ASSESSMENT OF THE RELIABILITY OF RESERVES ESTIMATES OF PUBLIC COMPANIES IN THE U.S. AND CANADA

A Thesis

by

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Submitted to the Office of Graduate and Professional Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

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May 2019

Major Subject: Petroleum Engineering

ABSTRACT

Estimation of reserves is a process used to quantify the volumes of hydrocarbon fluids that can be recovered economically from a reservoir, field, area or region, from a given date forward. A considerable level of uncertainty is involved throughout the reserves-estimation process. Unfortunately, individuals are poor at assessing uncertainty, with a common tendency for overconfidence (underestimation of uncertainty) and optimism.

There are a few studies that address the reliability of reserves estimates, but none of them quantify the reliability of these estimates. This research aims to assess quantitatively the reliability of reserves estimates of public companies filing in the U.S. and Canada. To do this I measured biases in reported reserves estimates for 34 companies filing in Canada and 32 companies filing in the U.S. over the time period 2007 to 2017.

Canadian companies explicitly report technical revisions of proved (1P) and proved-plus-probable (2P) reserves. U.S. companies do not report "technical revisions," but instead report "revisions of previous estimates" and revisions due to price changes of proved (1P) reserves separately. I calculated Revisions Other Than Price (ROTP) by subtraction for U.S. companies and assumed the difference was the same as "technical revisions."

Based on probabilistic reserves definitions, it is reasonable to assume that proved reserves estimates are expected to have positive technical revisions 90% of the time, while proved-

plus-probable reserves estimates are expected to have positive revisions 50% of the time. The reliability of proved and proved-plus-probable reserves estimates was assessed using calibration plots, in which the frequency of positive technical revisions is plotted against the estimate probability. Calibration plots can be used to measure confidence bias, ranging from underconfidence to complete overconfidence, and directional bias, ranging from complete pessimism to complete optimism.

"Technical revisions" reported by 34 Canadian companies for the 11-year period were positive an average of 72% for 1P reserves and an average of 54% for 2P reserves, whereas the expected values were 90% and 50%, respectively. Thus, on average over this time period, filers in Canada overestimated 1P reserves and underestimated 2P reserves. Considering the entire reserves distributions, bias measurements indicate that filers in Canada were moderately overconfident and slightly pessimistic. Revisions Other Than Price (ROTP) calculated for 32 U.S. companies for the 11-year period were positive an average of only 51% for 1P reserves, compared to an expected 90%. Thus, on average over this time period, filers in the U.S. overestimated 1P reserves significantly. Considering the entire reserves distributions, bias measurements indicate that filers in the U.S. were somewhere between complete overconfidence and neutral directional bias, and moderate overconfidence and complete optimism. The biases in reserves estimates filed in both Canada and the U.S. suggest that adjustments in reserves estimation procedures are warranted.

Three groups of professionals can benefit from this study: (1) estimators, who can use the methodology to track their technical revisions over time, calibrate them, and use this information to adjust future estimation procedures; (2) investors, who can analyze reported reserves estimates to compare volumes fairly; and (3) regulators, who can ensure that filers are complying with appropriate criteria for 1P and 2P reserves.

DEDICATION

This thesis is dedicated primarily to God, in whom I fully trust and to my mother, husband, and daughter, for all their love, wisdom and support.

ACKNOWLEDGMENTS

I would like to thank my committee chair, Dr. Duane A. McVay, and co-chair, Dr. W. John Lee, for all their support, teaching and guidance throughout the course of my research. I would also like to thank Dr. Thomas A. Blasingame for being willing to serve on my advisory committee.

I also want to extend my gratitude to the Harold Vance Department of Petroleum Engineering at Texas A&M University for giving me the opportunity to pursue a Master's degree.

Thanks also to my friends, colleagues, faculty, and staff of the Harold Vance Department of Petroleum Engineering for making my time at Texas A&M University a great experience.

And finally, my gratitude to my husband Gonzalo, for his encouragement, patience and love, to my dear mother Stella for keeping me in her prayers, and to my daughter Paula for making me proud and bringing happiness and joy to my life.

CONTRIBUTORS AND FUNDING SOURCES

Contributors

This work was supervised by a thesis committee consisting of Professor Duane A. McVay (advisor) and Professor W. John Lee (co-advisor) of the Department of Petroleum Engineering and Professor Thomas A. Blasingame of the Departments of Petroleum Engineering and Geology & Geophysics.

All work for the thesis was completed independently by the student.

Funding Sources

No outside funding was received for the research and compilation of this document.

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1. INTRODUCTION

1.1 Statement and Significance of the Problem

Oil and gas reserves estimation is the process of evaluating quantitatively the economically recoverable hydrocarbons in a field, area, or region. This is one of the most essential and complex procedures in the petroleum industry; it consists of the integration of geological and engineering data to conduct field/well performance evaluations and generate production forecasts. These production forecasts are combined with prices to generate revenue forecast, which are combined with capital investments and operating expenses to generate economic evaluations, which will be affected by market factors such as oil and gas prices. This process involves a considerable level of uncertainty; the exact quantity of hydrocarbons to be recovered cannot be known until production reaches the economic limit and the reservoir is abandoned.

Assessing the uncertainty in reserves estimates is an important process. Unfortunately, humans are poor at assessing uncertainty, i.e., we are biased. Several authors have reported on the tendency for overconfidence and optimism in the petroleum industry (Capen 1976; Welsh et al. 2005; McVay and Dossary 2014).

Reliability of the estimations of reserves is a major issue in the oil industry. Reliable means that over a large number of reserves estimates, the frequency of outcomes would correspond to the probabilities of reserves stated by reserves definitions. For example, we would expect actual remaining production to exceed proved reserves estimates approximately 90% of the time. Reserves estimates have a strong impact on companies' outcomes, such as:

- Value of the stock of the company.
- Contracts and unitization agreements.
- Project planning; i.e., failure to reliably estimate reserves could lead to oversized or undersized facilities and infrastructure, leading to economic harm.
- Reserves write downs and bankruptcy, e.g., Royal Dutch Shell Group in 2004 and Enron in 2001 (Olsen et al. 2011). In the case of Shell, the company announced a 3.9 billion BOE reduction in proved reserves in January 2004; as a result of this announcement the value of the company dropped 6.9%. Due to Enron's collapse in 2001, a new securities regulation (Sarbanes-Oxley) was adopted.

Reserves volumes should be as reliable as possible so that investors can be confident they are comparing volumes fairly: "Tightly controlled and audited reserves volumes are meant to provide investors with the confidence that a barrel of reserves at Company A bears the same uncertainty as a barrel at Company B" (Beliveau and Baker 2003).

1.2 Status of the Question

Previous authors (Franzen and Sawyer, 1980; Demirmen, 2005; Robinson and Elliot, 2005) analyzed different sets of data in different periods of time to determine the reliability of reserves estimates.

Franzen and Sawyer (1980) analyzed biases in the initial estimates made for 40 off-shore field development projects over a ten-year period, and sought to determine the reliability of variables such as project time, drilling time, oil production, and oil reserves. The authors examined the differences between the initial development scenario used to justify installation of the platform and the actual or most current field development results after installation of the platform and completion of development drilling. They used a statistical analysis based on paired comparisons to determine the effect of a single variable. The authors concluded that, for project time, the average estimates were 22.5% below the actual time, and, for drilling time, on average the estimates were 23.4% below the actual drilling time. Regarding initial production rates, the results indicate that the estimated oil rates on average were 23% above the actual values. In general, estimators exhibited optimism by predicting that projects will be completed sooner, will require less drilling time, and will have higher production rates than what actually occurred. However, regarding reserves estimates, the authors could not draw any clear conclusions due to the large variance presented on the recoverable volumes and hence, there was a large uncertainty of what the true or actual reserves would be (Franzen and Sawyer 1980).

Demirmen (2005) reviewed field Estimated-Ultimate-Recovery (EUR) variations for the North Sea and for the Gulf of Mexico (GOM) (the author used the term “reserves” rather than “EUR,” defining “reserves” as the best estimate of total recoverable volume including production). For the North Sea, the author reviewed 15 major oil fields for a period from

1974 to 2003, observing a clear tendency that on average, EUR from these fields grew over this time period by a factor of 2.7.

For the GOM, the author normalized pre- and post-production EUR variations for 14 large deep-water fields and concluded that, in general, from year one of production, EUR variations in the GOM were more pronounced than those in the North Sea, as the majority of large GOM deep-water fields had reached the same amount of EUR growth within a much shorter period after production start. The author concluded that the reliability of reserves estimates is poor, as many fields show wide fluctuations in reserves estimates over time, with a tendency toward underestimation of reserves (Demirmen 2005).

Robinson and Elliot (2005) reviewed "technical revisions" in annual information forms. They analyzed 216 filings of Canadian companies using data available from the Canadian Securities Administrators (CSA) for the year 2003, which was the year that Canadian companies changed from reporting under Policy 2B and started reporting under new regulation National Instrument 51-101 "Standards of Disclosure for Oil and Gas Activities" (CSA 2015). The authors excluded some companies from the analysis because they found some inconsistencies, mainly attributed to it being the first year of reporting under new regulations. The authors assessed the number of companies that had positive technical revisions and the average volume of the positive revisions. For light and medium oil, out of 138 companies, 55 (40%) presented positive technical revisions for 1P and 66 (48%) for 2P reserves. For natural gas, out of 155 companies, 47 (30%) presented positive technical revisions for 1P and 59 (38%) for 2P. The authors did not explain why there are more positive revisions for 2P than 1P. The authors compare the proportion of technical revisions and the average volume of the technical revisions for 1P and 2P to the anticipated values. Based on the results they concluded for 1P that the proportion of positive revisions is much lower than the expectation (they expected for 1P positive revisions should occur in the vast majority of the companies), and for 2P the proportion of positive revisions and the magnitude of the average revision are close to the anticipated values (positive reserves revisions should equal negative reserves revisions). The authors mentioned that “technical revisions will continue to be analyzed in subsequent years” (Robinson and Elliott 2005).

Robinson and Elliot (2005) conclude that reserves estimates were generally optimistic, but they did not present any calculation of how they determined this bias. This study was done for one year in which a change in reporting could cause some noise into the results. A better approach to determine the tendency for optimism or pessimism would be to analyze the technical revisions of these companies for a longer period of time.

Even though reserves estimation is one of the most important tasks in the oil and gas industry, many studies suggest that reserves estimates are not very reliable. There are not many studies that quantify the reliability of reserves estimates. Therefore, estimators, investors, and regulators have little guidance on whether reserves estimates can be considered reliable or not.

1.3 Research Objective

The objective of this study is to assess the reliability of proved (1P) and proved-plus-probable (2P) reserves estimates reported by public companies in the U.S. and Canada. To do this I measured biases in reported reserves estimates for 34 companies filing in Canada and 32 companies filing in the U.S. over the time period 2007 to 2017 (when information was available).

2. OVERVIEW OF RESERVES

2.1 Reserves Definitions

The Securities and Exchange Commission (SEC) "Modernization of Oil and Gas Reporting" defines reserves as "estimated remaining quantities of oil and gas and related substances anticipated to be economically producible, as of a given date, by application of development projects to known accumulations" (SEC 2009).

Reserves are categorized according to the range of uncertainty associated with the estimates:

- Incrementally, as proved (high confidence), probable (less confidence), and possible (least confidence), and
- Cumulatively, as proved (high degree of confidence that the stated volume or more will be recovered), proved-plus-probable (equally likely that more or less than the stated volume will be recovered) and proved-plus-probable-plus-possible (a low probability that the stated volume or more will be recovered).

The Canadian Oil and Gas Evaluation Handbook (COGEH) defines proved reserves as "those reserves that can be estimated with a high degree of certainty to be recoverable" (COGEH 2018). The Securities and Exchange Commission (SEC) in the "Modernization of Oil and Gas Reporting" defines proved reserves as "those quantities of oil and gas, which, by analysis of geoscience and engineering data, can be estimated with reasonable certainty to be economically producible from a given date forward, from known reservoirs, and under existing economic conditions, operating methods, and government regulations" (SEC 2009).

If deterministic methods are used to estimate proved reserves, reasonable certainty means a high degree of confidence that the quantities will be recovered. If probabilistic methods are used, there should be at least 90% probability that the quantities actually recovered will equal or exceed the estimate (FASB 2010).

The certainty criterion for proved-plus-probable (2P) reserves is a 50% probability that the quantities recovered will equal or exceed the estimated 2P reserves. In other words, it should be equally likely that either more or less than the stated volume will be recovered.

2.2 Disclosure Requirements for Reporting Oil and Gas Activities

2.2.1 Canadian Standards of Disclosure for Oil and Gas Activities

In Canada, the Canadian Securities Administrators (CSA) is an umbrella organization of Canada's provincial and territorial securities regulators. Its objective is to improve, coordinate and harmonize regulation of the Canadian capital markets (CSA 2018).

The CSA, National Instrument (NI) 51-101, "Standards of Disclosure for Oil and Gas Activities" referred to COGEH as the resource-evaluation standard to be followed in Canada (COGEH 2018). Part 4 of NI 51-101 is the requirement for disclosure of an annual reconciliation of changes in estimates of gross proved reserves, gross probable reserves and gross proved-plus-probable reserves. This is required by country, product type, and reserves-change category. An associated explanation is also required for any disclosure that occurs in each reserves-change category (CSA 2015).

Reserves reconciliation compares reserves estimates on the effective date, (generally December 31 of the current year), with the corresponding estimates at the end of the preceding year, which is the opening balance of the reconciliation. The closing balance is the result of this comparison.

Reserves-change categories are provided verbatim from the original source to prevent misunderstanding of the regulations. Reserves-change categories that add to inventory defined in

Table 2.1, reserves-change categories that reduce inventory are shown in **Table 2.2**, and reserves-change categories that fluctuate within inventory are shown in **Table 2.3**.

Table 2.1—Reserves-change categories that add to inventory (COGEH Vol. 1 2018, 240-241).

Reserves-change Category	**Definition**
Discoveries	Additions to volumes in reservoirs where no volumes were previously booked. Any positive or negative changes to an estimate after the initial assignment and reporting should be recorded as a technical revision.
Extensions	Additions to volumes resulting from capital expenditures for step-out drilling in previously discovered reservoirs. Any positive or negative changes to an estimate after the initial assignment and reporting should be recorded as a technical revision.

Table 2.1—Continued.

Reserves-change Category	Definition
Improved Recovery	Additions to volumes resulting from capital expenditures associated with the installation of improved recovery schemes (secondary or tertiary projects such as waterfloods, miscible injection, steam-assisted gravity drainage (SAGD)). Any positive or negative changes to an estimate after the initial assignment and reporting of the improved recovery program should be recorded as a technical revision.
Infill Drilling	Additions to volumes resulting from capital expenditures for infill drilling in previously discovered reservoirs that were not drilled as part of an enhanced recovery scheme. Any positive or negative changes to an estimate after the initial assignment and reporting should be recorded as a technical revision.
Acquisitions	Positive additions to volume estimates because of purchasing interests in oil and gas properties.

Table 2.2—Reserves-change categories that reduce inventory (COGEH Vol. 1 2018, 241).

Reserves-change Category	Definition
Dispositions	Reductions in volume estimates because of selling all or a portion of an interest in oil and gas properties.
Production	Reductions in the volume estimates due to production during the time period being reconciled.

Table 2.3—Reserves-change categories that fluctuate within inventory (COGEH Vol. 1 2018, 241).

Reserves-change Category	Definition
Economic Factors	Changes to volumes between the current and previous reporting periods resulting from different price forecasts, inflation rates, and regulatory changes.
Technical Revisions	Positive or negative volume revisions to an estimate resulting from new technical data or revised interpretations on previously assigned volumes, performance and operating costs. Positive technical revisions are usually associated with better reservoir performance and operating costs and negative revisions with poorer reservoir performance and operating costs.

The intention of this research is to assess the reliability of reserves estimates due to technical factors. Thus, the focus of this study will be specifically on "technical revisions," even though "economic factors" also affect the reliability of the reserves. Based on reserves definitions, it is reasonable to assume that a positive "technical revision" is expected in proved reserves 90% of the time and a positive "technical revision" is expected in 2P reserves 50% of the time. Therefore, by measuring the percentage of positive "technical revisions," the reliability of probabilistic reserves estimates is assessed.

This proposed method for assessing reliability is consistent with a validation process described in section 4.6.1 of the latest edition of COGEH, where the technical reserves revisions are tracked over time to validate the past reserves estimates and to determine whether reserves were prepared in a manner consistent with the reserves definitions (COGEH 2018). **Table 2.4** summarizes the "technical revisions" that should be expected for each reserves or resource category according to COGEH.

Table 2.4—Technical reserves/resources revisions expected by category (COGEH 2018).

Reserves Category	**Entity Level**	**Reported Level**
1P, 1C, Low	Positive revisions should occur in significantly more of the entities than negative revisions.	Negative revisions should seldom occur at this level.
2P, 2C, Best	Positive revisions should roughly equal negative revisions.	Only minor positive or minor negative revisions should occur at this level.
3P, 3C, High	Negative revisions should occur in significantly more of the entities than positive revisions.	Positive revisions should seldom occur at this level.

