

MASTER

ACTUARIAL SCIENCE

MASTER'S FINAL WORK

INTERNSHIP REPORT

**LOSS RESERVING METHODS FOR AN ICELANDIC
WORKERS' COMPENSATION PORTFOLIO: A
COMPARISON OF CHAIN LADDER,
BORNHUETTER-FERGUSON, AND BENKTANDER
METHOD**

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Abstract, Keywords, and Journal of Economic Literature (JEL) Codes

Abstract

This report addresses the challenge of estimating outstanding claims reserves for a workers' compensation portfolio at Sjóvá-Almennar tryggingar hf, an Icelandic insurance company. The analysis covers accident years 2010 to 2025. Monetary figures have been modified to protect confidentiality.

Multiple reserving methods are applied to both paid and incurred development triangles, the Chain Ladder, the Bornhuetter-Ferguson, the Benktander, and the Average Cost method. To assess the sensitivity of the results, the portfolio is evaluated under two inflation frameworks, the Wage Index and the Consumer Price Index, and under three outlier scenarios, including the full dataset and exclusions at the 99.5th and 95th percentiles.

The results show that incurred models can produce negative Incurred But Not Reported (IBNR) estimates due to a systematic case reserve redundancy, making them unsuitable for balance-sheet provisioning. On a paid basis, the Wage Index adjustment provides a more realistic inflation structure for workers' compensation than the Consumer Price Index. The Benktander method applied to the paid Wage Index triangle is selected as the best estimate, producing an outstanding reserve of 1,283 M. This result is cross validated by the Average Cost Benktander estimate of 1,300 M, a difference of only 1.3%. The convergence of two independent approaches, one based on aggregate payments and the other on frequency and severity components, provides a high degree of confidence in the reliability of this estimate.

KEYWORDS: Loss Reserving; Chain Ladder Method; Bornhuetter-Ferguson Method; Benktander Method; Average Cost Method; Workers' Compensation.

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AI Disclosure

For clarity and transparency, I disclose that an artificial intelligence tool was used in the making of this report. This AI-based language model served two main purposes,

- To facilitate discussions around the theoretical foundations and the relative properties of the actuarial methods used throughout this analysis.
- To support the revision of text, addressing grammatical errors, phrasing, and helping to ensure that the text is clear and accurate for a non-native English writer.

All numerical computations, data processing, and reserve estimates were carried out independently by the writer using Microsoft Excel. The AI tool was not involved in any quantitative analysis, nor did it generate findings or conclusions. The tool was used as a discussion partner and did not have access to the underlying research data.

The use of AI in this report has been limited to a supportive role and does not compromise the work's academic integrity. All external sources have been cited appropriately. The contents of this report are the author's own work and responsibility.

Embla Laufey Gunnarsdóttir, June 2026.

Glossary

AC Average Cost. 8, 15, 16, 20, 28, VIII

BF Bornhuetter-Ferguson. 7–10, 15, 16, 18–22, 24–26, 28, 29, VIII

CBNI Covered But Not Incurred. 3, VIII

CL Chain Ladder. 6, 7, 9, 10, 15–23, 25, 26, 28, VIII

CPI Consumer Price Index. 12, 14, 23, 24, 26, 28, VIII

DF Development Factor. 17, 18, 20, VI, VIII

FME Financial Supervisory Authority of Iceland (Fjármálaeftirlitið). 1, 11, VIII

FÍT Actuarial Association of Iceland (Félag íslenskra tryggingastærðfræðinga). 1, 10, 11, VIII

GB Benktander. 8, 9, 15, 16, 19–22, 24–26, 28, 29, V, VIII, XI

IBNR Incurred But Not Reported. 3, 4, 18–20, 24, 26, 28, 30, I, VIII

JEL Journal of Economic Literature. I, VIII

RBNS Reported But Not Settled. 3, 4, 14, VIII

WI Wage Index. 12, 14, 17, 18, 22–24, 26, 28, 29, V, VI, VIII, XI

1 Introduction

Claims reserving is one of the most critical functions in general insurance. Insurers are required to set aside sufficient funds to cover the future costs of claims that have already occurred but have not been fully settled. The accuracy of these reserves directly affects the financial position of the insurer, the premiums charged to the policyholders, and the regulatory capital required under solvency framework.

In Iceland, the insurance market has undergone significant regulatory development in recent years. The Solvency II framework was fully implemented on 1 October 2016 through Act No. 100/2016, aligning Icelandic insurance regulation with the European Union standard (EIOPA, 2021). Prior to this, the Financial Supervisory Authority of Iceland (Fjármálaeftirlitið) (FME) approved the classification proposal submitted by the Actuarial Association of Iceland (Félag íslenskra tryggingastærðfræðinga) (FÍT) in 2014, which established standardized categories for non-life insurance business (Fjármálaeftirlitið, 2014). These developments created a more structured environment for actuarial reserving practices in the Icelandic market.

Workers' compensation insurance presents particular reserving challenges. Claims in this line of business are usually long tailed, meaning that the payments are spread out over many years after the accident occurs. At the same time, the development of individual claims is driven by both the frequency of new reports and the severity of each claim, which tends to vary over time. For an actuary selecting a reserving method, the choice depends on how volatile the development pattern is, how much weight should be given to a priori expectations based on historical experience versus current observed payments, and whether the data supports a stable projection.

The practical challenge addressed in this report is how to estimate credible ultimate cost of claims and the resulting outstanding reserves, for a specific homogeneous group within a workers' compensation portfolio at Sjóvá-Almennar tryggingar hf. Sjóvá is one of Iceland's largest insurance companies, providing non-life and life insurance products

to both individuals and businesses. The portfolio covers the accident years 2010 to 2025, and the monetary values are adjusted for inflation over this period.

The objective of this analysis is to apply and compare several standard reserving methods to this portfolio and to identify which method produces the most credible estimate. The methods evaluated include the Chain Ladder, the Bornhuetter-Ferguson, the Benktander, and the Average Cost method. To examine the impact of different data treatments on the results, the analysis is also performed under two alternative inflation adjustments (the Consumer Price Index and the Wage Index) and under different outlier exclusion thresholds.

The rest of this report is structured as follows. Chapter 2 reviews the theoretical background, covering basic concepts in loss reserving, the structure of development triangles and development factors, and the reserving methods used in this analysis. Chapter 3 describes the data source and the structure of the raw data, followed by the cleaning and adjustments applied, including the construction of the development triangles and the selection of reserving methods. Chapter 4 presents the results, including the sensitivity analysis for inflation adjustments and outlier exclusions. Chapter 5 concludes the report with a summary of the key findings, a discussion of limitations, and recommendations for future research.

2 Key Concepts/Theory

This chapter introduces the theoretical foundation for the analysis, covering basic reserving concepts, development triangles, and the specific methods applied in this report.

2.1 Basic concepts in loss reserving

The fundamental problem loss reserving addresses is that, on any valuation date, an insurer has claims that have been incurred but have not yet been paid. Some of these claims have been reported to the insurer but remain unsettled. These are referred to as Reported But Not Settled (RBNS). Other claims have occurred but not been reported. These are referred to as IBNR. A third category, Covered But Not Incurred (CBNI), refers to claims that will happen in the future but are covered by policies in force on the balance date (Neuhaus, 2014). While IBNR and CBNI track different stages of a claim's life cycle, they are handled in the same way because actuaries have no concrete data for either at the valuation date (Neuhaus, 2014).

