-zero duration gap can be justified for an insurer from the point of view of the interest rate risk minimization is under the assumption of going concern. Panning (1995) argues that assets and liabilities related to future business (i.e. both new business and renewals of the existing business) must be considered if one wants to minimize the sensitivity of real economic value (as opposed to equity market value) to interest rate movements. The duration of future losses is longer than that of future premiums because for any one-time premium inflow the losses corresponding to it are spread over time. Therefore, the net duration of future business is negative, and to counterbalance it, an insurance company should increase the duration of its existing assets. Then the duration gap will be zero from the point of view of an investment manager who performs estimation of all the (highly uncertain) parameters of the future business: timing, value, duration etc. At the same time, anyone else who analyses only verifiable existing business recorded under appropriate accounting principles will observe a positive duration gap.

The most straightforward way to manage duration of a portfolio and its duration gap is to rebalance the portfolio by buying or selling fixed income securities. However, in most cases a faster and more flexible way to adjust duration is hedging interest rate risk with derivatives. Derivatives overlay can be employed both to achieve the target duration or to temporarily deviate from it. For example, an investment manager who wants to have a positive duration gap based on long-term market views but expects a market turmoil in the near future may temporarily eliminate the gap with derivatives overlay, avoiding the need to sell any bonds [6].

The most efficient derivative instruments for managing duration are government bond futures, interest rate swaps, and government bond options. These instruments can be employed to reach a variety of duration management goals, but we analyze how they can be employed on the example of the most common application — elimination of a duration gap. As usually assumed in immunization theory, we assume no basis risk.

Futures position required to eliminate a duration gap can be defined as a position whose change in market value (due to an interest rate movement) is such that it fully offsets the change in portfolio equity value (due to the same interest rate movement):

$$\Delta F = -\Delta MV_E \qquad (11)$$

$$\Delta MV_E = -Duration\,Gap \cdot MV_A \cdot \Delta i \qquad (12)$$

$$\Delta F = -ModDur_B \cdot \Delta i \cdot P \cdot N \qquad (13)$$

$$N = -\frac{Duration\,Gap \cdot MV_A}{ModDur_B \cdot P} \qquad (14)$$

where ΔF — change in market value of the futures position; ΔMV_E — change in the portfolio equity value (assets minus liabilities); Δi — change in interest rate; $ModDur_B$ — modified duration of the underlying bond; P — price of one futures contract; N — number of futures contracts to buy (if positive) or sell (if negative).

As an example, when duration gap is positive, N is negative (since MV_A, $ModDur_B$, and P can only be positive). That is, an investment manager has to short N futures contracts. If interest rate goes up, portfolio equity value decreases, i.e. ΔMV_E is negative. However, the price of futures contracts also decreases. Hence the value of the short position goes up and positive ΔF exactly offsets negative ΔMV_E. When duration gap is negative, an investment manager has to buy N futures contracts, the opposite effects take place, and in case of a decline in interest rate ΔF again offsets negative ΔMV_E [1; 3].

Swap position to eliminate a duration gap is defined by the notional principal amount required to make modified duration of a portfolio with an interest rate swap overlay equal to the target modified duration:

$$MV_A \cdot ModDur_{Target} = MV_A \cdot ModDur_A + $$
$$+ NP \cdot ModDur_{Swap} \qquad (15)$$

$$NP = MV_A \cdot \frac{ModDur_{Target} - ModDur_A}{ModDur_{Swap}} \qquad (16)$$

where NP — notional principal amount.

Duration of the fixed leg of a swap is equal to the duration of a bond with the same cash flow pattern and maturity. At the same time, duration of the floating leg of a swap is close to the floating payments frequency (i.e. 0.5 years for the standard euro zone interest rate swap). Duration of a swap contract is equal to duration of the leg you are long minus duration of the leg you are short. That is, duration of a fixed rate receiver swap is positive, while duration of a fixed rate payer swap is negative. Therefore, if the difference between target and actual modified duration is positive (i.e. duration gap is negative), an investment manager has to go long a receiver swap of appropriate notional principle to increase modified duration to the desired value. In the opposite case a payer swap should be entered to decrease modified duration.