According to COGEH, entity level refers to the discrete part of an oil and gas asset for which a reserves calculation is performed prior to aggregation. For example, a reserves entity may be an individual well zone, a group of well zones, or a pool. Report level refers to the sum of individual reserves estimates to be contained in a report. Reported reserves commonly refers to the total reserves a company owns (COGEH 2018).

2.2.2 U.S. Standards of Disclosure for Oil and Gas Activities

In the United States, the mission of the SEC is to protect investors, and to maintain fair, orderly, and efficient markets to facilitate capital formation. The regulations that govern the securities industry in the United States derive from a simple and straightforward concept: all investors, whether large institutions or private individuals, should have access to certain basic facts about an investment prior to buying it, and so long as they hold it. Then, with the aim of achieve this, the SEC requires public companies to disclose meaningful financial and other information to the public (SEC 2009).

Reserves-change categories are provided verbatim from the original source to prevent misunderstanding of the regulations. Reserves-change categories that add to inventory are defined in **Table 2.5**, reserves-change categories that reduce inventory are shown in **Table 2.6**, and reserves-change categories that fluctuate within inventory are shown in **Table 2.7**.

Table 2.5—Reserves-change categories that add to inventory (FASB 2010).

Reserves-change Category	**Definition**
Discoveries	Discovery of new fields with proved reserves or of new reservoirs with proved reserves in old fields.
Extensions	Additions in proved reserves resulting from extensions of proved acreage of previously discovered (old) reservoirs through additional drilling in periods subsequent to discovery.
Improved Recovery	Changes in reserves estimates resulting from application of improved recovery techniques. If not significant, such changes shall be included in revisions of previous estimates.
Purchases of Minerals in Place	Purchases of minerals in place.

Table 2.6—Reserves-change categories that reduce inventory (FASB 2010).

Reserves-change Category	**Definition**
Sales of Proved Minerals in Place	Sales of proved minerals in place.
Production	Production.

Table 2.7—Reserves-change categories that fluctuate within inventory (FASB 2010).

Reserves-change Category	**Definition**
Revisions of Previous Estimates	This item represents changes in previous estimates of proved reserves, either upward or downward, resulting from new information (except for an increase in proved acreage) normally obtained from development drilling and production history or resulting from a change in economic factors.

There are differences in the names and aggrupation of the reserves-change categories between the U.S. and Canada (**Table 2.8**). An example of a reserves reconciliation for a company that filed in both Canada and the U.S. is presented in **APPENDIX A**.

Table 2.8—Reserves-change categories grouping.

	U.S.	CANADA
Opening Balance	Beginning of the Year	Beginning of the Year
Additions	Purchases of Minerals in Place Extensions and Discoveries Improved Recovery	Acquisitions Extensions and Improved Recovery Discoveries
Reductions	Sales of Minerals in Place Production	Dispositions Production
Fluctuations	Revisions of Previous Estimates	Technical Revisions Economical Factors
Closing Balance	End of the Year	End of the Year

Sources: For U.S., the FASB and for Canada, Form 51-101F1.

2.2.3 Reserves Estimations and Disclosure—Differences between U.S. and Canada

The main differences between Canadian and U.S reserves estimations and disclosures are:

- It is mandatory for companies that file in Canada to report 1P and 2P reserves, while for companies that file in U.S. it is mandatory to report only 1P reserves.
- Filers in Canada report gross reserves while filers in U.S. report net reserves. Gross reserves are defined as the working-interest share of reserves prior to the deduction of interests owned by others (burdens). Net reserves are the working, net carried, and royalty-interest reserves after deduction of all applicable burdens (COGEH 2018).
- Filers in Canada estimate reserves using forecasted prices while filers in the U.S. estimate with a fixed, recent average historical price. In Canada, companies can use their own forecasted prices, which means the forecasted prices can vary from

company to company. Conversely, in the U.S., companies all use the same fixed average historical price, adjusted by transportation and quality.

- Filers in Canada present “technical revisions” separately from “economic changes,” while filers in the U.S. present technical and economical revisions grouped in “revisions of previous estimates.”
- In the inventory, filers from both Canada and the U.S. present reserves-change items for each product. Filers in Canada present “economic changes” by product but unlike them, filers in the U.S. present explanations related to price changes by total fluid without specifying what the changes were in the individual components of the total fluids, making it difficult to calculate the revisions due to price change for each product.

Reasons behind the Difference in Price Estimations

In the U.S., estimates of reserves quantities are determined using a fixed average historical price, making these estimates in someway not realistic. The objective of reserves estimations in the U.S. is to provide the public with comparable information about volumes, not fair value of a company. On the other hand, Canadian companies estimate both reserves volume and economic value. Therefore, a price forecast is necessary to calculate the future revenue and present economic value of the reserves.

2.3 Estimated Ultimate Recovery (EUR) and Reserves

Some techniques to calculate reserves begin with the estimation of EUR from which the cumulative production is subtracted to arrive at the estimate of reserves. If the initial EUR is reliable, EUR should remain constant over the life of the field, and reserves will decrease as production increases.

The following example adapted from Robinson and Elliott (2004) presents an idealized example of annual reserves reconciliation for a field that has produced for 10 years. It is assumed that, during the life of this field, reserves changed due to only "technical revisions" and production. In other words, the field reserves did not change due to discoveries, extensions, improved recovery, or sales (Robinson and Elliott 2004). The certainty levels associated with the initial reserves estimates at time zero are:

- High case (3P), P10, reserves estimate = 180 MMbbls,
- Medium case (2P), P50, reserves estimate = 100 MMbbls, and
- Low case (1P), P90, reserves estimate = 20 MMbbls.

These certainty levels mean that there is a high probability (90%) that the reserves will be 20 MMbbls or more, an equally likely probability (50%) that the reserves will be 100 MMbbls or more, and a low probability (10%) that the reserves will be 180 MMbbls or more. **Fig. 2.1** presents an inverse-cumulative distribution function (inverse-CDF) for this reserves example.

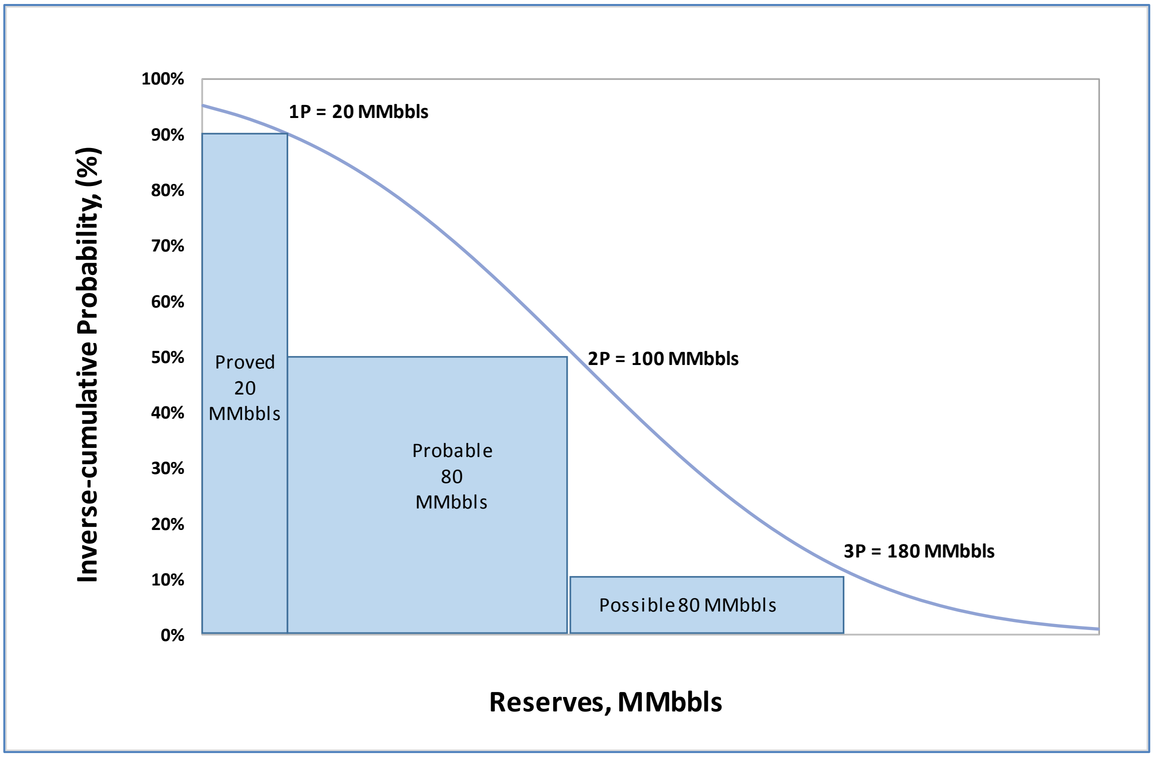


Fig. 2.1—Probabilistic distribution of reserves, example.

Table 2.9 presents a summary of annual reserves reconciliation. The input data are the measured production and the reserves estimates (input data shown in blue in the table). At year zero, the only information given is the initial EUR that corresponds to the initial reserves estimates, and the certainty levels associated with this estimate. At end of year one, the production for the year and new estimates of reserves, based on the information gathered during this year, were obtained. The new EUR would be the addition of the cumulative production and the new reserves estimate, and the technical revisions are the difference between EUR in each year.

Table 2.9—Reserves reconciliation example, adapted from (Robinson and Elliott 2004).

Year	Production (MMbbls)		1P (MMbbls)			2P (MMbbls)			3P (MMbbls)		
Initial	Yearly	Cum	EUR	Tech Revisions	Reserves	EUR	Tech Revisions	Reserves	EUR	Tech Revisions	Reserves
0		0.0	20		20	100		100.0	180		180
1	18.0	18.0	34	14	16.0	102	2	84.0	160	-20	142.0
2	15.5	33.5	50	16	16.5	99	-3	65.5	145	-15	111.5
3	13.3	46.8	70	20	23.2	103	4	56.2	131	-14	84.2
4	11.4	58.2	82	12	23.8	99	-4	40.8	119	-12	60.8
5	9.8	68.1	77	-5	8.9	104	5	35.9	114	-5	45.9
6	8.5	76.6	89	12	12.4	102	-2	25.4	121	7	44.4
7	7.3	83.8	94	5	10.2	105	3	21.2	114	-7	30.2
8	6.3	90.1	98	4	7.9	104	-1	13.9	109	-5	18.9
9	5.4	95.5	100	2	4.5	105	1	9.5	106	-3	10.5
10	4.5	100.0	100	0	0.0	100	-5	0.0	100	-6	0.0

In this example, 1P EUR, a conservative estimate, increases with time as new information is obtained. Thus, positive revisions occur in a majority of years. The 2P EUR, the median, does not change substantially over time since the number of positive revisions equals the number of negative revisions. The 3P EUR, a high estimate, decreases with time since negative revisions occur in most years. The uncertainty range in the EUR decreases as the quantity of information available increases with time (**Fig. 2.2**). At the end of field life, EUR is equal to cumulative production.

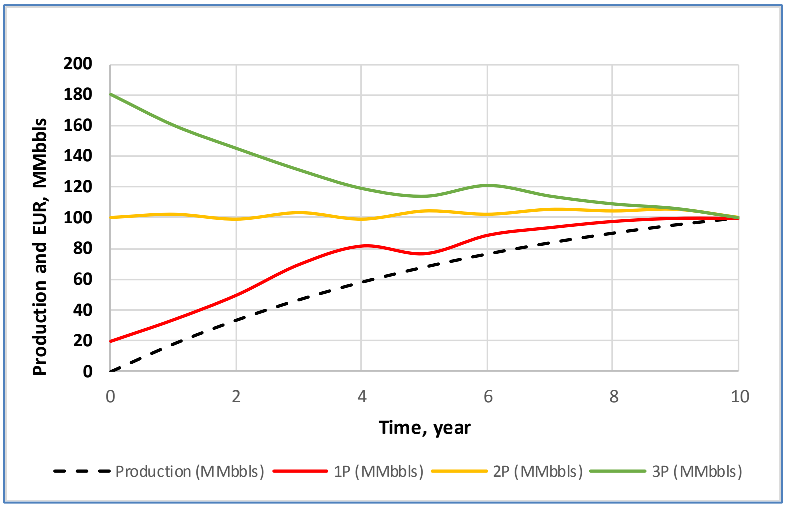


Fig. 2.2—Example of field cumulative production and EUR over time.

As a general tendency, 1P, 2P, and 3P reserves decrease as the reservoir is depleted (**Fig. 2.3**). Reserves could fluctuate each year depending on the difference between the Technical Revisions (TR) and the rate of extraction; e.g., proved reserves increases from 16.5 to 23.2 MMbbls from year 2 to 3 due to technical revisions increases larger than production in this year. At the end of the life of the field, there is no uncertainty and reserves are zero**.**

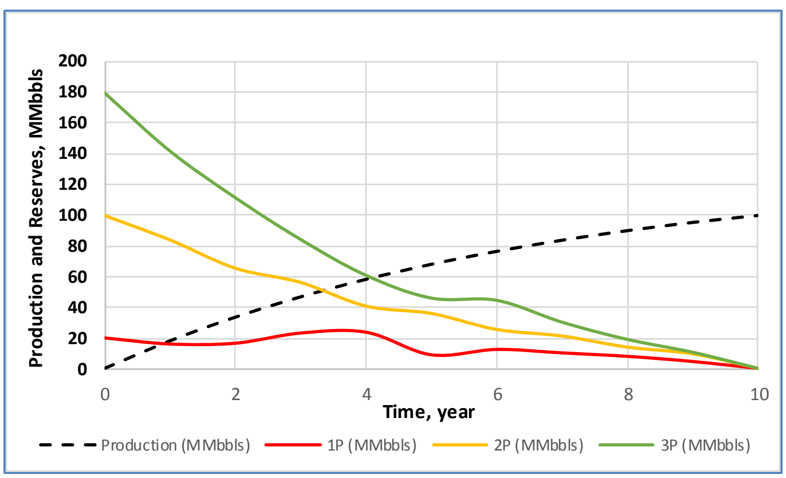


Fig. 2.3—Example of field cumulative production and reserves estimates over time.

For this idealized example, 9 of 10 proved technical revisions are positive, 9 of 10 3P technical revisions are negative, and 5 of 10 2P technical revisions are positive (**Fig. 2.4**). **Fig. 2.5** is a visualization of the relationships among EUR, reserves, production, and technical revisions for proved reserves. The red line is the EUR, the blue shading corresponds to the reserves, the black dash line is the cumulative production, and the differences between the EUR's each year are the technical revisions. When no other inventory items affect the annual reconciliation, the proved EUR and reserves, cumulative production, and technical revisions should change approximately as in Fig. 2.5.

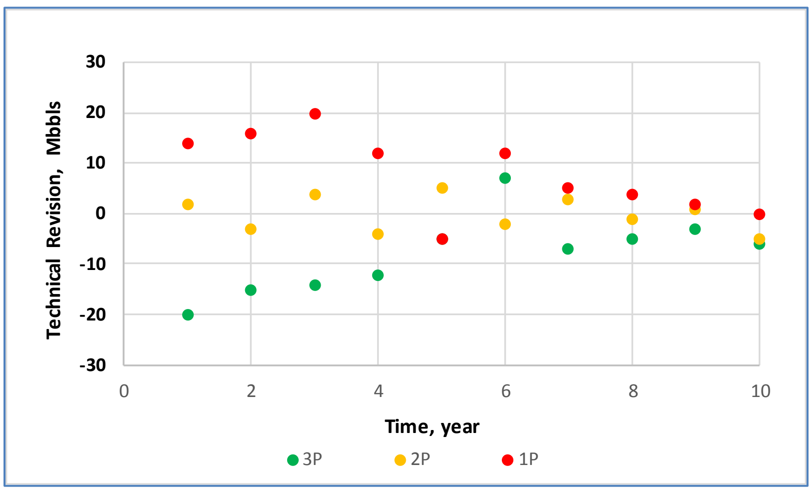


Fig. 2.4—Technical revisions over time.

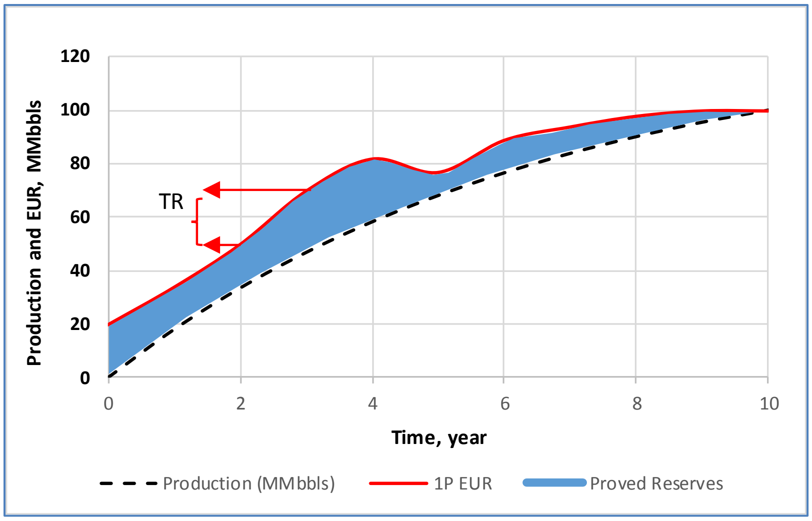


Fig. 2.5—Cumulative field production, proved EUR and reserves estimates, and technical revisions (TR) over time.