An actuary has to estimate the total future payments in both these categories, that is, they have to estimate the value of all future payments arising from claims that are currently outstanding or incurred but not yet reported. This estimate is often referred to as the outstanding claim provision or loss reserve (Neuhaus, 2014).

Estimating the outstanding claims is a core task in general insurance. Without a reliable estimate, neither the underwriting nor the accounting function of an insurance company can produce trustworthy results. (Neuhaus, 2014).

Claims and premium information are associated with different time dimensions. Claims are linked to the accident and reporting dates, while premium information is linked to the policy's underwriting date or coverage period.

The main time dimensions used in this report are the following:

- **Accident date:** the date of the loss event leading to the claim. Claims are grouped by the accident period (typically a year) to form an accident-year cohort.
- **Reporting date:** the date on which the claim is first recognized in the insurer's official files. The time between the accident date and the reporting date is called the reporting delay.
- **Underwriting date:** the policy inception date or the most recent renewal date.

Other examples of these dimensions include:

- **Valuation date:** the date on which claims are valued.
- **Development date:** a term describing the delay after a selected reference point, usually the accident date. The development date typically starts at zero (Neuhaus, 2014).

A full three-dimensional model separates claims by accident period, reporting delay, and valuation delay. This allows the actuary to model RBNS and IBNR claims separately, but it requires more data and more complex estimates than a two-dimensional model. Most practical reserving studies use a two-dimensional model, where the two dimensions are the accident period and the development period. Here, the reporting delay and the valuation delay are combined into a single dimension. The data is arranged in a development triangle, with accident years as rows and development years as columns (Neuhaus, 2014).

The two-dimensional model described above is the basis for all calculations in this report. Reporting delay and valuation delay are combined into a single development period, and all data are arranged in standard development triangles.

2.2 Development triangles

Before presenting the reserving methods, one must understand what development triangles, sometimes called run-off triangles, are and how they are built, as the methods are built on them.

Development triangles are most often presented in two different forms described below. One can always calculate one triangle from the other and vice versa, meaning both forms present the same underlying data but in different ways.

2.2.1 Incremental triangles

An incremental development triangle arranges claims data with accident years along the rows and the development period along the columns. Each cell contains the observed amount during each individual development period. This format is useful for methods such as Bornhuetter-Ferguson and for inspecting payment patterns.

2.2.2 Cumulative triangles

A cumulative development triangle also arranges claims data with accident years and the development period, but each cell contains the total amount observed up to each period. That is, the cumulative value for accident year j at the development period e is the sum of all incremental values for accident year j , up to and including that period e . Cumulative triangles are the natural format for the Chain Ladder method.

Figure 3 shows an example of both triangles side by side. The empty cells in the lower right part of the triangles represent the future values that the reserving methods aim to estimate.

FIGURE 1: (a) Incremental triangle

AY \ Dev	0	1	2	3	4
1	100	150	120	80	50
2	110	160	130	70	
3	120	170	110		
4	130	155			
5	140				

FIGURE 2: (b) Cumulative triangle

AY \ Dev	0	1	2	3	4
1	100	250	370	450	500
2	110	270	400	470	
3	120	290	400		
4	130	285			
5	140				

FIGURE 3: Example development triangles: (a) incremental and (b) cumulative, with accident years as rows and development periods as columns. Empty cells represent future, yet to be observed values.

2.2.3 Development factors and cumulative proportions

The average development factors δ_e^* are calculated from the cumulative triangles as the volume weighted average ratio of cumulative amounts between successive periods:

$$\delta_e^* = \frac{\sum_{j=1}^{J_e} C_{j,e}}{\sum_{j=1}^{J_e} C_{j,e-1}} \quad (1)$$

where $C_{j,e}$ is the cumulative amount for accident year j at development period e and J_e is the number of accident years with observed values in both development periods $e - 1$

and e . For the earliest development periods, J_e usually equals the total number of accident years in the triangle. For later periods, it decreases because the recent accident years have not yet developed that far.

Let A_e denote the accumulated development factor at development period e , calculated as the product of the development factors up to that period:

$$A_e = \prod_{k=1}^e \delta_k^*$$

The cumulative development pattern p_j for accident year j is then defined as the ratio of the accumulated development factor at its current development stage to the accumulated development factor at ultimate:

$$p_j = \frac{A_{D(j)}}{A_E} \quad (2)$$

where $D(j)$ is the last observed development period for accident year j , and E is the final development period at which the claims are assumed to be fully developed. Thus, $A_{D(j)}$ represents the accumulated development factor at the current stage, while A_E represents the accumulated development factor at ultimate development period. Their ratio gives the cumulative development pattern for accident year j at the current valuation date and indicates how much of the ultimate claims amount has emerged at the current valuation date.

2.3 The reserving methods

In this section, the reserving methods that were applied in this analysis are described.

2.3.1 Chain Ladder

The method that is most widely used to estimate the total outstanding loss reserves is the Chain Ladder (CL). The main reason for this is the simplicity of the method, it is easy to apply and requires only basic arithmetic. The method is described as distribution-free as it requires no assumptions about the underlying probability distribution of claims, only a multiplicative relationship between successive development periods (Mack, 1993).

This method has some important limitations. Mack (1993) notes that the CL estimates for the most recent accident years are highly sensitive to small variations in the observed

data, which can be problematic when those years are immature and the data is sparse. The method also assumes that accident years develop independently of each other, an assumption that can be violated by calendar year effects such as changes in claims handling practices (Mack, 1993).

In the CL method, the last observed cumulative amount for each accident year is multiplied by development factors. These factors are estimated from historical data as a weighted average of the ratios between successive development periods, allowing the ultimate claims to be calculated (Neuhaus, 2014):

$$U_j^{CL} = \frac{C_j}{p_j} \quad (3)$$

where C_j is the paid amount up to accident year j and p_j is the cumulative development pattern. The outstanding reserve for accident year j is then $R_j = U_j - C_j$.

Because this method relies only on the data in the development triangle, it does not require an external measure of risk exposure (Neuhaus, 2014). Mack further derived a distribution-free formula for the standard error of these estimates, enabling the actuary to quantify the prediction uncertainty, a contribution that has become the standard approach in practice (Mack, 1993).

2.3.2 Bornhuetter-Ferguson

The Bornhuetter-Ferguson (BF) method takes a different approach to estimate outstanding claims. Instead of just relying on observed development, this method blends two sources of information to estimate the ultimate claims. It combines an a priori estimate of how many claims there will ultimately be, based on prior knowledge, pricing, external data, or benchmarks, and the actual observed development pattern. Predictions for future periods are the product of three components: risk exposure, expected claim rate per unit of exposure, and the expected proportion of the total claims that will emerge in a specific development delay (Schmidt and Zocher, 2008).

- Risk exposure: how much exposure is at risk (e.g., number of policies, earned premium, or other measures) for that period.
- Expected claim rate per unit of exposure: the anticipated cost or frequency of claims per unit of exposure.
- Expected proportion of the total claims that will emerge in that development delay: the share of the ultimate claims expected to be reported or paid in that future

development interval.

The outstanding reserve for the BF method is:

$$R_j^{BF} = (1 - p_j) \times U_j^0 \quad (4)$$

The corresponding ultimate claims can be expressed as:

$$U_j^{BF} = C_j + R_j^{BF} = C_j + (1 - p_j) \times U_j^0 \quad (5)$$

where C_j is the paid amount up to accident year j , p_j is the cumulative development pattern, and U_j^0 is the a priori estimate of the ultimate claims for accident year j . This estimate can be derived from different sources, such as expected loss ratios, pricing information, or on a frequency-severity approach as described in the section about the Average Cost (AC) method.