If the goal is to close the duration gap, the required notional principle is the following:

$$Duration\,Gap_{Target} = ModDur_{Target} -$$

$$-ModDur_L \cdot \frac{MV_L}{MV_A} = 0 \quad (17)$$

$$ModDur_{Target} = ModDur_L \cdot \frac{MV_L}{MV_A} \quad (18)$$

$$NP = MV_A \cdot \frac{ModDur_L \cdot \frac{MV_L}{MV_A} - ModDur_A}{ModDur_{Swap}} \quad (19)$$

As an example, when the duration gap is positive, an investment manager has to go long a payer interest rate swap of *NP* notional principle amount. If interest rate goes up, portfolio equity value decreases, i.e. ΔMV_E is negative:

$$\Delta MV_E = -Duration\,Gap \cdot MV_A \cdot \Delta i \quad (20)$$

At the same time swap market value (which is 0 at the time of contract initiation) goes up as the duration of payer swap is negative:

$$\Delta MV_{Swap} = -ModDur_{Swap} \cdot NP \cdot \Delta i \quad (21)$$

$$NP = MV_A \cdot \frac{ModDur_L \cdot \frac{MV_L}{MV_A} - ModDur_A}{ModDur_{Swap}} \quad (22)$$

$$\Delta MV_{Swap} = -ModDur_{Swap} \cdot MV_A \times$$
$$\times \frac{ModDur_L \cdot \frac{MV_L}{MV_A} - ModDur_A}{ModDur_{Swap}} \cdot \Delta i \quad (23)$$

$$\Delta MV_{Swap} = -MV_A \cdot \left(-Duration\,Gap\right) \cdot \Delta i =$$
$$= Duration\,Gap \cdot MV_A \cdot \Delta i == -\Delta MV_E \quad (24)$$

Therefore, swap market value increases and exactly offsets the decrease in portfolio equity value. When duration gap is negative, an investment manager has to go long a receiver interest rate swap of NP notional principle amount. Duration of a receiver swap is positive, so its value will go up if interest rate declines and will again offset the decrease in portfolio equity value [2].

Option position required to eliminate a duration gap can be defined as a position whose change in market value (due to an interest rate movement) is such that it fully offsets the change in portfolio equity value (due to the same interest rate movement):

$$\Delta O = -\Delta MV_E \quad (25)$$

$$\Delta MV_E = -Duration\,Gap \cdot MV_A \cdot \Delta i \quad (26)$$

$$\Delta O = \delta \cdot \left(-ModDur_B\right) \cdot \Delta i \cdot B \cdot N \quad (27)$$

$$N = -\frac{Duration\,Gap \cdot MV_A}{\delta \cdot ModDur_B \cdot B} \quad (28)$$

where ΔO — change in market value of the option position; ΔMV_E — change in the portfolio equity value; Δi — change in interest rate; $ModDur_B$ — modified duration of the underlying bond; B — price of one underlying bond; δ — delta of an option showing sensitivity of its value to the value of the underlying bond (between 0 and 1 for call options and between –1 and 0 for put options); N — number of option contracts to buy (call options if the duration gap is negative and put options if the duration gap is positive).

As an example, when the duration gap is positive, an investment manager has to buy N put options. N can only be positive (since MV_A, $ModDur_B$, and B can only be positive, Duration Gap is positive, and delta of a put option is negative). If interest rate goes up, portfolio equity value decreases, i.e. ΔMV_E is negative. However, the price of bonds underlying put options also decreases. Hence the value of long put options position goes up and positive ΔO offsets negative ΔMV_E.

When the duration gap is negative, an investment manager has to buy N call options. N again can only be positive (since MV_A, $ModDur_B$, and B can only be positive, Duration Gap is negative, and delta of a call option is positive). If interest rate goes down, portfolio equity value decreases, i.e. ΔMV_E is negative. However, the price of bonds underlying call options increases. Hence the value of long call options position goes up and positive ΔO offsets negative ΔMV_E.

Managing duration with options is the least efficient of the 3 strategies. First, the cost incurred (option premium multiplied by the number of contracts purchased) may be very large. Second, delta of a government bond option is more sensitive to interest rate fluctuations than modified duration of a government bond underlying a futures contract or modified duration of an interest rate swap. As a consequence, the required option position (which is a function of delta) may vary significantly with interest rates changes. Therefore, in practice duration is typically managed via government bond futures and interest rate swaps depending on the particular situation. The advantage of futures is that they are standardized exchange-traded instruments while swaps are traded in the over-the-counter market where a counterparty has to be found. On the other hand, bond futures have a very limited number of maturities which makes this instrument suitable only for simple duration management. Swaps can be tailored for a particular situation allowing for a more sophisticated duration management, e.g. key rate duration steering via forward starting interest rate swaps. This may be useful, for example, if an active portfolio manager wants to generate alpha through bond-picking but maintain the same exposure to interest risk as that of the benchmark at all the points of the yield curve [1; 3].

Conclusions and directions for further research. The paper concludes that traditional ALM methods, while foundational, are not flexible enough to address the complexities of modern financial markets. The integration of derivatives into ALM strategies offers a more dynamic approach to managing interest rate risks. By utilizing tools such as government bond futures, interest rate swaps, and government bond options, insurance companies can more effectively manage their duration gap and optimize their portfolios. Further research can be directed towards a deeper study of the effectiveness of derivatives in the context of risk management in property & casualty insurance companies versus life insurance companies. Modelling performance of specific portfolios of different types of insurers will contribute to improving ALM efficiency.

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