3. RESERVES RELIABILITY

Reliability of reserves estimates is a major issue in the oil industry, as these estimates influence project-investment decision making, project planning, company stock valuation, reserves write-downs, and even bankruptcy.

McVay and Dossary (2014) stated that chronic overconfidence and optimism bias are common in nearly everyone, including oil and gas industry professionals. A key way to improve the reliability of reserves estimates is to eliminate biases in these estimates. To eliminate biases, it is first necessary to measure them. One way to measure biases is to look back and compare previous probabilistic estimates to the actual values when they become known (Alarfaj and McVay 2016). Unfortunately, in the case of reserves estimates, the actual volumes will be known only at the end of the life of the field.

Continuous probabilistic assessments are often expressed in terms of cumulative or inverse-cumulative distributions. In the case of reserves, the inverse-cumulative is used. P90 means there is a 90% probability the actual value will be greater than or equal to the P90 estimate. P50 means there is a 50% probability the actual value will be greater than or equal to the P50 estimate, and P10 means there is a 10% probability the actual value will be greater than or equal to the P10 estimate.

Proved reserves estimates are expected to have positive “technical revisions” in proved reserves 90% of the time. Similarly, 2P reserves are expected to have positive “technical revisions” 50% of the time. If our continuous probabilistic assessments are unbiased, or reliable, the actual “technical revisions” for 1P reserves should be positive in approximately 9 of 10 years, and the actual “technical revisions” for 2P reserves should be positive in approximately 5 of 10 years.

The reliability of the reserves estimates is analyzed by comparing the observed frequency of positive “technical revisions” to the assigned probability dictated by reserves definitions. While the magnitudes of the revisions may be important, reliability in this thesis refers to reliability of assigned probabilities, and probabilities relate to frequencies.

In probabilistic assessments, overconfidence causes the estimated distribution to be too narrow (i.e., we are too certain of the possible outcomes). Optimism causes the estimated distribution to shift in the more desirable, or beneficial, direction. Thus, an optimistic estimated distribution would shift to the right for value-based assessments (**Fig. 3.1**) and to the left for cost-based assessments. Optimism can occur when we ignore or fail to consider possible negative outcomes or give them less weight than equally-probable positive outcomes (Alarfaj and McVay 2016).

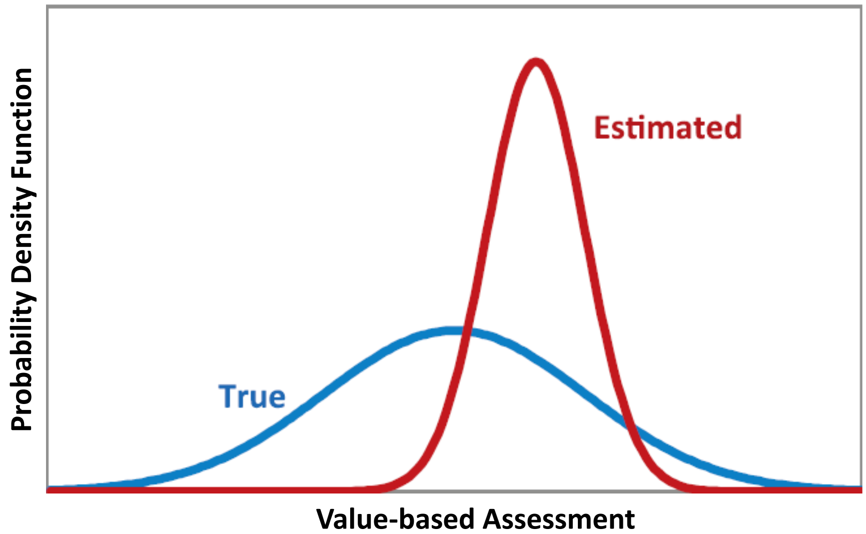


Fig. 3.1—Estimated distribution showing overconfidence and optimism, from (McVay 2015).

The overconfidence-bias (CB) parameter was defined by McVay and Dossary (2014) as a parameter that ranges from 0.0 to 1.0. A value of 0.0 denotes that the entire true distribution was sampled. A value greater than 0.0 indicates that only a subset of the true distribution was sampled, resulting in an estimated distribution narrower than the true distribution. A value of one indicates no distribution at all, i.e., a point estimate.

Additionally, they defined the directional-bias (DB) parameter for a CDF as a parameter that ranges from -1.0 to 1.0 and specifies the location of the estimated distribution relative to the true distribution. A DB value of -1.0 (complete pessimism) means that only the lowest possible outcomes of the true distribution were considered. A DB value of +1.0 (complete optimism) means that only the highest possible outcomes of the true distribution were considered (McVay and Dossary 2014).

3.1 Measuring Confidence and Directional Biases with Calibration Plots

The reliability of probabilistic assessments can be measured on a calibration plot in which the frequency of outcomes is plotted against the assessed probability of outcomes (**Fig. 3.2**). Reliable probabilistic forecasts will fall on the unit-slope line on a calibration plot; e.g., P90 means there is a 90% probability the actual value will be greater than or equal to the P90 estimate for an inverse-cumulative distribution function (inverse-CDF). This means that for a group of probabilistic forecasts, if the forecasts are probabilistically reliable, then the actual values will be more than the P90 estimates about 90% of the time.

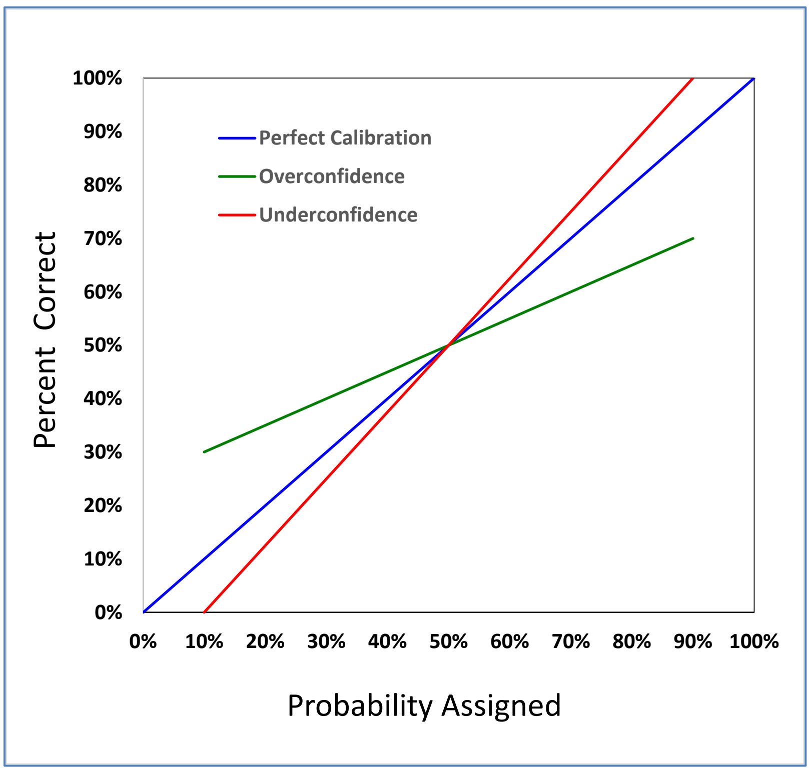


Fig. 3.2—Calibration plot with underconfidence, overconfidence and perfect calibration.

A slope less than 1 indicates overconfident probabilistic assessments. For example, for a group of P90 assessments the actual values were more than the P90 estimates only 70% of the time, and for the P10 assessments the actual values were more than the P10 estimates 30% of the time (green line in Fig. 3.2). The estimated P90-P10 (80%) ranges are in actuality only P70-30 (40%) ranges because the estimated distributions are too narrow. A slope greater than 1 indicates underconfident probabilistic assessments. Because the occurrence of underconfidence (overestimation of uncertainty) is apparently rare, it is mentioned only briefly in this document.

In a calibration plot, the directional bias is assessed as a vertical shift in the line with respect to the unit-slope line. In a cumulative distribution function (CDF), positive directional bias (optimism for value-based assessments) is present when the line is shifted upward (i.e., falls above the 0.5 proportion-correct value), and negative directional bias (pessimism for value-based assessments) is present when the line is shifted downward (**Fig. 3.3**). In this research, all the probabilistic assessments are all for value-based quantities (reserves and reserves revisions).

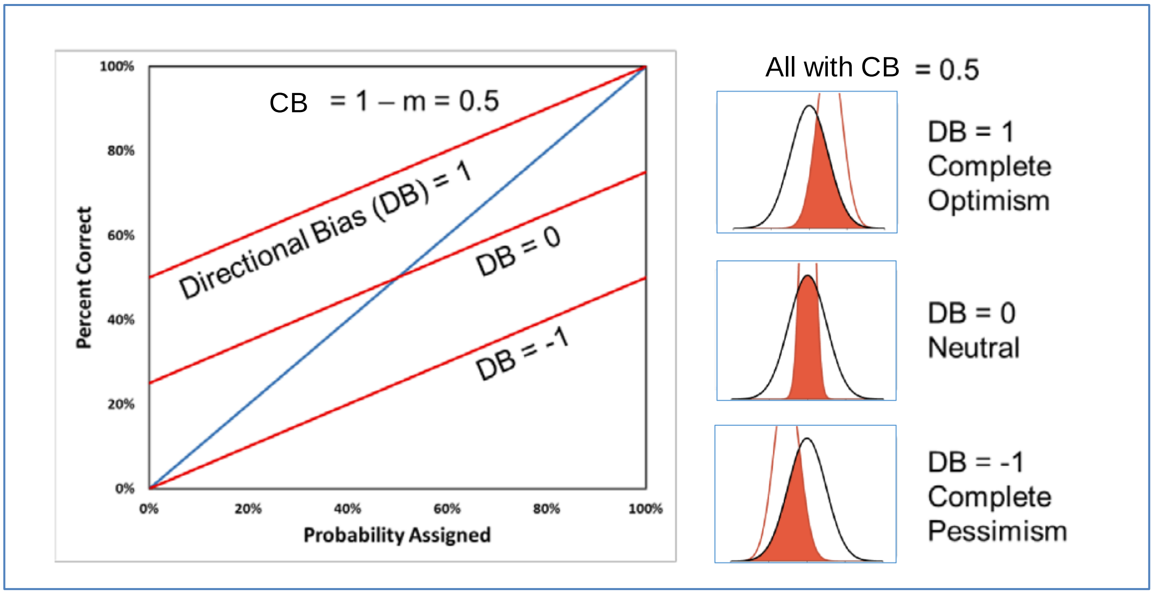


Fig. 3.3—Example of confidence and directional biases (Modified from Alarfaj, 2016).

Fig. 3.3 presents a cumulative distribution example with CB equal to 0.5. This means that only half of the true distribution has been sampled (overconfidence), and it is represented by a slope *m* equal to 0.5 on the calibration plot, where CB is equal to 1 – *m*. The three red lines represent (a) neutral or no directional bias (DB = 0), when only the middle of the distribution is sampled (middle red line), (b) optimism (DB = 1), when only the highest possible outcomes of the true distribution were considered (top red line), and (c) pessimism (DB = -1), when only the lowest possible outcomes of the true distribution were considered (bottom red line).

When the probabilistic assessments are presented in the form of cumulative distribution functions (CDFs) rather than inverse-cumulative distribution functions (inverse-CDFs), the relationships between the slope *m* and intercept *a* of the line in the calibration plot and the biases are based on the following equations presented by Alarfaj and McVay (2016).

$$CB_{OC} = 1 - m \quad (1)$$

$$DB_{OC} = \frac{2a}{1-m} - 1 \quad (2)$$

$$CB_{UC} = \frac{1}{m} - 1 \quad (3)$$

$$DB_{UC} = 1 - \frac{2a}{1-m} \quad (4)$$

Truncated normal distributions will generate straight lines in calibration plots (McVay and Dossary 2012). Full distributions will generate curves in calibration plots (Alarfaj and McVay 2016). The equations above are used in this study to approximate confidence and directional biases from the straight lines constructed with two points (P90 and P50).

To illustrate the relationship between the CDF and the inverse-CDF, an example is presented. **Fig. 3.4** shows a calibration plot constructed when the probabilistic assessments are presented in the form of CDFs, and **Fig. 3.5** shows a calibration plot constructed when the same probabilistic assessments are presented in the form of inverse-CDFs.

In the particular example presented in Fig. 3.4, the actual probability range from the group of P10-P90 estimations is 0.64 - 0.2 = 0.44, a lower value than from the perfectly-calibrated line where the probability range is 0.9 - 0.1 = 0.8. This indicates the estimations are overconfident; i.e., the estimated uncertainty is narrower than actual, corresponding to a slope less than one (*m*=0.55).

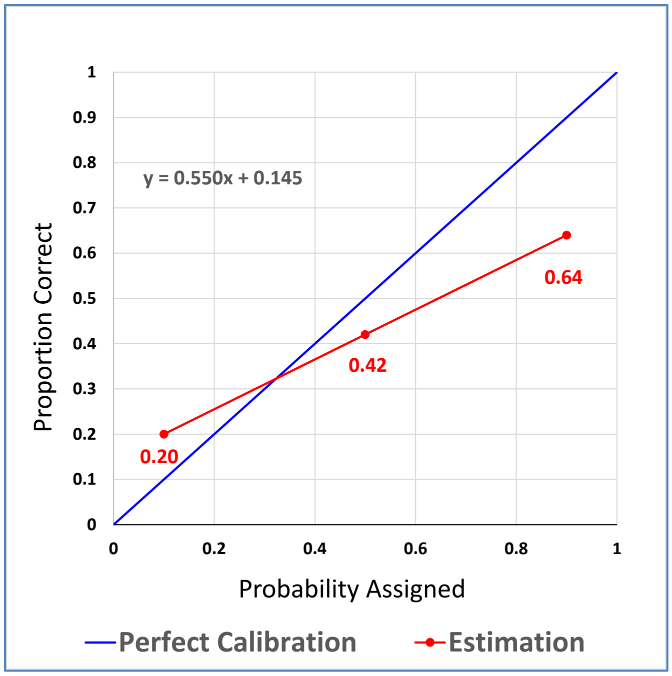


Fig. 3.4—Example of calibration plot with probabilistic assessments presented in CDF form.

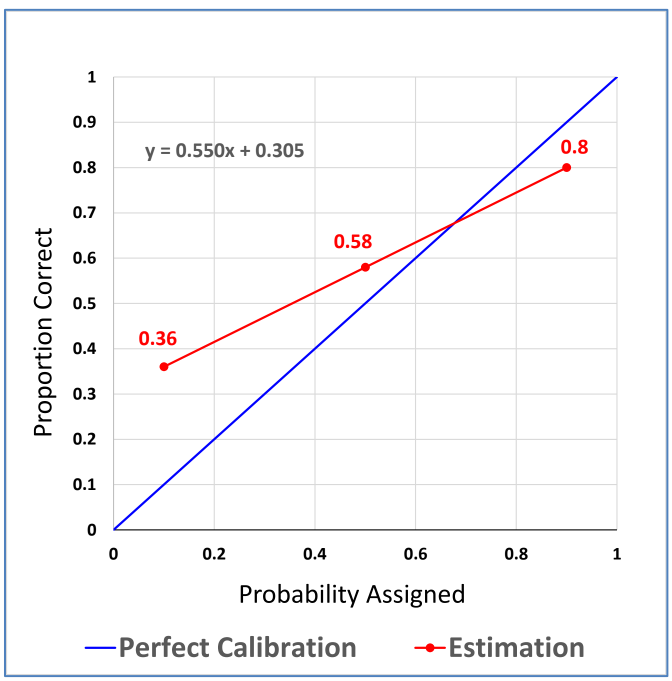


Fig. 3.5—Example of calibration plot with probabilistic assessments presented in inverse-CDF form.

Fig. 3.4 and Fig. 3.5 (CDF and inverse-CDF plots) display the same slope (same confidence bias). However, in a CDF representation, pessimism is indicated when the calibration curve is below the P50 (Fig. 3.4), and in an inverse-CDF representation pessimism is indicated when the calibration curve is above the P50 (Fig. 3.5). This difference occurs because the proportion correct in a CDF is the complement of the inverse-CDF. In other words, when the representation changes from CDF to inverse-CDF, the proportion correct at P10 on the CDF plot corresponds to 1 minus the same proportion correct at P90 on the inverse-CDF. Thus, a difference in the intercept between the representations is expected.

Reserves estimates are usually represented with inverse-CDFs. Alarfaj and McVay (2016) equations are applicable to CDFs representations. As mentioned above, the slope does not change between the CDF and inverse-CDF representations. Thus, the same equation for DB_{OC} is applicable for both representations. However, because the intercept changes between representations it was necessary to derive an equation to calculate the DB for inverse-CDFs **(Eq. 5).**

$$DB_{OC} = 1 - \frac{2a}{1-m} \qquad (5)$$

The calculation for DB_{UC} in the case of CDF representations (Eq. 4) is the same as the calculation for DB_{OC} in the case of inverse-CDF representations (Eq. 5).