This means that the BF only uses the a priori estimate and the observed triangle to estimate the development pattern, which is the opposite of the Chain Ladder, which only depends on the observed data (Neuhaus, 2026).

This makes the BF method useful for recent and undeveloped accident years, where the observed data is still sparse. The advantage of this method is that it provides a stable estimate for these immature periods. The main disadvantage of this method is that it is relatively unresponsive to changes in the observed claim frequencies (Neuhaus, 2014).

2.3.3 Benktander method

The GB method combines two different sources of information: the cohort's own development data and a predetermined a priori claim rate (Neuhaus, 2026). This method blends these two sources through a simple credibility relationship that depends on maturity alone (Mack, 2000). The resulting ultimate claims estimate is given by:

$$U_j^{GB} = p_j \cdot U_j^{CL} + (1 - p_j) \cdot U_j^{BF} \quad (6)$$

where p_j is the cumulative development pattern for accident year j , U_j^{CL} and U_j^{BF} were defined by equations 3 and 5 respectively.

It is worth mentioning that the GB method is also called the iterated Bornhuetter-Ferguson method. This comes from the fact that the BF reserve can be produced by applying the BF procedure again to the BF posterior ultimate (Mack, 2000). Specifically,

the BF posterior ultimate is $U_j^{BF} = C_j + (1 - p_j) \times U_j^0$, and applying the BF reserve formula to this posterior yields $R_j^{GB} = (1 - p_j) \times U_j^{BF}$, which is exactly the Benktander reserve.

2.3.4 The spectrum of the three methods

The three methods described above form a spectrum. The CL method gives full credibility to the development of the cohort. BF, on the other hand, gives none. It relies entirely on an a priori claim rate. Finally, the GB method sits between these two methods, with a maturity based credibility factor p_j (Neuhaus, 2026). Mack (2000) shows that this ranking on the spectrum also reflects the performance of each method, as shown in Figure 4. The Chain Ladder is best for low-volatility portfolios, the Bornhuetter-Ferguson is best for high-volatility portfolios, and the Benktander method is optimal in the wide central region, where most of the real-world data lies.

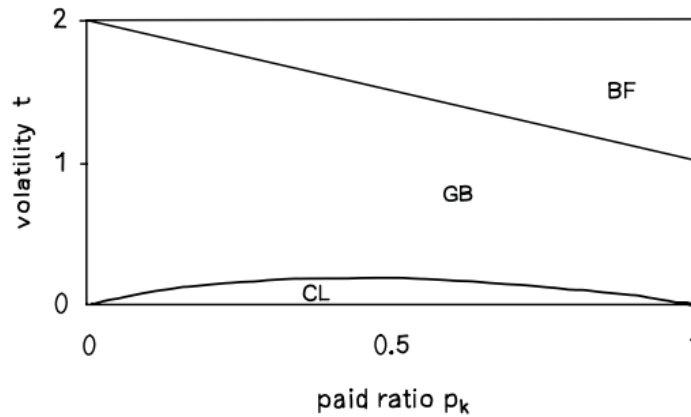


FIGURE 4: Adapted from Mack (2000)

2.3.5 Average Cost method

The Average Cost method splits the calculation of ultimate claims into a frequency component and a severity component, rather than projecting the total paid amounts directly like in the CL method. This allows for the claim counts and the claim costs to be modeled separately. In this method, two separate triangles are calculated, a triangle of reported claim counts and a triangle for paid amounts. From them, a third triangle is constructed, the average cost triangle, by dividing paid amounts by claim counts for each cell. The ultimate claim count is then projected from the claim count triangle, this projection can be done using several different methods, including CL, BF, and GB. For the severity

component, a single a priori average cost is selected based on the historical average costs observed in the average cost triangle. Finally, the ultimate claims are given by the product of the two components:

$$U_j^{AC} = N_j^{ult} \times \bar{C}_j^{ult} \quad (7)$$

where N_j^{ult} is the ultimate projected claim count and $\bar{C}_j^{ult}$ is the projected average cost per claim.

This method is useful in situations where the development pattern is unstable, which makes the use of CL and BF questionable as they both rely on stable development patterns (ADDACTIS Group, 2025). This method separates frequency and severity, making it suitable when one component follows a different path from the other.

The advantage of this method is its simplicity, it is quick to implement and easy to explain. However, its main limitation is that it does not take into account the development of claims, rather, it uses a stable average cost. This method is also sensitive to errors when estimating the ultimate volume of claims (ADDACTIS Group, 2025).

2.4 Regulatory context

Article 80 of Directive 2009/138/EC (Solvency II) requires insurers to classify their insurance and reinsurance obligations into homogeneous risk groups, and as a minimum by lines of business for the purpose of calculating technical provisions (European Parliament and Council, 2009). In Annex I of Commission Delegated Regulation (EU) 2015/35, the Solvency II Level 2 regulation, the specific lines of business are set out (European Commission, 2015).

Solvency II, originally adopted by the European Union in 2009, was incorporated into the EEA Agreement in 2011 and fully implemented in Iceland on 1 October 2016 through Act No. 100/2016 on Insurance Activity (EIOPA, 2021). As noted by FÍT, this classification of insurance contracts serves two main purposes, to provide information to supervisors via reporting templates and to calculate both technical provisions and risk margins (Félag íslenskra tryggingastærðfræðinga, 2013).

For statistical estimation, portfolios should be grouped into homogeneous risk groups, where claims develop in a similar pattern, before being analyzed (Neuhaus, 2014).

FÍT proposed recommendations on how companies can map their own classification to the Solvency II lines of business, noting that simplifications may be necessary when

there is little activity in a line and no possibility of statistical calculations (Félag íslenskra tryggingastærðfræðinga, 2013). The FME reviewed this proposal and approved it for use in the Icelandic market in 2014 (Fjármálaeftirlitið, 2014).

The Solvency II classification, as adapted by FÍT and approved by the FME, places the accident portfolio analyzed in this report under non-life class 3, Workers' compensation insurance (slysatryggingar launþega) (Alþingi, 2015). The claims in this line of business are governed by the Icelandic Tort Law (Skaðabótalög nr.50/1993) (Alþingi, 1993). This legal framework creates a distinct claim development profile and severity level compared to other lines of business.

3 Data and Methodology

The data used in this report is based on a real portfolio of Icelandic workers' compensation claims from Sjóvá-Almennar tryggingar hf. Sjóvá is one of Iceland's leading insurance companies, providing a comprehensive range of non-life and life insurance products to both individuals and businesses.

Monetary figures have been modified to protect the company's confidentiality. The relative relationship between values are preserved. All monetary values are reported in Icelandic krona (ISK).

This chapter describes the data preparation process and the methodology used to calculate the final estimates.

3.1 Data source and raw data

The data was provided directly by Sjóvá in a transactional Microsoft Excel format, covering the 15-year period from 2010 to 2025. Following the regulatory classification discussed in Section 2.4, the portfolio consists of a specific homogeneous group within the company's workers' compensation line of business. All processing and calculations were performed using Microsoft Excel.

The raw dataset contained three sheets:

1. **Transactional Records:** Individual claim payments and reserve entries.
2. **Price Indices:** Annual figures for earned premiums, the WI and the Consumer Price Index (CPI).
3. **Verification Triangles:** Pre-aggregated incremental triangles for both claims paid and incurred, used to validate manual aggregation.

These variables align with the standard actuarial requirements for individual claim records (Neuhaus, 2014).

Table I lists the variables available for each payment transaction.

TABLE I: Variables in the individual claim transaction data

Variable	Description
Claim ID	Unique identifier for each claim
Date of accident	Date the accident occurred
Year of accident	Accident year for cohort classification
Date of reporting	Date the claim was reported to the insurer
Date of booking	Date the transaction was recorded
Year of booking	Booking year for development triangle
Type	"Paid" or "Outstanding estimate"
Amount	The monetary value of the transaction

The Type variable distinguishes between actual claim payments and the outstanding case estimate.

3.2 Data cleaning and adjustments

The raw transactional data was imported into Excel and structured as a referable table using the Name Manager, creating the primary data used in this analysis. This structure was then used for the aggregation of individual payment records into development triangles. From this primary data, a summary table was derived containing the total payment per claim, along with additional calculated values needed for the analysis. This summary table served as the basis for the construction of the claim counts triangle.

To assess the sensitivity of the technical provisions to extreme observations, the dataset was split into three distinct scenarios, the full dataset, a dataset excluding claims with total payments exceeding the 99.5th percentile, and a dataset excluding the claims above the 95th percentile. For each of these scenarios, separate development triangles were constructed for both claims paid and claims incurred. The first three methods described in Section 2.3 were then applied to these triangles to measure the impact of large claims on the resulting reserves.

The average cost method, described in Section 2.3.5, was performed using the full, unadjusted data only. This was done to ensure that the ultimate claim count projections and the selected a priori average cost were based on the complete population of claims, providing a stable baseline for the severity-based estimates.

To account for economic trends and claims inflation over the study period, all reserve calculations were performed twice. The first set of calculations was adjusted using the WI, and the second set used the CPI. Comparing these different scenarios allows for the sensitivity of the technical provisions to be captured, both to large claim volatility and to different inflation assumptions. The results of these outlier adjustments and index comparison are reviewed in Section 4.2.

3.3 Construction of the development triangle

Using the primary data described in Section 3.2, incremental development triangles for both paid and incurred claims were constructed by aggregating transactional amounts by accident year and development year. This aggregation was performed using Excel Pivot tables and the SUMIFS function. The development year was defined as the booking year minus the accident year. For the paid triangle, only transactions categorized as "Paid" were included. For the incurred triangle, both "Paid" and "Outstanding estimate" entries were aggregated to reflect the total incurred at each development period.

To ensure the accuracy of the aggregation process, the resulting triangles were compared against the raw incremental triangles provided in the original dataset (see Section 3.1). Once the manual aggregation was confirmed to match, cumulative triangles were built by summing the incremental values across successive development periods. Following the standard actuarial practice, these cumulative triangles represent the total amount paid or incurred from the accident year up to each development period (Neuhaus, 2014).

In addition to these monetary triangles, a claim count triangle was constructed to support the frequency analysis. For this triangle, the development year was defined as the reporting year minus the accident year, rather than the booking year minus the accident year. That is because the count triangle tracks when claims enter the system rather than when payments are made. This was built to track the number of claims reported at each development period, providing the necessary frequency component needed for the Average Cost Method.

Three primary types of development triangles were constructed:

- **Claims Paid Triangles:** Aggregated the actual payments made.
- **Claims Incurred Triangles:** Aggregated the sum of cumulative paid amounts and the outstanding case estimates (RBNS) at each development period.
- **Reported Claim Count Triangle:** Aggregated the number of unique claim IDs

reported to the insurer in each period.

The resulting cumulative triangles serve as the base inputs for the Chain-Ladder, Bornhuetter-Ferguson, Benktander and the Average Cost methods discussed in Section 2.3.

3.4 Descriptive analysis of the triangle

The incremental and cumulative paid triangles constructed in Section 3.3 are presented in Appendix XIII and XIV. This section provides a summary of the structural features of these triangles before any reserving method is applied.

The paid triangle exhibits a pattern consistent with a long-tail line of business. The majority of payments are concentrated in the early development years, with the remaining proportion paid out slowly over the subsequent periods. The claim count triangle matures significantly faster, indicating that most of the accidents are reported and logged soon after they occur. The discrepancy between the fast reporting of counts and the slower development of paid amounts suggests that the primary source of volatility in this portfolio is claim severity rather than claim frequency.

The incurred triangle exhibits an unusual development pattern. After an initial upward revision in the early development years, the development factors fall below 100% in later periods before then stabilizing. This pattern indicated a systematic case reserve redundancy, where initial claims were set higher than the eventual settlement cost. This is common in workers' compensation, where medical cost development and disability duration take time to assess accurately.

To investigate if this incurred pattern was driven by a small number of extreme claims, the development factors were also calculated after applying the 99.5th and 95th percentile exclusion thresholds. The results of this analysis are presented in Section 4.3.

Detailed development factors, reserve estimates, the comparison of the outlier exclusions, and the inflation adjustments are presented in Chapter 4. The resulting cumulative triangles serve as the base input for the CL, BF, GB, and the AC methods discussed in Section 2.3. The application of these methods and the resulting estimates are presented in Chapter 4.

3.5 Selection of reserving methods

The descriptive analysis in Section 3.4 shows that the volatility in this portfolio varies significantly depending on the triangle being examined. These structural characteristics help inform the selection of the reserving methods used in the analysis.

The CL method is most appropriate for triangles that have stable development patterns. Since the claim count triangle shows a steady convergence toward 100% maturity, the CL method was a natural candidate to project the ultimate reported counts. As noted by Mack (2000), the performance of the CL method deteriorates as portfolio volatility increases. Given the higher volatility observed in the paid and incurred development triangles, the BF method is applied to provide more stable estimates by anchoring the results to an a priori expected loss ratio.

The GB method is selected as a middle ground between the CL and BF methods. It is well suited for the incurred triangle as it balances the data driven projections with the stability of the a priori baseline, reducing the impact of the distorted development factors.

Finally, the AC method is selected to leverage the clear separation between claim frequency and claim severity. By projecting the ultimate claim counts and average costs independently, this method takes advantage of how predictably claim counts develop, while isolating the more volatile severity component for a closer look. This decomposition is valuable given that the severity driven volatility in this portfolio was found to be a systematic feature rather than coming from a few extreme claims.

The application of these methods across the different development triangles is summarized in Table II.

TABLE II: Application of reserving methods by triangle type

Method	Paid triangle	Incurred triangle	Claim count triangle
Chain Ladder (CL)	✓	✓	✓
Bornhuetter-Ferguson (BF)	✓	✓	
Benktander (GB)	✓	✓	
Average Cost (AC)	✓		

The results are compared in Chapter 4 to assess the sensitivity of the reserve estimates to methodological choice.

4 Results - Application of Reserving methods

4.1 Application of reserving methods

This section applies all the reserving methods described in Section 2.3 to the workers' compensation portfolio adjusted using the WI. The results presented in this section use the full adjusted dataset without outlier exclusion. Sensitivity analysis for the inflation adjustments and the outlier exclusions is addressed in Sections 4.2 and 4.3.

4.1.1 Application of the Chain Ladder

The CL method was independently applied to the cumulative paid and incurred triangles using the volume weighted average development factors.

Paid Basis The paid development factors and cumulative payment proportions are shown in Table III. Development beyond lag 9 left out as the cumulative payment proportion reaches 100%, indicating that full development has been reached.

TABLE III: DF and cumulative payment proportions, WI adjusted, paid triangle.