Fig. 3.4 illustrates probabilistic assessments presented as CDF form. CB_{OC} and DB_{OC} were calculated using Eqs. 1 and 2 as:

$$CB_{OC} = 1 - m = 1 - 0.55 = 0.45$$

$$DB_{OC} = \frac{2a}{1 - m} - 1 = \frac{2 * 0.145}{0.45} - 1 = -0.36$$

Fig. 3.5 illustrates probabilistic assessments presented as inverse-CDF form. CB_{OC} and DB_{OC} were calculated using Eqs. 1 and 5 as shown below. The negative sign of DB_{OC} in both representations means that the estimations are pessimistic, which is consistent with the DB definition presented earlier in this document.

$$CB_{OC} = 1 - m = 1 - 0.55 = 0.45$$

$$DB_{OC} = 1 - \frac{2a}{1 - m} = 1 - \frac{2 * 0.305}{0.45} = -0.36$$

4. METHODOLOGY

4.1 Research Steps

1. Select the companies for the study. For Canada, 34 of 100 total companies that filed in 2018 under the Alberta Securities Commission (ASC) were selected randomly. For the U.S., 32 of 164 companies that filed in 2018 were selected based on the availability of information.
2. Create a database of publicly available reserves disclosures for Canadian and U.S. companies categorized by:
   a. Products: light-medium oil, heavy oil, gas, and unconventional resources (only for Canada).
   b. Years: from 2007 to 2017.
   c. Company.
   d. Company size: Subdivide by size based on 2017 production, where senior companies produce more than 100,000 BOE/D; intermediate companies produce from 10,000 to 100,000 BOE/D; and junior companies produce less than 10,000 BOE/D.
3. For Canadian companies, extract “technical revisions” from the reserves reconciliation. For U.S. companies, calculate Revisions Other Than Price (ROTP) by subtracting from “revisions of previous estimates” the price-related revisions. It is assumed that this difference is the desired “technical revisions.”

4. Create calibration plots, using the “technical revisions” information from Canada and ROTP information from the U.S. Measure biases and assess the reliability of reserves estimates based on the categories mentioned in Step 2.

For Canadian companies, the focus was on “technical revisions.” This information was extracted from the reserves reconciliation section in the Annual Information Form (AIF). The forms are stored in the System for Electronic Document Analysis and Retrieval webpage (SEDAR 2018). For U.S. companies, which disclose reserves in filings with the SEC, the focus was on ROTP, which were derived from “revisions of previous estimates” that are presented in the summary of proved reserves in Form-10K and/or Form 40-F. The forms are stored in the SEC webpage under the Electronic Data Gathering Analysis and Retrieval (EDGAR 2018). Thus, the primary sources of information for this research project are the two webpages, SEDAR and EDGAR.

5. MEASUREMENT OF THE RELIABILITY OF RESERVES ESTIMATES

In Chapter 3, it was explained how to assess the reliability of probabilistic estimates through the use of calibration plots. This chapter applies these concepts to assess the reliability of reserves estimates made by U.S. and Canadian companies.

5.1 Database Specifications

The database created consists of three tables (datasets)—one for Canadian companies by combined-product (general), another for Canadian companies by individual-product (detailed), and another for U.S. companies by combined-product.

5.1.1 Canadian Dataset

The Canadian AIF presents the requirements for disclosure of an annual reconciliation of changes in estimates of gross proved reserves, gross probable reserves and gross proved-plus-probable reserves. This is required by country, product type, and reserves-change category. An associated explanation is also required for any disclosure that occurs in each reserves-change category. The general dataset presents reserves estimates and technical revisions based on reports of combined-products by company and by year. These estimates and revisions are expressed as total fluids in MMboe, which combines oil and gas using the energy-content relation of 6 Mcf gas for 1 bbl oil. Because Canadian companies must disclose reserves and technical revisions by product type, it was possible to create a detailed dataset, where reserves estimates and technical revisions were analyzed based on the report of individual-products by company and by year and expressed as total fluids in MMboe.

The information for both general and detailed datasets in Canadian filings were based on 34 companies—9 senior-size, 14 intermediate-size, and 11 junior-size. For the general dataset, 270 company-year records were analyzed (**Table 5.1**). For the detailed dataset, 963 company-year-product records were analyzed (**Table 5.2**). These 963 records are presented in yearly tables of a combination of company-product records and in company tables of a combination of year-product records. A list of all the input information for both datasets is presented in **APPENDIX B.**

Table 5.1—Canadian general dataset; company name, company size, years of analysis and number of records.

Company Number	Company Name	Company Size	From Year	To Year	Number of Records
1	Advantage Oil	Intermediate	2009	2017	9
2	ARC Resources Ltd.	Senior	2008	2017	10
3	Bellatrix Exploration Ltd.	Intermediate	2009	2017	9
4	Bonavista Energy Corporation	Intermediate	2010	2017	8
5	Canadian Natural	Senior	2010	2017	8
6	Canacol Energy Ltd	Intermediate	2009	2017	9
7	Cardinal Energy Inc	Junior	2013	2017	5
8	Cenovus Energy Inc	Senior	2010	2017	8
9	Connacher Oil and Gas Limited	Junior	2008	2015	8
10	Crescent Point Energy Corp	Senior	2009	2017	9
11	Delphi Energy Corp	Junior	2008	2017	10
12	Granite Oil Corp	Junior	2008	2017	10
13	Husky Energy Inc	Senior	2010	2017	8
14	Iron bridge -former RMP Energy Inc	Junior	2007	2017	11
15	Jura Energy Corp.	Junior	2013	2017	5
16	Kelt Exploration Ltd.	Intermediate	2014	2017	4
17	Niko Resources Ltd	Junior	2007	2017	11
18	NuVista Energy Ltd	Intermediate	2008	2017	10
19	Paramount Resources Ltd	Intermediate	2008	2017	10
20	Parex Resources Inc.	Intermediate	2011	2017	7
21	Pengrowth Energy Corporation	Intermediate	2010	2017	8
22	PetroShale Inc	Junior	2013	2017	5
23	Peyto Exploration & Development Corp	Intermediate	2010	2017	8
24	Raging River Exploration Inc.	Intermediate	2013	2017	5
25	Repsol Oil & Gas Canada Inc. ("ROGCI")	Senior	2012	2016	5
26	Seven Generations Energy Ltd.	Senior	2014	2017	4
27	Strategic Oil & Gas Ltd	Junior	2012	2017	6
28	Suncor Energy Inc.	Senior	2010	2017	8
29	Surge Energy Inc	Junior	2010	2017	8
30	Terra Energy Corp	Junior	2009	2017	9
31	Tourmaline Oil Corp	Senior	2010	2017	8
32	TransGlobe Energy Corporation	Intermediate	2007	2017	11
33	Vermilion Energy Inc	Intermediate	2010	2017	8
34	Whitecap Resources Inc.	Intermediate	2010	2017	8
					270

Table 5.2—Canadian detailed dataset; resource type, product type, number of companies and number of records.

Resource Type	Product Type	Number of Companies	Number of Records
Conventional Oil, MMbbls	Light & Medium Oil, MMbbls	33	249
	NGL, MMbbls	33	197
Conventional Gas, Bcf	Natural Gas, Bcf	33	241
Total Conventional			**687**
Unconventional Oil, MMbbls	Heavy Oil, MMbbls	24	138
	Tight Oil - Shale Oil, MMbbls	8	20
	Bitumen, MMbbls	6	43
	Synthetic Oil, MMbbls	1	8
Unconventional Gas, Bcf	Shale Gas, Bcf	12	39
	Coalbed Methane, Bcf	7	28
Total Unconventional			**276**
Total Records			**963**

5.1.2 U.S. Dataset

For the U.S. dataset, the information was based on 32 companies—23 senior-size, 6 intermediate-size, and 3 junior-size. In total, 332 records were analyzed (**Table 5.3**). A list of all the input information for these datasets is presented in APPENDIX B**.**

In contrast to Canadian companies, the explanations that U.S. companies provide for "revisions of previous estimates" are only for combined-product. The values of the reserves revisions by product were individually loaded into the dataset, but specifically the explanations of revisions due to price are provided only by combined-product. Therefore, it was not possible to create a detailed dataset by individual-product for U.S, companies.

Table 5.3—U.S. dataset; company name, company size, years of analysis and number of records.

Company Number	Company Name	Company Size	From Year	To Year	Number of Records
1	ANADARKO PETROLEUM CORP	Senior	2007	2017	11
2	ANTERO RESOURCES CORP	Senior	2011	2017	7
3	APACHE CORP	Senior	2007	2017	11
4	APPROACH RESOURCES INC	Junior	2007	2017	11
5	BONANZA CREEK ENERGY, INC.	Intermediate	2011	2017	7
6	CABOT OIL & GAS CORP	Senior	2007	2017	11
7	CHESAPEAKE ENERGY CORP	Senior	2007	2017	11
8	CIMAREX ENERGY CO	Senior	2007	2017	11
9	CNX RESOURCES CORP	Senior	2007	2017	11
10	CONCHO RESOURCES INC	Senior	2007	2017	11
11	CONTANGO OIL & GAS CO	Junior	2011	2017	7
12	CONTINENTAL RESOURCES, INC	Senior	2007	2017	11
13	DENBURY RESOURCES INC	Intermediate	2007	2017	11
14	DEVON ENERGY CORP/DE	Senior	2007	2017	11
15	DORCHESTER MINERALS, L.P.	Junior	2007	2017	11
16	ENCANA CORP	Senior	2007	2017	11
17	ENERGEN CORP	Intermediate	2007	2017	11
18	EOG RESOURCES INC	Senior	2007	2017	11
19	EP ENERGY CORP	Intermediate	2011	2017	7
20	EQT CORP	Senior	2007	2017	11
21	LINN ENERGY, INC.	Senior	2007	2017	11
22	NEWFIELD EXPLORATION CO /DE/	Senior	2007	2017	11
23	NOBLE ENERGY INC	Senior	2008	2017	10
24	OASIS PETROLEUM INC.	Intermediate	2008	2017	10
25	PDC ENERGY, INC.	Intermediate	2007	2017	11
26	PIONEER NATURAL RESOURCES CO	Senior	2007	2017	11
27	QEP RESOURCES, INC.	Senior	2007	2017	11
28	RANGE RESOURCES CORP	Senior	2007	2017	11
29	SM ENERGY CO	Senior	2007	2017	11
30	SOUTHWESTERN ENERGY CO	Senior	2007	2017	11
31	WHITING PETROLEUM CORP	Senior	2007	2017	11
32	WPX ENERGY, INC.	Senior	2009	2017	9
	Total				**332**

5.2 Reliability of Reserves Estimates Made by Canadian Filers

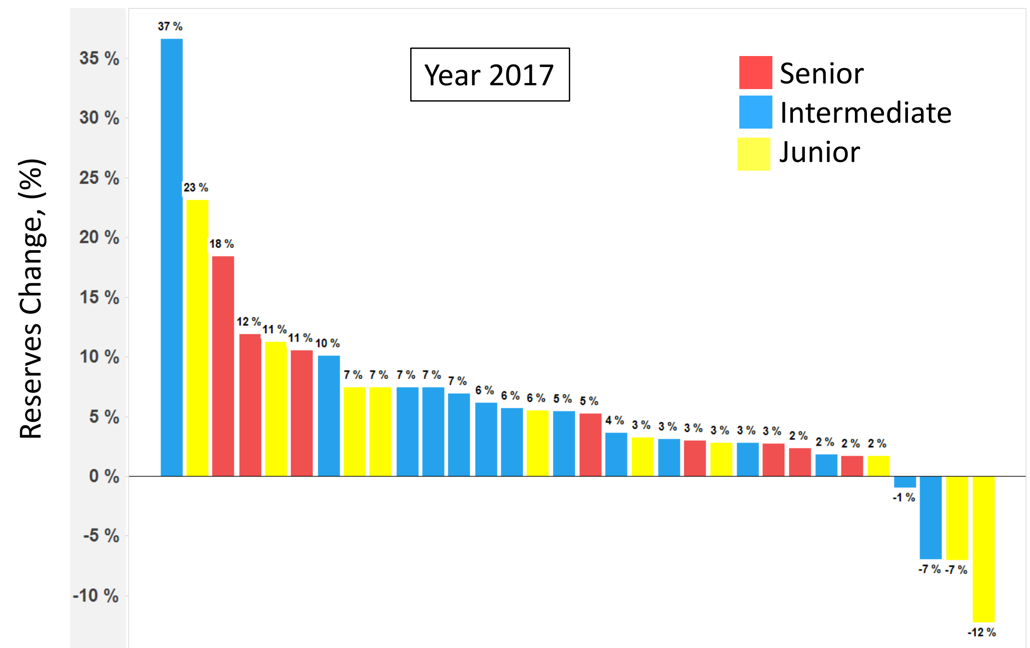
In this study I chose to compare reserves changes and technical revisions from different size oil and gas companies. The ratio of technical revisions to reserves at beginning of the year help to compare companies of different sizes. **Eq. 6** was used to calculate the reserves change (%) for each company.

$$Reserves\ Change\ (\%) = \frac{\text{Technical revisions over the year (MMboe)}}{\text{Proved reserves at beginning of the year (MMboe)}} * 100 \ldots\ldots (6)$$

Fig. 5.1 presents bar graphs of 1P reserves changes by company for 2017. The colors of the bars represent the company size (senior = red, intermediate = blue, and junior = yellow). The majority of the 32 companies analyzed in 2017 had modest changes (less than 10 percent of its initial reserves). The two extreme reserves changes were a positive one of 37% and a negative one of 12%. In 2017, 28 (88%) of the 32 companies had positive 1P reserves revisions. This means that for the year 2017, the proportion of positive technical revisions is very close to what is expected for P90 estimates.

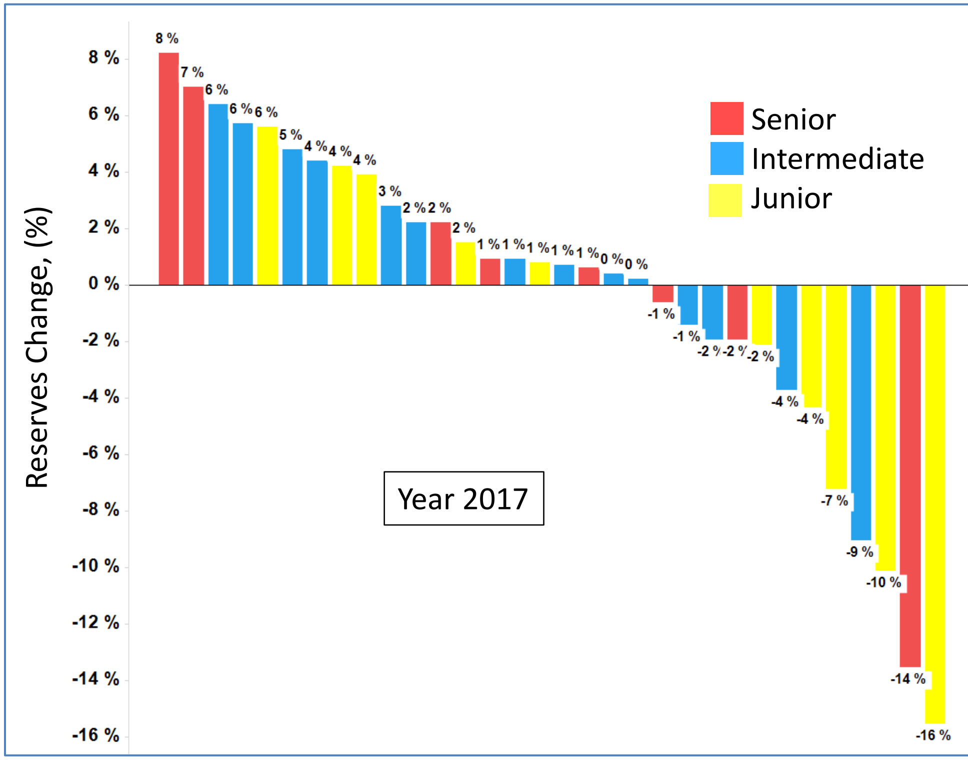
In the case of the 2P reserves analysis in 2017, there is a smaller variation in the magnitude of the reserves-change (**Fig. 5.2**). The two extreme reserves changes for 2P were positive of 8% and a negative of 16%. In 2017, 20 (63%) of 32 companies had positive 2P reserves revisions. This means that the proportion of positive technical revisions for 2P is a little more than what is expected for P50 estimates.

The results presented here are for the most recent year 2017. **APPENDIX C** presents corresponding plots for 1P and 2P for years 2008 to 2016. The compilation of results for the year 2007 to 2017 is presented in the following section.



Company Name	Proved Initial Reserves	Technical Revisions	Reserves (%) Change
Paramount Resources Ltd	59.65	21.84	37 %
Jura Energy Corp.	4.78	1.10	23 %
ARC Resources Ltd.	425.93	78.38	18 %
Seven Generations Energy Ltd.	825.11	98.36	12 %
Strategic Oil & Gas Ltd	9.33	1.04	11 %
Canadian Natural	5968.83	626.50	11 %
Advantage Oil	255.06	25.82	10 %
Cardinal Energy Inc	49.45	3.64	7 %
Granite Oil Corp	12.48	0.93	7 %
Kelt Exploration Ltd.	108.19	8.01	7 %
Parex Resources Inc.	63.77	4.75	7 %
NuVista Energy Ltd	133.83	9.23	7 %
Canacol Energy Ltd	54.26	3.32	6 %
Bellatrix Exploration Ltd.	158.40	9.09	6 %
Surge Energy Inc	52.50	2.90	6 %
TransGlobe Energy Corporation	29.92	1.62	5 %
Crescent Point Energy Corp	600.20	31.20	5 %
Whitecap Resources Inc.	251.47	8.98	4 %
Iron bridge -former RMP Energy Inc	16.36	0.52	3 %
Peyto Exploration & Development Corp	404.38	12.62	3 %
Husky Energy Inc	1224.47	36.28	3 %
Terra Energy Corp	74.26	2.06	3 %
Vermilion Energy Inc	175.81	4.95	3 %
Tourmaline Oil Corp	858.93	23.30	3 %
Suncor Energy Inc.	1812.50	41.50	2 %
Pengrowth Energy Corporation	285.49	5.26	2 %
Cenovus Energy Inc	2666.67	44.33	2 %
PetroShale Inc	25.13	0.43	2 %
Bonavista Energy Corporation	273.18	-2.53	-1 %
Raging River Exploration Inc.	71.58	-4.92	-7 %
Delphi Energy Corp	19.21	-1.34	-7 %
Niko Resources Ltd	38.73	-4.71	-12 %

Fig. 5.1—Canadian companies, proved reserves changes (%) - year 2017.



Company Name	2P Initial Reserves	Technical Revisions	2P Reserves (%) Change
ARC Resources Ltd.	736.73	60.10	8.2 %
Tourmaline Oil Corp	1746.82	121.99	7.0 %
Canacol Energy Ltd	80.96	5.18	6.4 %
NuVista Energy Ltd	257.36	14.57	5.7 %
Iron bridge -former RMP Energy Inc	27.70	1.55	5.6 %
Bellatrix Exploration Ltd.	228.54	10.90	4.8 %
Kelt Exploration Ltd.	194.06	8.59	4.4 %
Jura Energy Corp.	10.01	0.42	4.2 %
Cardinal Energy Inc	67.48	2.66	3.9 %
Peyto Exploration & Development ...	654.75	18.38	2.8 %
Advantage Oil	366.11	7.91	2.2 %
Seven Generations Energy Ltd.	1534.65	33.64	2.2 %
PetroShale Inc	31.45	0.48	1.5 %
Cenovus Energy Inc	3797.00	33.83	0.9 %
Whitecap Resources Inc.	355.36	3.18	0.9 %
Terra Energy Corp	94.91	0.72	0.8 %
Pengrowth Energy Corporation	608.13	3.99	0.7 %
Canadian Natural	9179.67	55.83	0.6 %
Vermilion Energy Inc	290.12	1.17	0.4 %
Parex Resources Inc.	111.90	0.26	0.2 %
Crescent Point Energy Corp	958.49	-5.32	-0.6 %
Paramount Resources Ltd	115.19	-1.60	-1.4 %
Bonavista Energy Corporation	414.21	-8.03	-1.9 %
Suncor Energy Inc.	3006.83	-56.67	-1.9 %
Granite Oil Corp	18.65	-0.40	-2.1 %
TransGlobe Energy Corporation	49.95	-1.87	-3.7 %
Surge Energy Inc	84.44	-3.64	-4.3 %
Niko Resources Ltd	60.39	-4.33	-7.2 %
Raging River Exploration Inc.	93.99	-8.48	-9.0 %
Delphi Energy Corp	36.45	-3.69	-10.1 %
Husky Energy Inc	2815.00	-380.30	-13.5 %
Strategic Oil & Gas Ltd	19.55	-3.04	-15.5 %

Fig. 5.2—Canadian companies, proved-plus-probable reserves changes (%) - year 2017.

5.2.1 Results of Reliability Analysis of Canadian General Dataset

Table 5.4 presents the number of companies with positive technical revisions per year and the proportion of positive technical revisions to the total number of companies for 1P and 2P reserves estimates. Based on the general dataset, 0.80 (80%) of the 1P reserves revisions were positive and 0.58 (58%) of the 2P reserves revisions were positive for all Canadian companies and years combined.

Table 5.4—Canadian general dataset, 1P and 2P number and fraction of companies with positive technical revisions per year.

Year	Companies Analyzed	Companies with Positive Revisions of 1P Reserves	Companies with Positive Revisions of 2P Reserves	Fraction of Positive 1P Reserves Revisions	Fraction of Positive 2P Reserves Revisions
2007	3	1	1	0.33	0.33
2008	9	6	4	0.67	0.44
2009	14	12	7	0.86	0.50
2010	25	19	15	0.76	0.60
2011	26	20	15	0.77	0.58
2012	28	23	16	0.82	0.57
2013	32	26	18	0.81	0.56
2014	34	30	21	0.88	0.62
2015	34	24	18	0.71	0.53
2016	33	26	21	0.79	0.64
2017	32	28	20	0.88	0.63
Total	**270**	**215**	**156**	**0.80**	**0.58**

Fig. 5.3 shows a calibration plot constructed with the information presented in Table 5.4. This calibration plot shows that results for the P90 reserves are what we would expect for P80 reserves, and results for P50 reserves are what we would expect for P58 reserves, indicating that what the estimators thought were 40% probability ranges (difference between the true distribution P90 and P50) actually represented 22% probability ranges

(difference between the estimate distribution P80 and P58). Therefore, it can be concluded that Canadian estimators as a whole are overconfident, as the true probability range is less than the estimated probability range. The separation between the values for year 2007 (light-blue points) and the other years is most likely due to only three companies being analyzed in 2007.

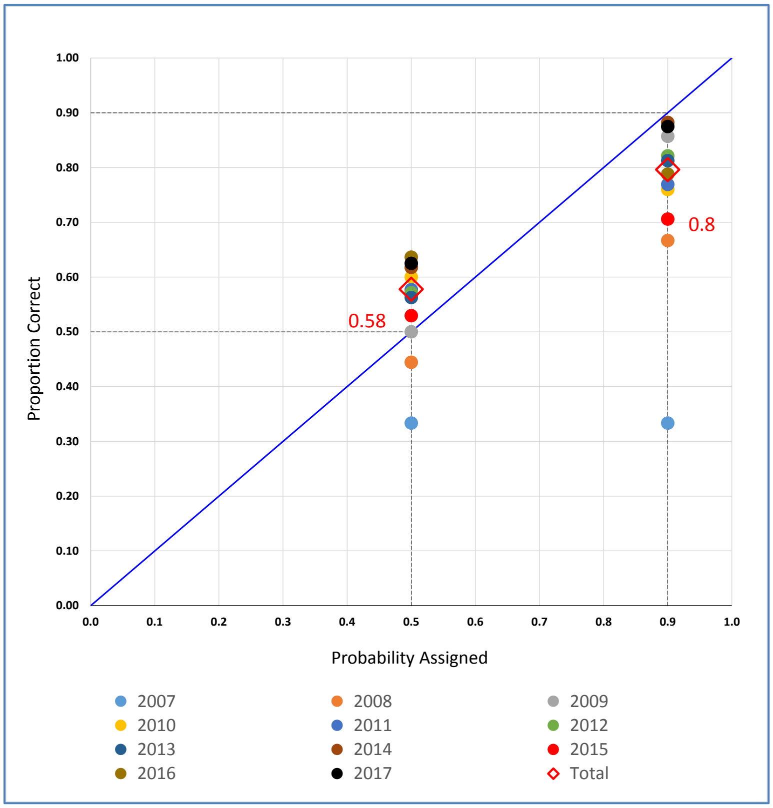


Fig. 5.3—Canadian general dataset, 1P and 2P reserves technical revisions calibration plot by year.

Table 5.5 presents the number of years with positive technical revisions per company and the proportion of positive technical revisions to the total number of companies for 1P and 2P reserves estimates. As Table 5.4 and Table 5.5 are analyzing the same dataset, the overall results and conclusions are the same as already presented.

Table 5.5—Canadian general dataset, 1P and 2P number and fraction of years with positive technical revisions per company.

Company Name	Years Analyzed	Years with Positive Revisions of 1P Reserves	Years with Positive Revisions of 2P Reserves	Fraction of Positive 1P Reserves Revisions	Fraction of Positive 2P Reserves Revisions
Advantage Oil	9	9	7	1.00	0.78
ARC Resources Ltd.	10	10	10	1.00	1.00
Bellatrix Exploration Ltd.	9	7	3	0.78	0.33
Bonavista Energy Corporation	8	5	4	0.63	0.50
Canacol Energy Ltd	9	7	5	0.78	0.56
Canadian Natural	8	8	8	1.00	1.00
Cardinal Energy Inc	5	4	3	0.80	0.60
Cenovus Energy Inc	8	8	4	1.00	0.50
Connacher Oil and Gas Limited	8	6	2	0.75	0.25
Crescent Point Energy Corp	9	9	7	1.00	0.78
Delphi Energy Corp	10	5	5	0.50	0.50
Granite Oil Corp	10	6	5	0.60	0.50
Husky Energy Inc	8	6	4	0.75	0.50
Iron bridge -former RMP Energy Inc	11	6	5	0.55	0.45
Jura Energy Corp.	5	3	2	0.60	0.40
Kelt Exploration Ltd.	4	4	4	1.00	1.00
Niko Resources Ltd	11	6	3	0.55	0.27
NuVista Energy Ltd	10	9	5	0.90	0.50
Paramount Resources Ltd	10	9	4	0.90	0.40
Parex Resources Inc.	7	7	6	1.00	0.86
Pengrowth Energy Corporation	8	7	7	0.88	0.88
PetroShale Inc	5	5	5	1.00	1.00
Peyto Exploration & Development Corp	8	3	3	0.38	0.38
Raging River Exploration Inc.	5	2	1	0.40	0.20
Repsol Oil & Gas Canada Inc. ("ROGCI")	5	3	1	0.60	0.20
Seven Generations Energy Ltd.	4	4	4	1.00	1.00
Strategic Oil & Gas Ltd	6	6	2	1.00	0.33
Suncor Energy Inc.	8	6	2	0.75	0.25
Surge Energy Inc	8	5	0	0.63	0.00
Terra Energy Corp	9	7	5	0.78	0.56
Tourmaline Oil Corp	8	8	8	1.00	1.00
TransGlobe Energy Corporation	11	9	8	0.82	0.73
Vermilion Energy Inc	8	8	7	1.00	0.88
Whitecap Resources Inc.	8	8	7	1.00	0.88
Total	270	215	156	**0.80**	**0.58**

A calibration plot that represents the fraction of years with positive technical revisions per company is presented in **Fig. 5.4**. The number located next to each point represents the number of companies that had a given fraction of positive revisions, e.g.**,** 13 companies had positive 1P reserves revisions in all years, or a fractional positive revision of 1.0.

In Fig. 5.3 each point represents the proportion correct each year for all companies that file in a respective year, around 32 companies per data point. In Fig. 5.4 each point represents the proportion correct of a company for a period of time, around 11 years per data point. Fig. 5.4 shows more variability by company than Fig. 5.3 shows by year, primarily because there are fewer years per company-data-point than companies per year-data-point. Another possible reason for the differences in variability in these two representations is that—because company estimates are made by humans who are subject to biases, and biases differ between humans—it is more likely there will be systematic differences in biases between companies than between years.

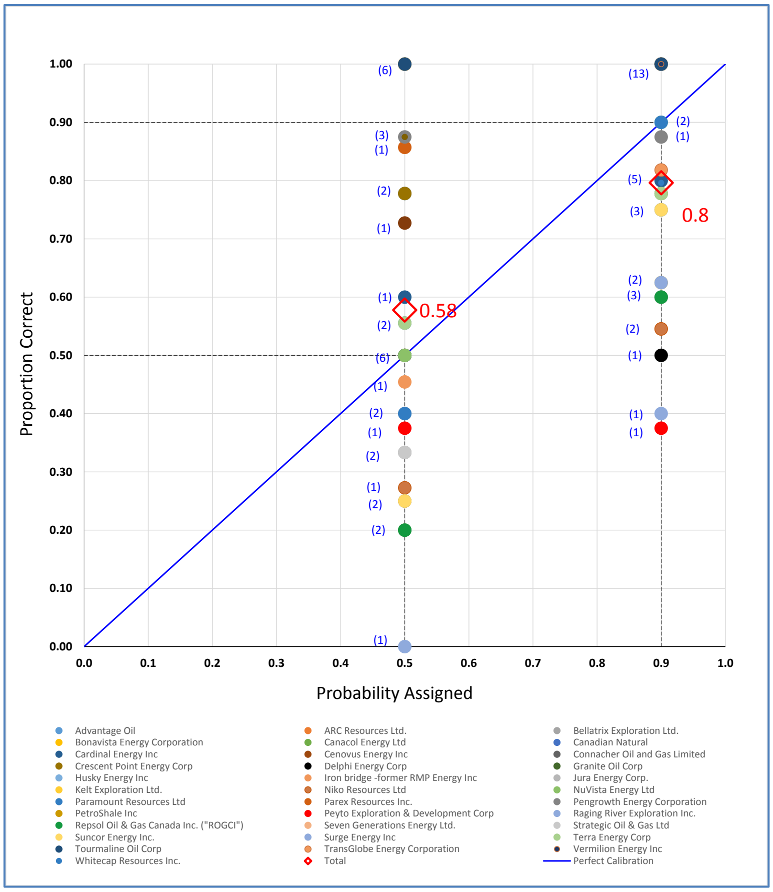


Fig. 5.4—Canadian general dataset, 1P and 2P reserves technical revisions calibration plot by company.

5.2.2 Results of Reliability Analysis of Detailed Canadian Dataset

Table 5.6 presents the number of company-product records with positive technical revisions (TR) each year and the fraction of positive technical revisions for 1P and 2P reserves estimates. **Fig. 5.5** shows a calibration plot constructed with the information presented in Table 5.6. For all years combined, 72% of company-product records have positive proved technical revisions whereas the expected result is 90%. With respect to the 2P reserves, 54% of company-product records have positive technical revisions; this value is very close to the expected of 50%. These results mean that 1P reserves are overestimated and 2P reserves are underestimated. It may seem counter-intuitive that, for both the general and detailed datasets, the overall fraction of positive revisions is too low for 1P reserves estimates but too high for 2P reserves estimates. It must be remembered that 1P and 2P reserves are not independent, but are two points on a single distribution for estimated reserves. The counter-intuition is explained by analyzing the calibration plot.

Table 5.6—Canadian detailed dataset, 1P and 2P number and fraction of company-product records with positive technical revisions per year.

Year	Number of Records	Number of Positive TR		Fraction Positive	
		1P	2P	1P	2P
2007	6	2	2	0.33	0.33
2008	24	17	11	0.71	0.46
2009	45	36	28	0.80	0.62
2010	89	65	47	0.73	0.53
2011	89	56	44	0.63	0.49
2012	103	74	61	0.72	0.59
2013	106	73	52	0.69	0.49
2014	116	88	55	0.76	0.47
2015	129	83	64	0.64	0.50
2016	131	97	76	0.74	0.58
2017	125	98	78	0.78	0.62
Total	**963**	**689**	**518**	**0.72**	**0.54**

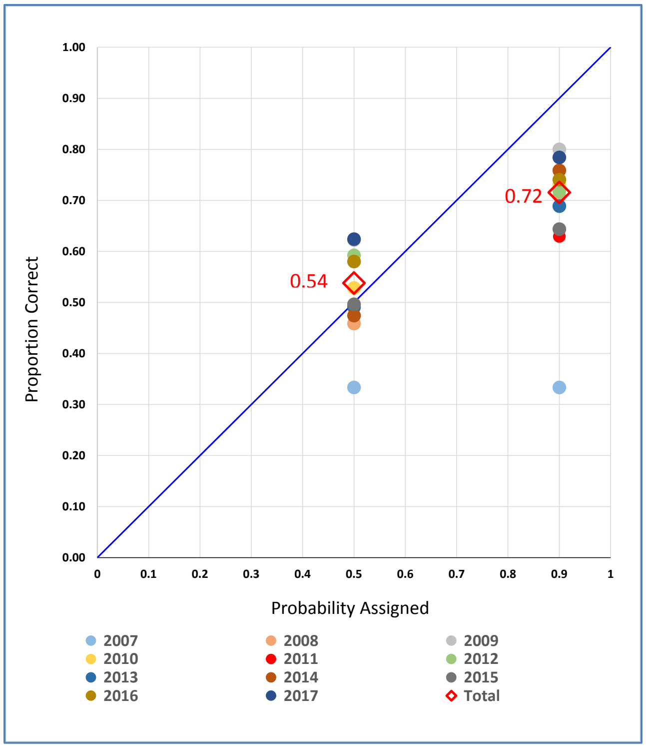


Fig. 5.5—Canadian detailed dataset, 1P and 2P reserves technical revisions calibration plot by year.