Lag	Weighted avg. DF	Accumulated DF	Cumulative p_j
0	100%	100%	5.35%
1	508.79%	508.79%	27.2%
2	236.17%	1201.62%	64.24%
3	135.78%	1631.53%	87.23%
4	109.25%	1782.50%	95.30%
5	102.17%	1821.13%	97.36%
6	101.50%	1848.44%	98.82%
7	101.06%	1868.12%	99.87%
8	100.05%	1869.02%	99.92%
9	100.08%	1870.60%	100.00%

Several key observations emerge from Table III. Cumulative payments surge dramatically in the first years. They jump from 5.53% in period 0 to 27.2% in period 1, and more than double to 64.24% by period 2. By the end of period 3, most of the ultimate losses (87.23%) have already been paid out. The remaining 12.77% of payments are stretched out slowly over the next 6 years. Thus, the development pattern clearly reveals a long-tailed behavior, which is typical for workers' compensation claims.

Incurred Basis The development factors extracted from the incurred triangle exhibit a notably different pattern, as shown in Table IV.

TABLE IV: DF and cumulative incurred proportions, WI adjusted, incurred triangle.

Lag	Weighted avg. DF	Accumulated DF	Cumulative p_j
0	100%	100%	61.62%
1	158%	158%	97.32%
2	111%	175%	107.76%
3	100%	176%	108.27%
4	98%	172%	106.29%
5	97%	167%	103.13%
6	98%	165%	101.38%
7	99%	163%	100.75%
8	100%	163%	100.24%
9	100%	162%	100.00%

The defining feature of the incurred data is that several weighted average development factors for the middle development periods drop below 100%. This decline indicates a pattern of case redundancy, where initial claims reserves set by adjusters were systematically higher than the ultimate settlement cost. Because traditional CL method strictly projects trends forward, these dipping factors force the model to calculate negative IBNR estimates for those specific periods.

The final resulting CL ultimate estimates and outstanding reserves for both the paid and incurred basis are presented in Section 4.4, Table XII.

4.1.2 Application of Bornhuetter-Ferguson

The BF method requires the selection of an a priori ultimate claims estimate U_j^0 . A loss ratio of 106.23%, reflecting the historical observed experience for this portfolio, was selected to calculate the baseline ultimate for each accident year with $U_j^0 = \text{premium}_j \times 1.0623$. The outstanding reserve for each accident is subsequently determined by $R_j^{BF} = (1 - p_j) \times U_j^0$.

Paid Basis The BF method produces larger reserves than the CL method for the most recent accident years. This difference occurs because the a priori framework assigns more weight to the expected ultimate than to the observed payments in the early accident years. For example, in accident year 2024 (where the cumulative proportion is only $p_{2024} = 0.0535$), the BF reserve is 403M compared to the CL outstanding estimate of 105M. For fully developed accident years (2010 – 2016), the BF reserve is zero as $p_j = 1$, leaving no outstanding liabilities.

Incurred Basis When applied to the incurred data, the stabilizing effect of the a priori estimate becomes particularly valuable for the most recent periods. For early development lags, where the incurred cumulative proportion is higher than the paid proportion (e.g., $p_0 = 61.62\%$), the method relies less on volatile case reserves and more on the 106.23% expected loss ratio baseline. However, for the middle accident years where case reserve redundancy drives p_j above 100% (peaking at 108.27% in period 3), the term $(1 - p_j)$ becomes negative. As a result, the BF method generates negative IBNR estimates for these mature periods, though these estimates remain anchored to the initial U_j^0 expectation rather than overreacting to individual data fluctuations.

The final resulting BF ultimate estimates and outstanding reserves for both the paid and incurred basis are presented in Section 4.4, Table XII.

4.1.3 Application of Benktander

As discussed in Section 2.3.3, the GB method applies a credibility weight of p_j to the CL ultimate and $(1 - p_j)$ weight to the BF prior estimate. The resulting estimate can be determined with Equation 6.

Paid Basis For the fully developed accident years (2010 – 2015), the GB ultimate matches both the CL and BF estimates, as $p_j = 1.00$ and the outstanding reserves for both underlying methods are zero. For the most recent years, the GB estimate lies between the CL and BF values, weighting the two sources proportionally to the cohort's maturity. The paid GB credibility weights for this portfolio range from $p_{2025} = 0.0535$ for the least mature year to $p_{2017} = 0.999$ for the oldest open year. Consequently, for the most recent accident year, the GB method assigns only 5.35% credibility to the highly volatile CL projection and 94.65% to the BF prior, keeping the final ultimate estimate anchored closer to the baseline expectations.

Incurred Basis When applied to the incurred triangle, the shifting values of p_j weights fundamentally alter how credibility is distributed. For the most recent accident year, the presence of initial case reserves means the cohort starts at a much higher maturity ($p_0 = 61.62\%$). Consequently, the GB method places a substantial 61.62% weight on the CL projection and only 38.38% to the BF prior baseline. The middle accident years present a different challenge. Because case reserve redundancy pushes cumulative proportions above 100%, the credibility weight p_j assigns more than 100% weight to the CL ultimate, while the complementary weight $(1 - p_j)$ becomes negative. As a result, the GB method ends up reflecting the same negative IBNR estimates observed in both CL and BF incurred implementations during these periods.

The final resulting GB ultimate estimates and outstanding reserves for both the paid and incurred basis are presented in Section 4.4, Table XII.

4.1.4 Application of Average Cost Method

The AC method estimates ultimate claims by separating claim frequency (accident counts) from claim severity (average cost per claim). This method is applied only to the paid triangle and the claim count triangle. The development patterns for both the claim counts and the average cost per claim are shown in Table V.

TABLE V: Development patterns for claim counts and average claim costs.

Lag	Count Avg.	Count Cum.	Cost Avg.	Cost Cum.
	DF	Ratio ($p_{j,\text{count}}$)	DF	Ratio ($p_{j,\text{cost}}$)
0	100%	65.50%	100%	10.20%
1	142%	92.85%	318%	32.30%
2	104%	96.72%	210%	67.90%
3	102%	98.32%	133%	90.50%
4	101%	99.09%	107%	96.50%
5	101%	99.73%	101%	97.90%
6	100%	99.73%	101%	99.20%
7	100%	100.00%	101%	99.90%
8	100%	100.00%	100%	99.90%
9	100%	100.00%	100%	100.00%

As shown in Table V, claim counts develop rapidly, reaching 92.85% maturity by period 1. This indicates that most accidents are reported and logged almost immediately. On the other hand, the average cost per claim shows a typical long-tail pattern, requiring nine full periods to reach complete maturity.

Chain Ladder Projections To project ultimate losses under this method, the CL approach was applied separately to the frequency and severity components. First, the ultimate claim count for each accident year was estimated by dividing the observed number of accidents by $p_{j,\text{count}}$. Similarly, the ultimate average cost was calculated by taking the current observed average cost (paid losses divided by the observed number of accidents) and dividing it by $p_{j,\text{cost}}$.

The product of these two independent projections yields the final ultimate paid estimate, with the outstanding reserve derived by subtracting payments to date. The joint maturity ratio ($p_{j,\text{count}} \times p_{j,\text{cost}}$) serves as the indicator for the total maturity of the paid losses under this framework.

For the most recent accident years (2024-2025), this approach produces unrealistically low ultimate average cost estimates. This happens because the observed average cost at early lags is very low, as claims are reported quickly while actual payments lag behind. Dividing this small initial severity by $p_{j,\text{cost}}$ fails to fully capture the long-tail development of the portfolio, leading to understated estimates for the most recent years. To address this issue, the ultimate severity for these two years was set to the volume-weighted average cost per claim derived from the mature accident years (2016-2019). This period was selected for its stable and representative severity values, whereas the earlier fully developed years (2010-2015) exhibited more volatile results. The severity was calculated as the sum of CL ultimate paid losses divided by the sum of CL ultimate claim counts over that period.