Fig. 5.6 shows a calibration plot with a line connecting points corresponding to the overall analysis at the assigned probabilities P50 and P90. Because conclusions are drawn based on this line, it is intrinsically assumed that the P10 will fall on this same line. The assigned P90 corresponds to a proportion correct of 0.72, while the assigned P50 corresponds to a proportion correct of 0.54. The extrapolated assigned P10 is closer to a proportion correct of 0.35, indicating that what the estimators thought were 80% (P90-P10) probability ranges on average were actually 37% probability ranges. These results show that the distributions for these Canadian reserves estimates are narrower than they should be, indicating overconfidence (underestimation of uncertainty) in reserves estimates. This is consistent with the slope of the line being less than one. The line is slightly shifted up from the P50-0.50 point, which is an indication of pessimism for reserves estimates that are expressed in terms of inverse-CDFs. Using Eqs. 1 and 5, the confidence and directional biases are:

$$CB_{OC} = 1 - m \ = 1 - 0.44 = 0.56$$

$$DB_{OC} = 1 - \frac{2a}{1-m} = 1 - \frac{2 * 0.32}{0.56} = -0.14$$

A CB_{OC} of 0.56 indicates moderate overconfidence (underestimation of uncertainty), while DB_{OC} of -0.14 indicates slight pessimism.

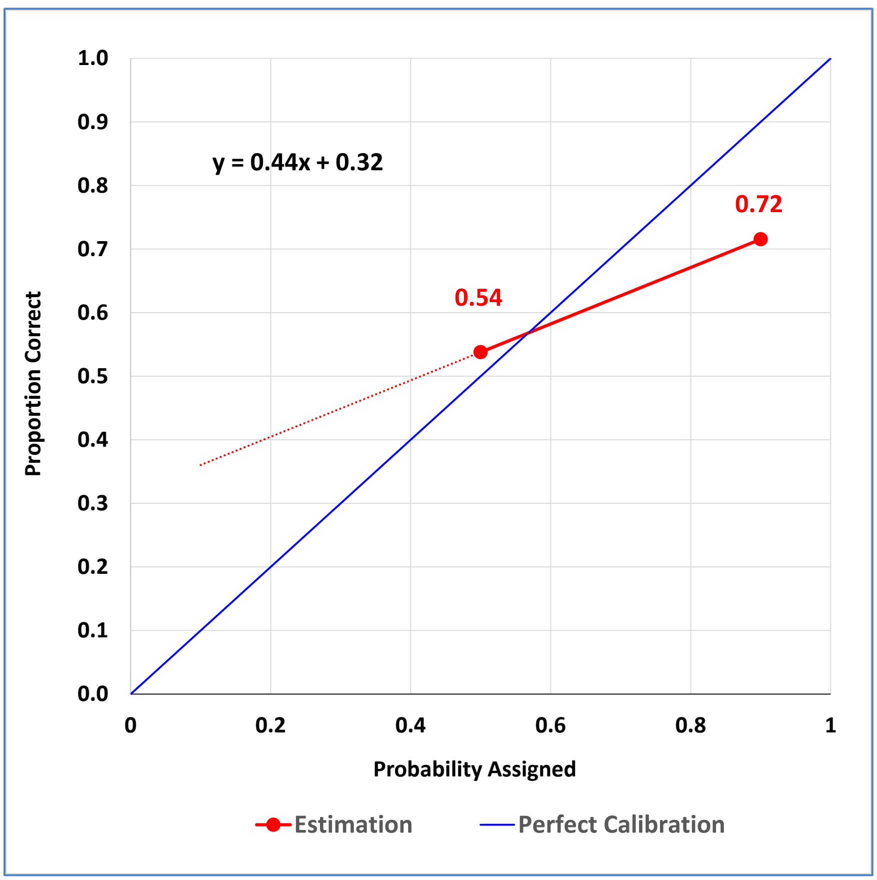


Fig. 5.6—Canadian detailed dataset, 1P, 2P and best fit of reserves technical revisions calibration plot with overall results.

To further illustrate, **Fig. 5.7** presents plots of PDFs (left) and inverse-CDFs (right), each with two distributions—the true distribution (perfectly-calibrated) and the estimated distribution displaying overconfidence and pessimism. The inverse-CDFs show that for the 1P (P90), the true distribution displays lower reserves than the estimated distribution, while for the 2P (P50), the true distribution displays higher reserves than the estimated distribution. For these results, the P90 reserves on the estimated distribution corresponds to a 0.72 on the true distribution, and the P50 reserves on the estimated distribution corresponds to a 0.54 on the true distribution.

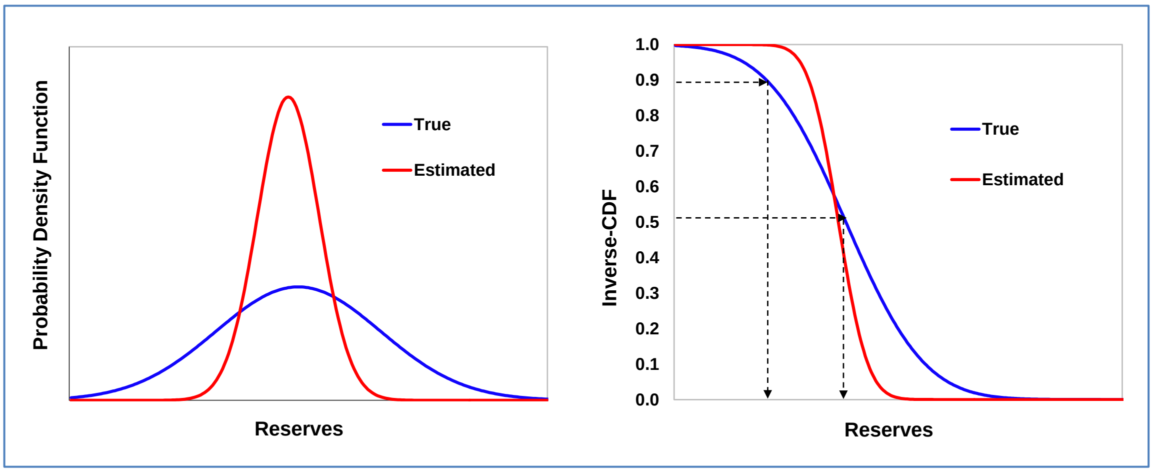


Fig. 5.7—Comparison between true and estimated in PDFs (left) and inverse-CDFs (right) representations.

Table 5.7 presents the positive technical revisions of year-product records per company, and their respective fractions for 1P and 2P reserves. As Table 5.6 and Table 5.7 are analyzing the same dataset, the overall results and conclusions are the same as already presented.

Table 5.7—Canadian detailed dataset, 1P and 2P number and fraction of year-product records with positive technical revisions per company.

Company Name	Number of Records	Number of Positive TR		Fraction Positive	
		1P	2P	1P	2P
Advantage Oil	34	22	20	0.65	0.59
ARC Resources Ltd.	46	41	37	0.89	0.80
Bellatrix Exploration Ltd.	39	27	20	0.69	0.51
Bonavista Energy Corporation	32	15	8	0.47	0.25
Canadian Natural	48	43	28	0.90	0.58
Canacol Energy Ltd	23	15	13	0.65	0.57
Cardinal Energy Inc	18	15	11	0.83	0.61
Cenovus Energy Inc	33	28	20	0.85	0.61
Connacher Oil and Gas Limited	21	16	11	0.76	0.52
Crescent Point Energy Corp	42	35	27	0.83	0.64
Delphi Energy Corp	33	19	16	0.58	0.48
Granite Oil Corp	26	18	15	0.69	0.58
Husky Energy Inc	33	24	19	0.73	0.58
Iron bridge -former RMP Energy Inc	36	18	14	0.50	0.39
Jura Energy Corp.	8	5	4	0.63	0.50
Kelt Exploration Ltd.	12	10	9	0.83	0.75
Niko Resources Ltd	28	15	9	0.54	0.32
NuVista Energy Ltd	40	29	17	0.73	0.43
Paramount Resources Ltd	34	25	17	0.74	0.50
Parex Resources Inc.	12	11	8	0.92	0.67
Pengrowth Energy Corporation	47	39	32	0.83	0.68
PetroShale Inc	10	10	9	1.00	0.90
Peyto Exploration & Development Corp	23	12	12	0.52	0.52
Raging River Exploration Inc.	19	12	7	0.63	0.37
Repsol Oil & Gas Canada Inc. ("ROGCI")	30	15	12	0.50	0.40
Seven Generations Energy Ltd.	15	13	10	0.87	0.67
Strategic Oil & Gas Ltd	18	16	9	0.89	0.50
Suncor Energy Inc.	27	18	12	0.67	0.44
Surge Energy Inc	34	18	8	0.53	0.24
Terra Energy Corp	21	17	11	0.81	0.52
Tourmaline Oil Corp	27	15	16	0.56	0.59
TransGlobe Energy Corporation	23	16	10	0.70	0.43
Vermilion Energy Inc	42	32	29	0.76	0.69
Whitecap Resources Inc.	28	24	17	0.86	0.61
Total	**963**	**689**	**518**	**0.72**	**0.54**

Fig. 5.5 presented a calibration plot by year, where each point represents the fraction of companies with positive technical revisions with respect to all companies that filed in the specific year. **Fig. 5.8** presents a calibration plot by company, where each point represents the fraction of years with positive technical revisions with respect to all years for this

specific company. One reason for the lower variability in the data presented in the calibration plot constructed by year (Fig. 5.5) versus the calibration plot by company (Fig. 5.8) is that there are fewer years (11) than companies (34). Another reason could be that it is more likely there will be systematic differences in biases between companies than between years, as mentioned earlier.

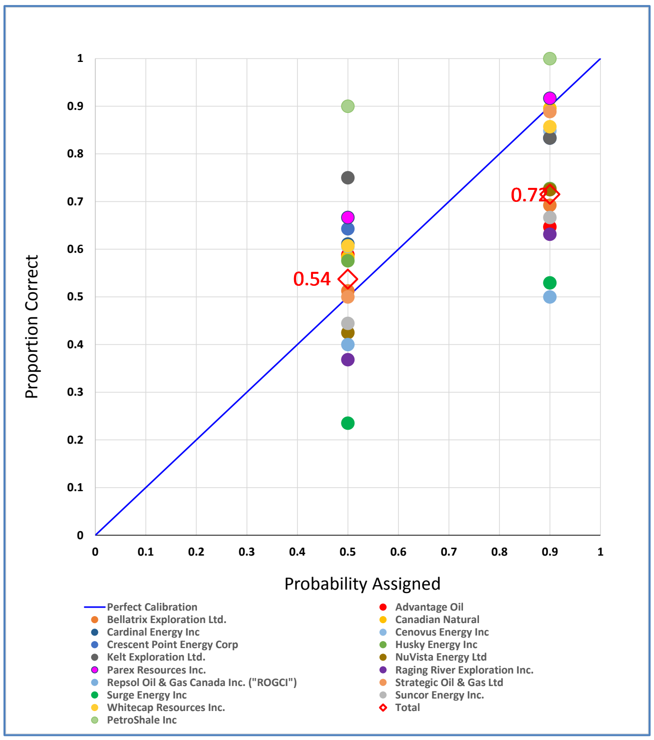


Fig. 5.8—Canadian detailed dataset, 1P and 2P reserves technical revisions calibration plot by company.

<u>Reliability Analysis by Year</u>

Using Eqs. 1 and 5, confidence and directional biases were calculated for each year (**Table 5.8**) from the calibration lines for each year (**Fig. 5.9**). All years are characterized by overconfidence bias; i.e., estimated reserves distributions tend to be too narrow. Year 2009 is the most pessimistic, year 2015 has an almost neutral directional bias, and year 2014 has wider ranges. A positive value of DB is an indication of optimism, while a negative DB value is an indication of pessimism. There are more years with pessimism (calibration line above the P50-0.50 point). An almost neutral bias appears in some years, and only two years indicate optimism bias.

Table 5.8—Canadian detailed dataset, bias calculation per year.

Year	Fraction Positive		Slope	Intercept	CB	Interpretation	DB	Interpretation
	1P	2P						
2007	0.33	0.33	0.00	0.33	1.00	Overconfidence	0.33	Optimistic
2008	0.71	0.46	0.63	0.15	0.38	Overconfidence	0.22	Optimistic
2009	0.80	0.62	0.44	0.40	0.56	Overconfidence	-0.44	Pessimistic
2010	0.73	0.53	0.51	0.28	0.49	Overconfidence	-0.11	Slightly Pessimistic
2011	0.63	0.49	0.34	0.33	0.66	Overconfidence	0.02	Almost Neutral
2012	0.72	0.59	0.32	0.43	0.68	Overconfidence	-0.27	Pessimistic
2013	0.69	0.49	0.50	0.24	0.50	Overconfidence	0.04	Almost Neutral
2014	0.76	0.47	0.71	0.12	0.29	Overconfidence	0.18	Optimistic
2015	0.64	0.50	0.37	0.31	0.63	Overconfidence	0.01	Almost Neutral
2016	0.74	0.58	0.40	0.38	0.60	Overconfidence	-0.27	Pessimistic
2017	0.78	0.62	0.40	0.42	0.60	Overconfidence	-0.41	Pessimistic
Total	**0.72**	**0.54**	**0.44**	**0.32**	**0.56**	**Overconfidence**	**-0.14**	**Slightly Pessimistic**

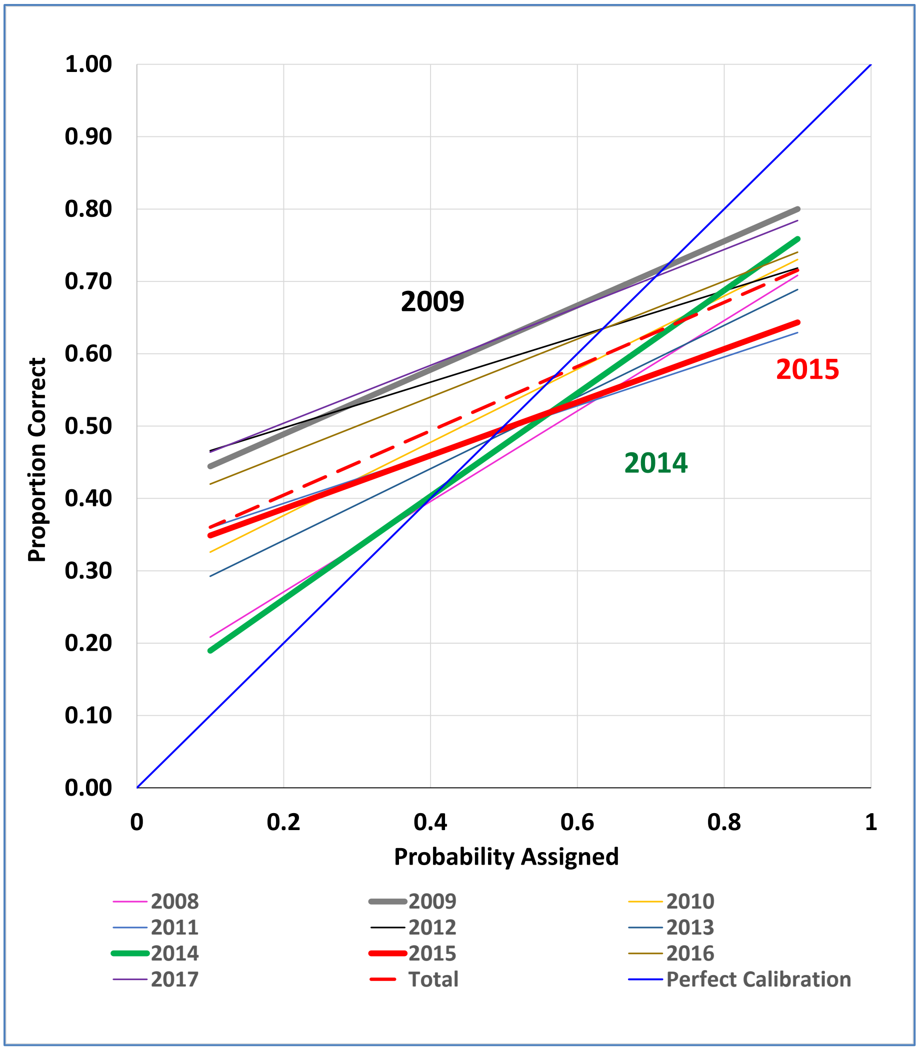


Fig. 5.9—Canadian detailed dataset, 1P and 2P reserves technical revisions calibration plot by year.

Fig. 5.10 presents confidence and directional biases variation versus time for the Canadian detailed dataset, each with a generated trend line ignoring the first data points because insufficient data was collected in 2007. This Fig. 5.10 shows that there is no significant change in these biases over time; i.e., the trend lines have small slopes. There is no tendency for the biases to converge to zero over time, as one would hope and expect.

Instead, the biases appear to be moving away from zero. Thus, it can be concluded that there is no significant improvement in the probabilistic reliability of reserves estimates over this time period; if anything, they are getting worse. It appears that reserves estimators are not tracking and calibrating revisions, measuring biases, and making appropriate corrections in subsequent years. If estimators were to do these things, it is expected the biases would converge to zero over time.