While this adjustment addresses the youngest years, the method still overstates reserves for the middle accident years due to a leveraging effect in the intermediate development lags. This persistent volatility highlights the need for the more stable BF and GB frameworks.

Bornhuetter-Ferguson and Benktander Extensions To stabilize the low estimates produced by the CL approach in the recent years, the BF framework was adapted to the frequency-severity structure. This required establishing a priori estimates for both claim counts and average cost. First an overall factor θ , was calculated by dividing the sum of all CL ultimate claim counts by total premiums. The a priori claim count for each accident year j was then calculated as $\theta \times \text{Premium}_j$.

Second, an a priori claim cost (severity) was established. Because the initial results were found to be highly sensitive to the years included in the average, three different iterations were evaluated:

1. **Historical Baseline:** Calculated as the average of the final observed average cost from the fully matured accident years (2010-2018). This resulted in excessively high reserve estimates.
2. **Recent Maturity Baseline:** Calculated by averaging the final observed average cost for the more recent mature years (2015-2018) to better capture recent cost structures.
3. **Blended Baseline:** Calculated as the arithmetic mean of the second baseline and the average cost per claim derived from the incremental payments in the paid triangle. This final blended baseline was selected as it serves as a representative mean across all calculated severity indicators.

The final BF outstanding reserve is then determined by applying the joint unpaid proportion of these two a priori components:

$$R_j^{BF} = (\text{A priori count}_j \times \text{A priori Cost}) \times (1 - p_{j,\text{count}} \times p_{j,\text{cost}}) \quad (8)$$

Finally, the GB method was applied by blending these frequency-severity CL and BF outstanding estimates using the standard credibility weights. This approach successfully counters the understated CL projections in the most recent accident years by incorporating the stable premium-driven BF counts, while remaining anchored to the blended severity baseline.

The resulting estimates for each of the frequency-severity projection framework, alongside the corresponding standard method results, are summarized in Table VI.

TABLE VI: Reserve estimates under the Average Cost method compared with standard methods (WI normal, paid basis, in millions).

Reserving method	Standard method		Average Cost method	
	Ultimate	Outstanding	Ultimate	Outstanding
Chain Ladder (CL)	14,086	1,069	15,118	2,101
Bornhuetter-Ferguson (BF)	14,323	1,305	14,097	1,080
Benktander (GB)	14,301	1,283	14,317	1,300

4.2 Sensitivity to inflation adjustments

To evaluate how sensitive the reserves are to the choice of economic indicator, the observed triangles were adjusted using two different indices, the Wage Index (WI) and the

Consumer Price Index (CPI). The choice of index scales the monetary values differently, which in turn alters the development factors and the estimated reserves.

Tables VII and VIII show how the CPI adjustment deflates observed payments more aggressively than the WI. This results in lower cumulative payment proportions (p_j) for the most recent accident years. For example, at development lag 0, the paid maturity ratio is 5.35% under WI but only 4.70% under CPI.

TABLE VII: Weighted average development factors (DF) and accumulated factors, WI vs. CPI adjusted.

Lag	Weighted Avg. DF		Accumulated DF	
	WI	CPI	WI	CPI
0	100.00%	100.00%	100.00%	100.00%
1	508.79%	535.09%	508.79%	535.09%
2	236.17%	246.62%	1,201.62%	1,319.67%
3	135.78%	138.36%	1,631.53%	1,825.91%
4	109.25%	110.33%	1,782.50%	2,014.49%
5	102.17%	102.26%	1,821.13%	2,059.95%
6	101.50%	101.82%	1,848.44%	2,097.35%
7	101.06%	101.26%	1,868.12%	2,123.86%
8	100.05%	100.06%	1,869.02%	2,125.16%
9	100.08%	100.10%	1,706.00%	2,127.24%

TABLE VIII: Cumulative payment proportions (p_j), WI vs CPI adjusted, paid triangle.

Lag	WI p_j (%)	CPI p_j (%)	CPI/WI (%)
0	5.35	4.70	87.9%
1	27.20	25.15	92.5%
2	64.24	62.04	96.6%
3	87.23	85.84	98.4%
4	95.30	94.70	99.4%
5	97.36	96.84	99.5%
6	98.82	98.59	99.8%
7	99.87	99.84	100.0%
8	99.92	99.90	100.0%
9	100.00	100.00	100.0%

The impact of these differences on the final reserves is shown in Table IX. Although the WI framework produces higher absolute ultimate liabilities (reflecting higher inflation in wages and medical costs), the CPI framework actually results in higher outstanding reserves for the paid triangle. Under the standard CL method, the CPI outstanding reserve is 1.182 M compared to 1.069 M under WI.

This happens because the CPI adjustment deflates observed payments more than the WI, making recent payments appear smaller. This lower implied development forces the model to project a larger remaining tail, which increases the outstanding reserve. On an incurred basis, this effect is even clearer. The CPI adjustment pushes the incurred maturity ratios above 100% for several accident years, leading to negative IBNR estimates in the BF and GB methods.

TABLE IX: Baseline comparison of ultimate and outstanding reserves (WI vs. CPI, in millions).

Method / Index	Paid Basis (Normal)		Incurred Basis (Normal)	
	Ultimate	Outstanding	Ultimate	Outstanding
Chain Ladder				
Wage Index (WI)	14,086	1,069	14,448	1,431
Consumer Price Index (CPI)	11,399	1,182	11,508	1,292
Bornhuetter-Ferguson (106% LR)				
Wage Index (WI)	14,323	1,305	14,415	1,398
Consumer Price Index (CPI)	11,552	1,335	11,486	1,270
Benktander (106% LR)				
Wage Index (WI)	14,301	1,283	14,431	1,413
Consumer Price Index (CPI)	11,550	1,333	11,496	1,279

The choice of index is therefore not just a matter of scaling, it fundamentally changes the implied development of the portfolio. For a workers' compensation line, where medical and wage cost typically rise faster than general consumer prices, the WI provides a more realistic adjustment for observed trends. Consequently, the WI-normal scenario is used as the baseline for the final comparison in Section 4.4.

4.3 Impact of outlier thresholds

As outlined in Section 3.2, the dataset was evaluated under three scenarios, the full dataset, a 99.5% quantile exclusion, and a 95% quantile exclusion. This was done to evaluate how sensitive the portfolio was to large claims. Rather than comparing absolute monetary values across scenarios, the effect of these outlier adjustments was best seen through the development factors. Tables X and XI present the development factors under each threshold for the paid and incurred data, respectively under the WI baseline.

The paid development factors show a sharp increase at lag 0 under the 95% threshold, jumping from 508% to 1169%. This reflects the fact that removing claims above the 95% quantile removes a substantial portion of early paid volume, inflating the ratio between successive periods.

TABLE X: Development factors across outlier thresholds, paid basis.

Lag	Normal	99.5%	95%
0	508%	575%	1169%
1	236%	230%	228%
2	136%	136%	133%
3	109%	110%	109%
4	102%	102%	102%
5	102%	101%	101%
6	101%	101%	101%
7	100%	100%	100%
8	100%	100%	100%

The incurred factors tell a different story. At the 95% threshold, several incurred development factors drop below 100% in the intermediate lags. This suggests that the case reserve redundancy is not solely driven by a small number of large claims. At the 99.5% threshold, both paid and incurred factors remain close to the unadjusted baseline, suggesting that excluding claims above the 99.5th percentile has a limited effect on the overall development structure.

Overall, the analysis shows that the choice of outlier threshold has a limited effect on the reserve estimates. While 95% exclusion produces visible shifts in the early development factors, particularly on the paid side, the resulting differences in ultimate reserves are modest relative to the spread already seen between CL, BF and GB. This suggests that the results presented in Section 4.4 are not materially driven by the treatment of large claims. For the remainder of this report, the unadjusted (Normal) dataset is used as the baseline, and the full reserve comparison across methods is presented under that scenario.

TABLE XI: Development factors across outlier thresholds, incurred basis.

Lag	Normal	99.5%	95%
0	158%	160%	153%
1	111%	111%	104%
2	100%	100%	93%
3	98%	97%	95%
4	97%	97%	96%
5	98%	98%	97%
6	99%	99%	98%
7	100%	99%	99%
8	100%	100%	100%

4.4 Final Comparison and Best Estimate

The selection of a best estimate requires balancing model stability against the unique characteristics of this workers' compensation portfolio. Based on the sensitivity analysis in Section 4.2, the WI economic framework was selected over the CPI because it more accurately captures the wage-replacement costs that drive these long-tails.

Table XII presents the total ultimate and outstanding reserves calculated across all methodologies.

TABLE XII: Comparison of total ultimate and outstanding reserves (WI normal, in millions).

Reserving Method	Paid Basis		Incurred Basis	
	Ultimate	Outstanding	Ultimate	Outstanding
Chain Ladder (CL)	14,086	1,069	14,448	1,431
Bornhuetter-Ferguson (BF)	14,323	1,305	14,415	1,398
Benktander (GB)	14,301	1,283	14,431	1,413
Average Cost - CL version	15,118	2,101	—	—
Average Cost - BF version	14,097	1,080	—	—
Average Cost - GB version	14,317	1,300	—	—

The incurred-basis models are rejected due to systematic case reserve redundancy. The development factors falling below 100% in the middle lags can produce negative IBNR estimates under the traditional models. This case reserve redundancy makes the incurred-basis results unsuitable for balance-sheet provisioning. Similarly, the standard CL model is excluded for its over responsiveness to immature payments in the most recent accident years.

This volatility is even more pronounced in the Average Cost CL version, which produced the highest overall estimate of 2,101 M. As discussed in Section 4.1.4, this is primarily due to a "leveraging" effect where early reported counts combined with low initial payments lead to an over projection of severity. The BF and GB versions of the Average Cost method successfully corrected this by anchoring the results to the portfolio frequency (θ) and blended severity baseline.

The Benktander (GB) method applied to the paid WI triangle is selected as the best estimate, producing an ultimate claims estimate of 14,301 M and an outstanding reserve estimate of 1,283 M. This choice is cross validated by the Average cost GB method, which produces nearly identical result, with ultimate claims estimate of 14,317 M and outstanding reserve estimate of 1,300 M. The fact that two independent approaches, one based on aggregate payments and the other on frequency and severity components, arrive at a minimal difference of only 1.3% provides a high degree of confidence in the reliability

of this estimate. A year-by-year comparison of outstanding reserves under both methods is provided in the Appendix, Figure 5.

5 Conclusion

The objective of this project was to investigate different reserving methods for an Icelandic workers' compensation portfolio characterized by a long-tail development and significant inflation exposure. During the course of this work, several reserving methods were applied and evaluated, including the Chain Ladder (CL), Bornhuetter-Ferguson (BF), Benktander (GB) method, and Average Cost (AC) tested on both paid and incurred bases and under two economic frameworks (WI and CPI). The analysis ultimately identified the Benktander GB method applied to the paid WI triangle as the most credible estimate.

The key findings from this evaluation can be summarized as follows:

- **The WI framework is better suited** to this portfolio than the CPI, because workers' compensation costs are driven primarily by wage growth rather than general consumer price inflation.
- **The incurred basis models are unreliable** for this portfolio. Systematic case reserve redundancy in the middle development lags produces factors below 100%, distorts the incurred development pattern, and results in negative IBNR estimates for some mature accident years.
- **The pure Chain Ladder on paid basis overreacts** to immature payments in the most recent accident years, producing volatile and unstable estimates that do not reflect the underlying development pattern.
- **The Benktander (GB) method provides a credible middle ground** by blending the data driven Chain Ladder with the premium driven Bornhuetter-Ferguson estimate. It weights observed claim payments more heavily as the portfolio matures, while relying on the a priori baseline for recent, less developed years.
- **Cross-validation through the Average Cost method confirms the result.** The aggregate Benktander estimate of 1,283 M and Average Cost Benktander estimate

of 1,300 M differ by 1.3%. This convergence between two independent approaches, one based on aggregate payments and the other on claim counts and severity, provides strong confidence in the final estimate.

Based on these findings, the best estimate of the outstanding reserve for the portfolio is estimated at 1,283 M, produced by the standard Benktander (GB) method on paid WI triangles.

5.1 Limitations

While the results of this project provide a clear best estimate, several limitations should be acknowledged.

First, the analysis is based on a single Icelandic workers' compensation portfolio. The findings regarding the instability of incurred basis models and the relative performance of the Benktander (GB) method may not generalize to other portfolios, particularly those with different claim settlement patterns or less pronounced inflation exposures.

Second, the Bornhuetter-Ferguson (BF) and Benktander (GB) methods both rely on an a priori expected loss ratio of 106.23%, which was calculated from the portfolio's historical claim experience. While this is a data driven estimate, it assumes that the past loss patterns remain representative of future development. If the portfolio's risk profile shifts due to changes in inflation, regulation, or claim settlement practices, the a priori baseline may no longer reflect the true expected ultimate cost.

Third, the outlier analysis in Section 4.3 tested two outlier exclusions (99.5% and 95%) to assess the sensitivity of the results to large claims. While both thresholds produced differences in the final reserves, the thresholds themselves were selected as common industry benchmarks rather than being derived from a formal extreme value analysis. A more rigorous approach, such as fitting a Pareto distribution to the tail of the claims distribution, could provide a more principled basis for outlier treatment.

Finally, the most recent accident years (2023-2025) remain immature, with limited development history. All reserving methods are sensitive to the extrapolation of early development patterns, and the stability of the best estimate for these years will naturally improve as more payment data becomes available.

5.2 Recommendations for future research

The findings of this analysis suggests several directions for future research that could strengthen the application of the Benktander method in workers' compensation reserving.

First, the a priori loss ratio of 106.23% was derived directly from the historical experience of this portfolio. Future research could explore more systematic approaches to selecting the a priori estimate, for example by incorporating external benchmarking data from the Icelandic insurance market or applying Bayesian methods that allow the prior to be updated as new accident years develop.

Second, the incurred triangle in this study exhibited a systematic case reserve redundancy, which led to negative IBNR estimates under the traditional models. A useful next step would be to develop models that explicitly account for how case reserves are typically set too high early on and then revised downward as claims mature.

Third, this analysis used a single wage index to adjust for inflation over the study period. Since medical costs and wages do not always move together, further work could apply separate indices for each component to see whether this leads to more accurate reserve projections.

Finally, the near identical results between the aggregate Benktander estimate and the Average Cost Benktander estimate, differing by only 1.3%, suggests that combining these two approaches into a single blended framework may give a more stable best estimate. Exploring how such a blend would interact with the credibility weights of the Benktander method is a promising area for further study.