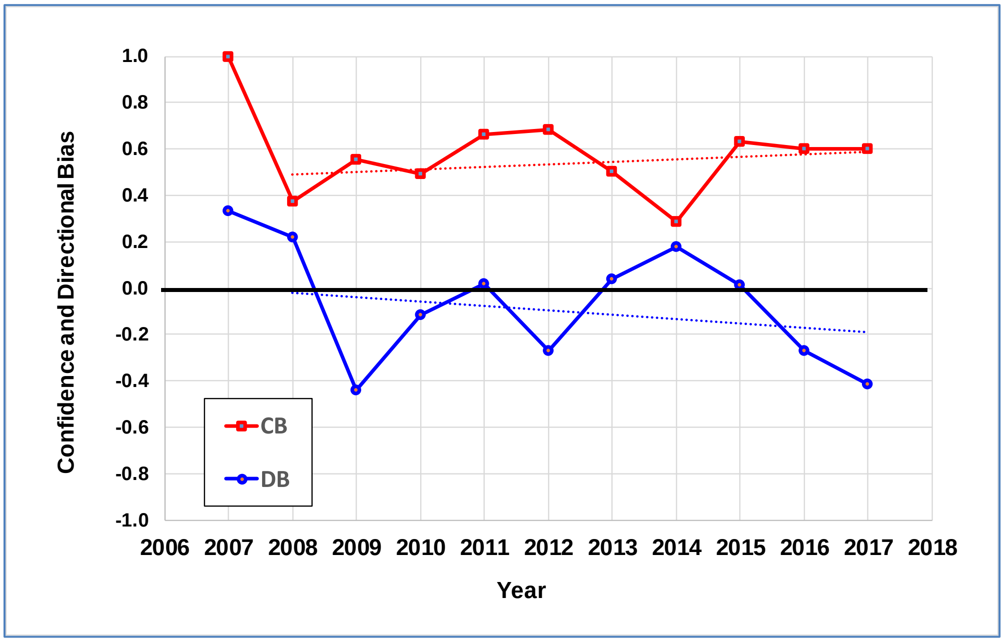


Fig. 5.10—Canadian detailed dataset, confidence bias (CB), and directional bias (DB) variation per year.

Reliability Analysis by Company

Using Eqs. 1 and 5, the confidence and directional biases were calculated for each company (**Table 5.9**). There are some companies with directional bias values out of range (lower than -1 and higher than 1). The reason why some companies get DB out of the range is because the straight-line approximation is not reasonable for these cases. As mentioned in Chapter 3, these bias calculations are based on a straight line constructed with two points. Overconfidence bias is present for all companies. This is confirmed by slopes less than one and confidence bias greater than zero.

Table 5.9—Canadian detailed dataset, bias calculation per company.

Company Number	Company Name	Number of Records	Fraction of Positive Revisions		Slope	Intercept	CB	Interpretation	DB	Interpretation
			1P	2P						
1	Advantage Oil	34	0.65	0.59	0.15	0.51	0.85	Overconfidence	-0.21	Pessimistic
2	ARC Resources Ltd.	46	0.89	0.80	0.22	0.70	0.78	Overconfidence	-0.78	Pessimistic
3	Bellatrix Exploration Ltd.	39	0.69	0.51	0.45	0.29	0.55	Overconfidence	-0.05	Pessimistic
4	Bonavista Energy Corporation	32	0.47	0.25	0.55	-0.02	0.45	Overconfidence	1.10	Optimistic
5	Canadian Natural	48	0.90	0.58	0.78	0.19	0.22	Overconfidence	-0.76	Pessimistic
6	Canacol Energy Ltd	23	0.65	0.57	0.22	0.46	0.78	Overconfidence	-0.17	Pessimistic
7	Cardinal Energy Inc	18	0.83	0.61	0.56	0.33	0.44	Overconfidence	-0.50	Pessimistic
8	Cenovus Energy Inc	33	0.85	0.61	0.61	0.30	0.39	Overconfidence	-0.54	Pessimistic
9	Connacher Oil and Gas Limited	21	0.76	0.52	0.60	0.23	0.40	Overconfidence	-0.12	Pessimistic
10	Crescent Point Energy Corp	42	0.83	0.64	0.48	0.40	0.52	Overconfidence	-0.55	Pessimistic
11	Delphi Energy Corp	33	0.58	0.48	0.23	0.37	0.77	Overconfidence	0.04	Almost Neutral
12	Granite Oil Corp	26	0.69	0.58	0.29	0.43	0.71	Overconfidence	-0.22	Pessimistic
13	Husky Energy Inc	33	0.73	0.58	0.38	0.39	0.62	Overconfidence	-0.24	Pessimistic
14	Iron bridge -former RMP Energy Inc	36	0.50	0.39	0.28	0.25	0.72	Overconfidence	0.31	Optimistic
15	Jura Energy Corp.	8	0.63	0.50	0.31	0.34	0.69	Overconfidence	0.00	Neutral
16	Kelt Exploration Ltd.	12	0.83	0.75	0.21	0.65	0.79	Overconfidence	-0.63	Pessimistic
17	Niko Resources Ltd	28	0.54	0.32	0.54	0.05	0.46	Overconfidence	0.77	Optimistic
18	NuVista Energy Ltd	40	0.73	0.43	0.75	0.05	0.25	Overconfidence	0.60	Optimistic
19	Paramount Resources Ltd	34	0.74	0.50	0.59	0.21	0.41	Overconfidence	0.00	Neutral
20	Parex Resources Inc.	12	0.92	0.67	0.63	0.35	0.38	Overconfidence	-0.89	Pessimistic
21	Pengrowth Energy Corporation	47	0.83	0.68	0.37	0.49	0.63	Overconfidence	-0.58	Pessimistic
22	PetroShale Inc	10	1.00	0.90	0.25	0.78	0.75	Overconfidence	-1.07	Pessimistic
23	Peyto Exploration & Development Corp	23	0.52	0.52	0.00	0.52	1.00	Overconfidence	-0.04	Almost Neutral
24	Raging River Exploration Inc.	19	0.63	0.37	0.66	0.04	0.34	Overconfidence	0.77	Optimistic
25	Repsol Oil & Gas Canada Inc. ("ROGCI")	30	0.50	0.40	0.25	0.28	0.75	Overconfidence	0.27	Optimistic
26	Seven Generations Energy Ltd.	15	0.87	0.67	0.50	0.42	0.50	Overconfidence	-0.67	Pessimistic
27	Strategic Oil & Gas Ltd	18	0.89	0.50	0.97	0.01	0.03	Overconfidence	0.00	Neutral
28	Suncor Energy Inc.	27	0.67	0.44	0.56	0.17	0.44	Overconfidence	0.25	Optimistic
29	Surge Energy Inc	34	0.53	0.24	0.74	-0.13	0.26	Overconfidence	2.00	Optimistic
30	Terra Energy Corp	21	0.81	0.52	0.71	0.17	0.29	Overconfidence	-0.17	Pessimistic
31	Tourmaline Oil Corp	27	0.56	0.59	-0.09	0.64	1.09	Overconfidence	-0.17	Pessimistic
32	TransGlobe Energy Corporation	23	0.70	0.43	0.65	0.11	0.35	Overconfidence	0.38	Optimistic
33	Vermilion Energy Inc	42	0.76	0.69	0.18	0.60	0.82	Overconfidence	-0.46	Pessimistic
34	Whitecap Resources Inc.	28	0.86	0.61	0.63	0.29	0.38	Overconfidence	-0.57	Pessimistic
	Total	**963**	**0.72**	**0.54**	0.44	0.32	**0.56**	Overconfidence	**-0.14**	Pessimistic

Table 5.9, **Fig. 5.11** and **Fig. 5.12** show CB and DB by company for the Canadian detailed dataset. In general, it is observed that all companies are overconfident and the majority of the companies display pessimism bias. Fig. 5.11 specifically shows that company number 27, Strategic Oil & Gas Ltd. (with 18 records), is the most calibrated company with near-zero CB and near-zero DB. Consistently, the calibration plot presented in Fig. 5.12 shows

that Strategic Oil & Gas Ltd. is near perfectly calibrated, with a calibration line almost overlying the unit-slope line. In addition, Fig. 5.12 shows companies that have extreme combined biases—Niko Resources Ltd. (with 28 records), which is one of the most optimistic combined with some overconfidence bias, and ARC Resources Ltd. (with 46 records), which is one of the most pessimistic combined with a lot of overconfidence bias.

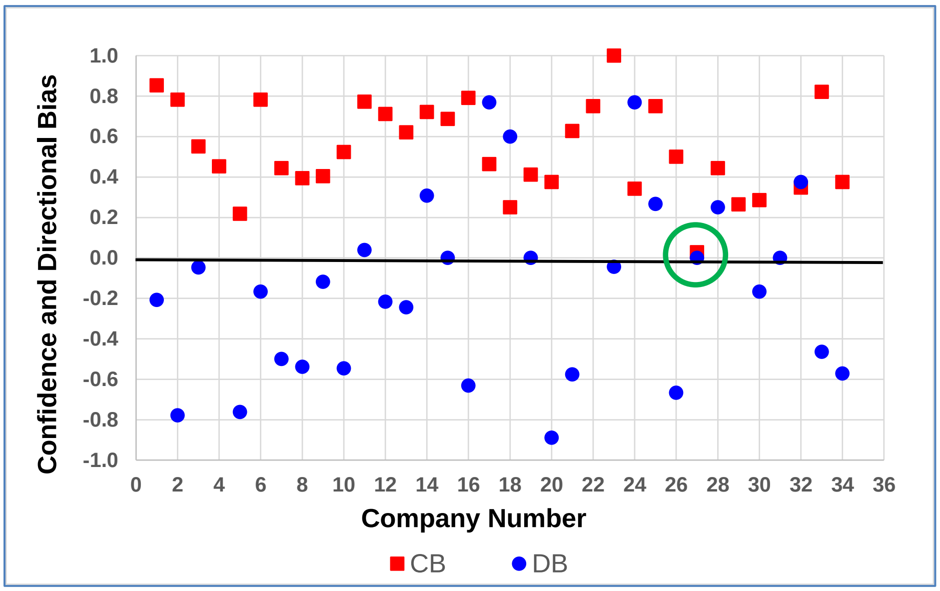


Fig. 5.11—Canadian detailed dataset, CB and DB per company.

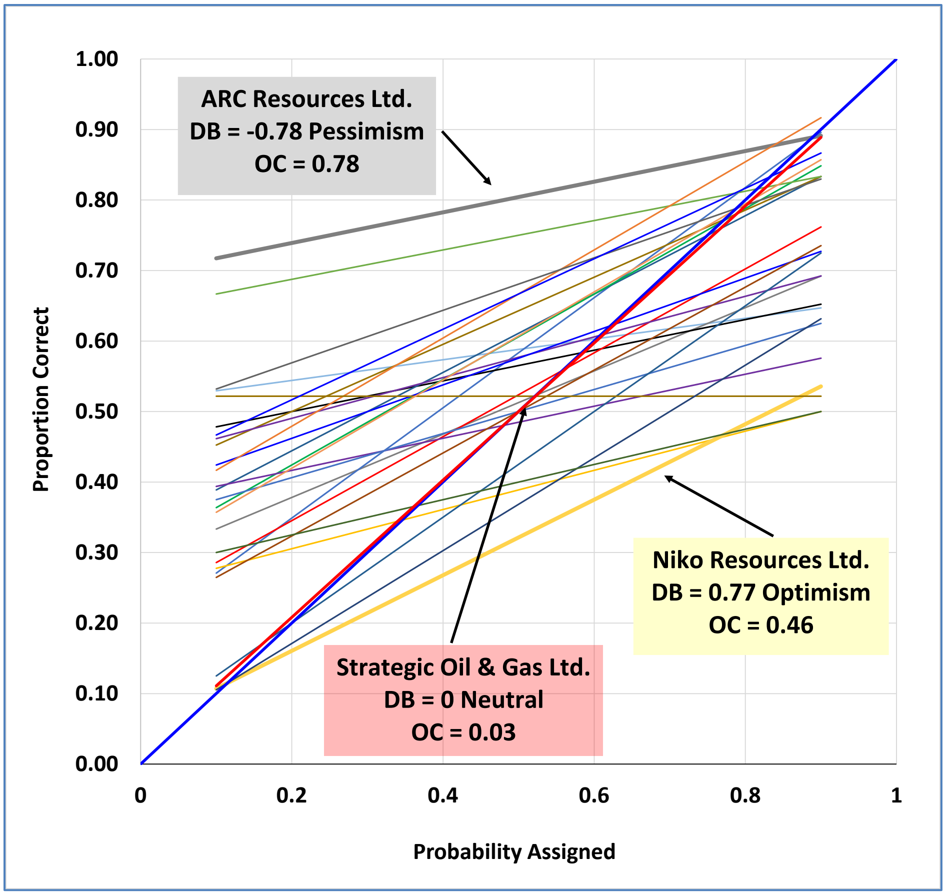


Fig. 5.12—Canadian detailed dataset, calibration plot by company.

Reliability Analysis by Company Size

I next investigated the reliability of reserves estimates by company size: senior, intermediate, and junior (**Fig. 5.13**). Using Eqs. 1 and 5, the confidence and directional biases for different sized companies were calculated (**Table 5.10)**. Results indicate that all three company sizes exhibit overconfidence. This particular set of data shows that DB increases as company size decreases—junior-sized companies are more optimistic than intermediate-sized companies, which are more optimistic than senior-sized companies.

Possible reasons for this tendency are that smaller companies may have more pressure to show good reserves estimates to investors, and larger companies may have more experienced reserves estimation personnel.

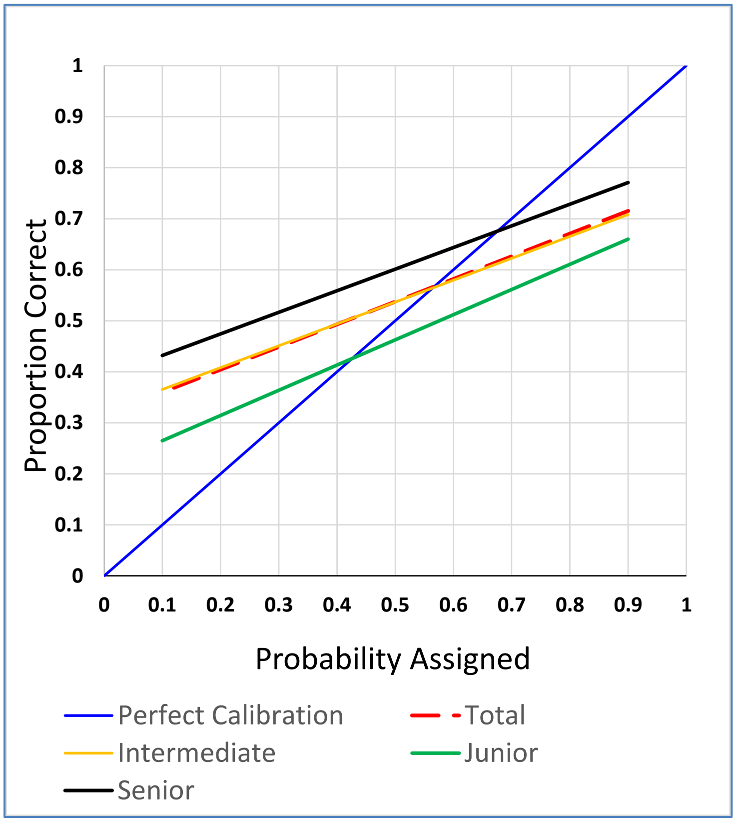


Fig. 5.13— Canadian detailed dataset, calibration plot by company size.

Table 5.10—Canadian detailed dataset, fraction of positive 1P and 2P reserves revisions for different company sizes.

Company Size	Number of Companies	Number of Records	Fraction Positive		Slope	Intercept	CB	DB
			1P	2P				
Junior	11	253	0.66	0.46	0.49	0.22	0.51	0.15
Intermediate	14	408	0.71	0.54	0.43	0.32	0.57	-0.13
Senior	9	302	0.77	0.60	0.42	0.39	0.58	-0.35

Reliability Analysis by Fluid Type

Another analysis performed was the reliability of reserves estimates by fluid type: oil, gas, and NGL. **Table 5.11** contains number of 1P and 2P positive revisions by company and fluid type, and overall fractions of positive revisions by fluid type. Gas and NGL present similar numbers of 1P and 2P positive revisions, and higher than the oil. A calibration plot by fluid type was generated based on this information (**Fig. 5.14**). The calibration plots for all fluids indicate overconfidence.

Table 5.11—Canadian detailed dataset, 1P and 2P number of positive technical revisions by company-year records, grouped by fluid type.