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A Appendix

This appendix presents the complete loss development triangles used in the analysis.

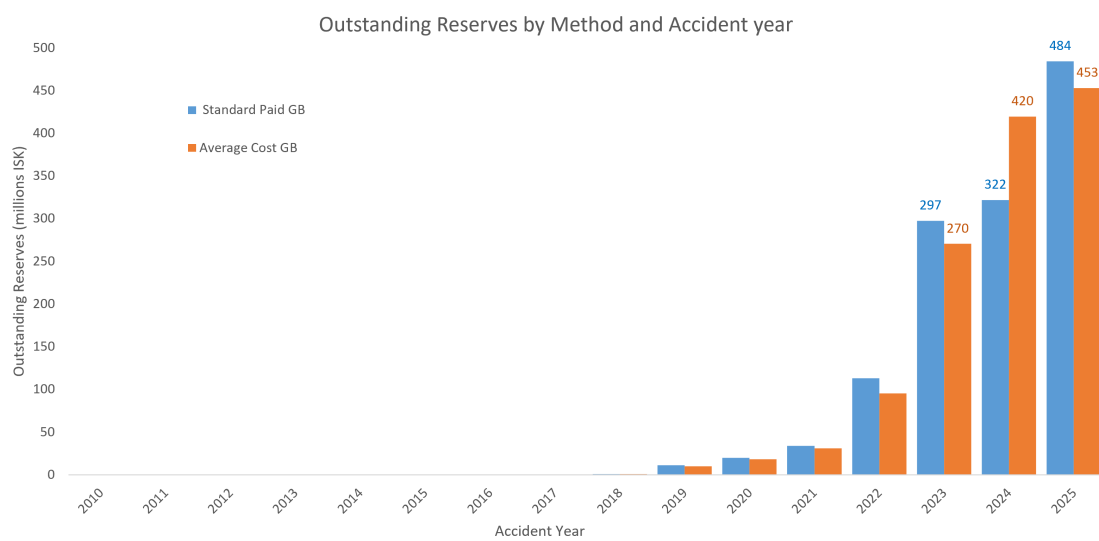


FIGURE 5: Comparison of outstanding reserve: Standard Paid Benktander (GB) vs. Average Cost Benktander (WI baseline).

TABLE XIII: Complete cumulative paid triangle (2010–2025, in millions of WI-adjusted).

Accident	Development Lag																
	Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
	2010	16.41	192.30	266.84	375.57	389.89	404.86	404.86	404.86	404.86	404.86	404.86	404.86	404.86	404.86	404.86	404.86
	2011	38.15	268.68	723.22	959.98	999.49	1,089.51	1,091.17	1,103.99	1,103.99	1,103.99	1,103.99	1,103.99	1,103.99	1,103.99	1,103.99	1,103.99
	2012	204.26	297.55	622.77	651.86	666.49	669.35	689.78	689.78	689.78	690.66	690.66	690.66	690.66	690.66	690.66	690.66
	2013	40.03	231.88	443.57	790.05	852.58	857.92	858.45	901.98	902.09	902.09	902.09	902.09	902.09	902.09	902.09	902.09
	2014	50.80	565.73	970.93	1,296.83	1,405.13	1,405.13	1,406.54	1,407.97	1,409.69	1,411.50	1,411.50	1,411.50	1,411.50	1,411.50	1,411.50	1,411.50
	2015	49.03	315.65	770.07	1,029.11	1,164.37	1,200.09	1,200.50	1,200.50	1,200.50	1,202.82	1,202.82	1,202.82	1,202.82	1,202.82	1,202.82	1,202.82
	2016	41.55	165.04	655.64	703.14	821.41	823.48	823.48	823.48	823.48	823.48	823.48	823.48	823.48	823.48	823.48	823.48
	2017	37.11	146.65	505.80	653.90	707.02	712.38	730.03	733.02	734.70	734.70	734.70	734.70	734.70	734.70	734.70	734.70
	2018	20.68	139.58	400.39	560.24	588.84	594.06	599.68	622.01	622.01	622.01	622.01	622.01	622.01	622.01	622.01	622.01
	2019	20.91	183.21	427.38	613.41	718.85	729.44	808.98	808.98	808.98	808.98	808.98	808.98	808.98	808.98	808.98	808.98
	2020	22.98	80.34	329.01	527.56	591.83	612.68	612.68	612.68	612.68	612.68	612.68	612.68	612.68	612.68	612.68	612.68
	2021	6.93	126.92	315.46	508.54	566.57	566.57	566.57	566.57	566.57	566.57	566.57	566.57	566.57	566.57	566.57	566.57
	2022	15.36	286.83	450.21	673.11	673.11	673.11	673.11	673.11	673.11	673.11	673.11	673.11	673.11	673.11	673.11	673.11
	2023	55.10	128.53	508.22	508.22	508.22	508.22	508.22	508.22	508.22	508.22	508.22	508.22	508.22	508.22	508.22	508.22
	2024	2.96	37.16	37.16	37.16	37.16	37.16	37.16	37.16	37.16	37.16	37.16	37.16	37.16	37.16	37.16	37.16
	2025	25.81	25.81	25.81	25.81	25.81	25.81	25.81	25.81	25.81	25.81	25.81	25.81	25.81	25.81	25.81	25.81

TABLE XIV: Complete cumulative incurred triangle (2010–2025, in millions of WL-adjusted).

Accident Year	Development Lag															
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
2010	16.41	192.30	266.84	375.57	389.89	404.86	404.86	404.86	404.86	404.86	404.86	404.86	404.86	404.86	404.86	404.86
2011	38.15	268.68	723.22	959.98	1,287.11	1,195.32	1,161.88	1,152.92	1,137.48	1,137.48	1,137.48	1,137.48	1,137.48	1,137.48	1,137.48	1,137.48
2012	204.26	408.18	645.28	738.72	736.54	740.57	744.95	729.24	714.43	715.31	715.31	715.31	715.31	715.31	715.31	715.31
2013	376.83	842.97	999.31	1,053.52	1,006.10	968.95	969.47	1,013.00	1,013.12	1,013.12	1,013.12	1,013.12	1,013.12	1,013.12	1,013.12	1,013.12
2014	1,152.60	1,619.63	1,674.43	1,824.87	1,637.68	1,653.11	1,654.52	1,655.95	1,655.95	1,635.52	1,635.52	1,635.52	1,635.52	1,635.52	1,635.52	1,635.52
2015	1,128.27	1,679.20	1,795.62	1,630.00	1,591.01	1,530.94	1,517.47	1,504.59	1,492.67	1,494.14	1,494.14	1,494.14	1,494.14	1,494.14	1,494.14	1,494.14
2016	783.84	983.36	1,302.90	1,209.43	1,234.88	1,099.11	1,039.88	1,013.66	1,013.66	1,013.66	1,013.66	1,013.66	1,013.66	1,013.66	1,013.66	1,013.66
2017	596.35	950.97	975.87	964.79	877.49	911.13	853.99	855.37	855.86							
2018	834.05	1,319.98	1,148.27	1,004.71	914.66	838.68	840.70	801.09								
2019	587.46	1,051.74	970.05	994.43	1,010.61	983.25	962.29									
2020	586.25	833.24	898.28	881.91	786.27	805.57										
2021	636.88	936.06	942.31	819.91	759.26											
2022	428.38	846.65	894.56	840.28												
2023	778.03	859.51	928.39													
2024	277.90	512.99														
2025	383.62															