Company Name	OIL			GAS			NGL		
	Number of Records	Number of Positive TR		Number of Records	Number of Positive TR		Number of Records	Number of Positive TR	
		1P	2P		1P	2P		1P	2P
Advantage Oil	13	4	6	12	10	9	9	8	5
ARC Resources Ltd.	22	18	16	14	13	13	10	10	8
Bellatrix Exploration Ltd.	18	9	6	12	10	7	9	8	7
Bonavista Energy Corporation	16	4	2	8	4	2	8	7	4
Canadian Natural	32	27	18	8	8	5	8	8	5
Canacol Energy Ltd	17	11	10	4	4	3	2	0	0
Cardinal Energy Inc	10	8	6	4	4	3	4	3	2
Cenovus Energy Inc	24	19	12	8	8	7	1	1	1
Connacher Oil and Gas Limited	12	10	6	5	3	2	4	3	3
Crescent Point Energy Corp	21	15	8	12	11	11	9	9	8
Delphi Energy Corp	10	6	5	13	7	6	10	6	5
Granite Oil Corp	11	7	4	9	6	6	6	5	5
Husky Energy Inc	20	16	13	10	6	5	3	2	1
Iron bridge -former RMP Energy Inc	11	2	1	14	8	7	11	8	6
Jura Energy Corp.	0	0	0	5	3	2	3	2	2
Kelt Exploration Ltd.	4	2	1	4	4	4	4	4	4
Niko Resources Ltd	11	7	5	11	5	2	6	3	2
NuVista Energy Ltd	17	10	3	13	10	6	10	9	8
Paramount Resources Ltd	11	7	5	13	11	7	10	7	5
Parex Resources Inc.	9	9	6	3	2	2	0	0	0
Pengrowth Energy Corporation	21	17	14	18	14	11	8	8	7
PetroShale Inc	5	5	5	5	5	4	0	0	0
Peyto Exploration & Development Co	7	5	5	8	5	5	8	2	2
Raging River Exploration Inc.	10	6	4	5	3	1	4	3	2
Repsol Oil & Gas Canada Inc.	15	8	6	10	5	4	5	2	2
Seven Generations Energy Ltd.	4	3	1	7	6	5	4	4	4
Strategic Oil & Gas Ltd	10	9	4	6	6	4	2	1	1
Suncor Energy Inc.	16	11	8	8	6	3	3	1	1
Surge Energy Inc	16	11	4	10	5	2	8	2	2
Terra Energy Corp	9	5	2	9	9	7	3	3	2
Tourmaline Oil Corp	8	2	2	11	9	11	8	4	3
TransGlobe Energy Corporation	21	16	10	1	0	0	1	0	0
Vermilion Energy Inc	15	12	10	19	15	13	8	5	6
Whitecap Resources Inc.	12	8	4	8	8	6	8	8	7
Total	**458**	**309**	**212**	**307**	**233**	**185**	**197**	**146**	**120**
Fraction of Positive TR		**0.67**	**0.46**		**0.76**	**0.60**		**0.74**	**0.61**

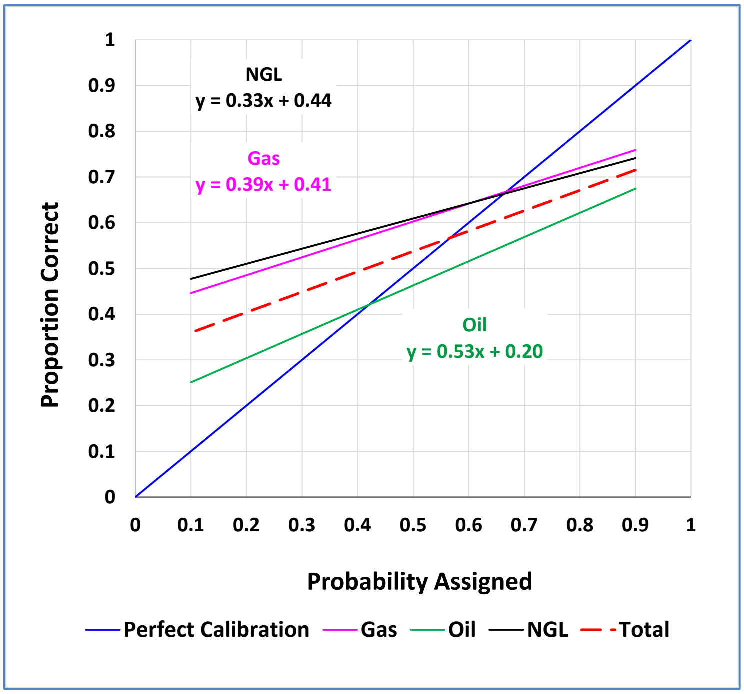


Fig. 5.14—Canadian detailed dataset, calibration plot by fluid type.

Using Eqs. 1 and 5, confidence and directional biases were calculated for different products (**Table 5.12**). Oil reserves estimates exhibit a positive directional bias that is an indication of optimism, whereas gas and NGL reserves estimates indicate slight pessimism. Since NGL is a by-product of gas production, it is expected to have similar tendencies for these two products. One possible reason for the oil to be more optimist than the gas and NGL is that because oil prices are higher, oil estimates will have more effect on the revenue forecast of the company.

Table 5.12—Canadian detailed dataset, bias calculation by fluid type.

Fluid Type	Number of Companies	Number of Records	Fraction Positive		Slope	Intercept	CB	DB
			1P	2P				
Oil	33	458	0.67	0.46	0.53	0.20	0.47	0.16
Gas	34	307	0.76	0.60	0.39	0.41	0.61	-0.34
NGL	33	197	0.74	0.61	0.33	0.44	0.67	-0.33

Reliability Analysis by Resource Type

Table 5.13 contains number of positive revisions of 1P and 2P reserves for each Canadian filer and the fraction of positive changes grouped by resource type (i.e., conventional or unconventional). A calibration plot by reservoir type was generated (**Fig. 5.15**). The number of positive technical revisions for 1P are very close between conventional and unconventional.

Table 5.13—Canadian detailed dataset, number of positive technical revisions for 1P and 2P reserves by company and resource type.

Company Name	Conventional			Unconventional		
	Number of Records	1P	2P	Number of Records	1P	2P
Advantage Oil	26	20	17	8	2	3
ARC Resources Ltd.	30	29	26	16	12	11
Bellatrix Exploration Ltd.	27	19	14	12	8	6
Bonavista Energy Corporation	24	14	7	8	1	1
Canadian Natural	24	22	10	24	21	18
Canacol Energy Ltd	15	10	8	8	5	5
Cardinal Energy Inc	13	11	8	5	4	3
Cenovus Energy Inc	17	16	13	16	12	7
Connacher Oil and Gas Limited	14	10	9	7	6	2
Crescent Point Energy Corp	27	26	22	15	9	5
Delphi Energy Corp	27	16	13	6	3	3
Granite Oil Corp	24	17	14	2	1	1
Husky Energy Inc	19	12	8	14	12	11
Iron bridge -former RMP Energy Inc	30	15	11	6	3	3
Jura Energy Corp.	8	5	4	0	0	0
Kelt Exploration Ltd.	12	10	9	0	0	0
Niko Resources Ltd	28	15	9	0	0	0
NuVista Energy Ltd	30	23	14	10	6	3
Paramount Resources Ltd	30	21	14	4	4	3
Parex Resources Inc.	10	9	6	2	2	2
Pengrowth Energy Corporation	24	20	17	23	19	15
PetroShale Inc	0	0	0	8	8	7
Peyto Exploration & Development Cor	23	12	12	0	0	0
Raging River Exploration Inc.	14	8	4	5	4	3
Repsol Oil & Gas Canada Inc.	15	5	3	15	10	9
Seven Generations Energy Ltd.	11	9	7	4	4	3
Strategic Oil & Gas Ltd	14	13	6	4	3	3
Suncor Energy Inc.	19	14	10	8	4	2
Surge Energy Inc	24	11	4	10	7	4
Terra Energy Corp	21	17	11	0	0	0
Tourmaline Oil Corp	24	12	13	3	3	3
TransGlobe Energy Corporation	13	7	4	10	9	6
Vermilion Energy Inc	24	21	17	18	11	12
Whitecap Resources Inc.	24	21	15	4	3	2
Total	**685**	**490**	**359**	**275**	**196**	**156**
Fraction of Positive TR		**0.72**	**0.52**		**0.71**	**0.57**

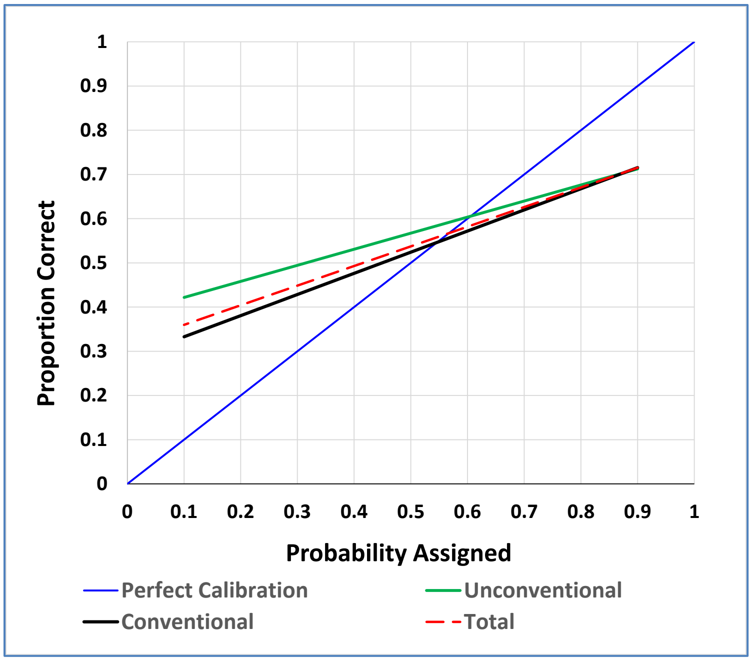


Fig. 5.15—Canadian detailed dataset, calibration plot by resource type.

Confidence and directional biases were calculated for the different resource types with Eqs. 1 and 5 (**Table 5.14**). While both resource types indicate overconfidence, unconventional estimations display more overconfidence than conventional. Unconventional resources should be more uncertain (wider uncertainty ranges) since this resource type is newer than conventional resources and more challenging. A possible explanation of this overconfidence could be a relative lack of experience in estimating these reserves, as it is more difficult to predict productivity in unconventional than conventional reservoirs. Reserves analysts were more pessimistic in their reserves estimates in unconventional resources (DB = -0.21) than in conventional resources (DB = -0.09).

Table 5.14—Canadian detailed dataset, bias calculation by resource type.

Product Class	Number of Companies	Number of Records	Fraction Positive		Slope	Intercept	CB	DB
			1P	2P				
Conventional	33	687	0.72	0.52	0.48	0.29	0.52	-0.09
Unconventional	29	276	0.71	0.57	0.36	0.39	0.64	-0.21

5.2.3 Results Comparison between General and Detailed Canadian Dataset

The fractions of positive technical revisions differ between the general dataset (combined-products) and the detailed dataset (individual-product) (**Table 5.15**). It is possible that when volumes of technical revisions of individual-products are added, multiple small positive volumes of one product added to a large negative volume of another product may result in a single negative volume of the combined-products (or vice versa). Thus, there should not be surprise at small differences in results when these two data sets are compared. **Fig. 5.16** shows the calibration plot with both datasets. The Canadian general dataset displays more pessimism than the detailed dataset. In both cases, the P90 estimate is less than the expected P90 result and the P50 estimate is greater than the expected P50 result, so that the overall conclusions are essentially the same.

Table 5.15—Results from reliability analysis of general and detailed Canadian datasets.

Canadian Datasets	Number of Records	Fraction of Positive 1P Revisions	Fraction of Positive 2P Revisions	CB	DB	Records Description
General Dataset	270	0.80	0.58	0.45	-0.34	Company-Year
Detailed Dataset	963	0.72	0.54	0.56	-0.13	Company-Year-Product

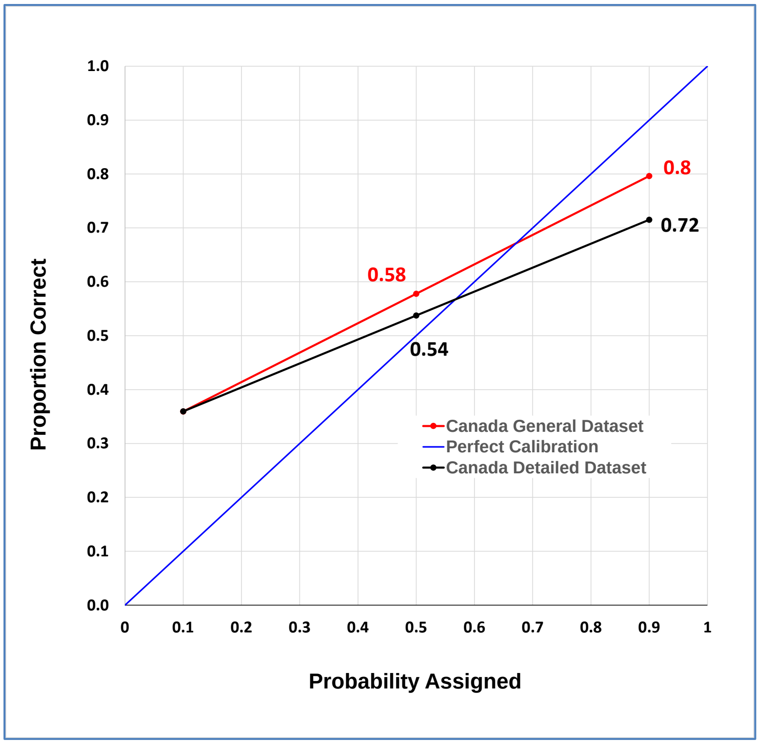


Fig. 5.16—Calibration plot comparing general and detailed Canadian datasets.

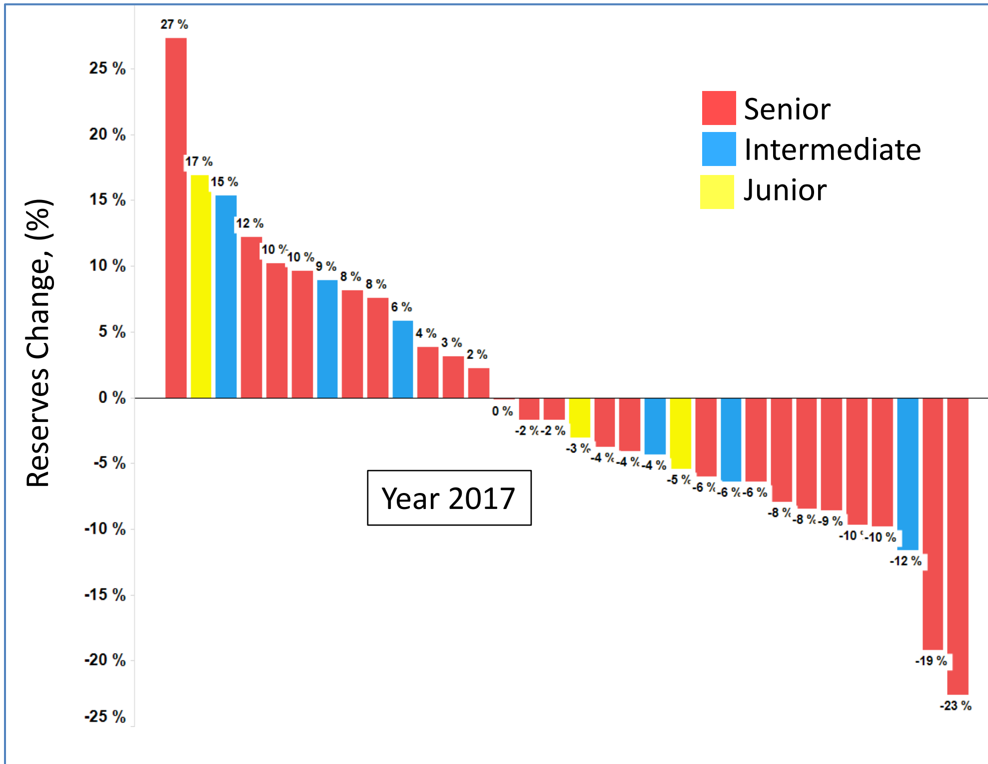
5.3 Reliability of Reserves Estimates made by U.S. Filers

Unlike in Canada, in the U.S. there is no specific technical-revision item. Thus, the focus parameter for addressing reliability of reserves estimates is Revisions Other Than Price (ROTP). As mentioned in Chapter 4, these revisions result from subtracting priced-related revisions from "revisions of previous estimates." The ratio of ROTP to proved reserves at the beginning of the year helps us compare reserves changes and technical revisions from different-size oil and gas companies.

The reserves change is calculated for each company using Eq. 7. A bar plot of reserves change for proved reserves by company for year 2017 is presented in **Fig. 5.17.** Additionally, **APPENDIX D** presents corresponding plots for years 2008 to 2016.

$$Reserves\ \ Change\ (\%) = \frac{\text{Technical ROTP (MMboe)}}{\text{Proved Reserves at beginning of the year (MMboe)}} * 100 \ldots. (7)$$

The majority of the 32 companies analyzed in 2017 had modest changes (less than 15% of reserves at the beginning of the year). The two extreme reserves changes were a positive 27% and a negative 23%. In 2017, 13 of 32 companies (41%) had positive ROTP, which is far from the 90% expected for a P90 estimate. It should be noted that this is for just one year, which is a small sample.



Company Name	1P Initial	ROTP	ROTP % change
NEWFIELD EXPLORATION CO /...	513	140	27 %
DORCHESTER MINERALS, L.P.	14	2	17 %
PDC ENERGY, INC.	341	52	15 %
SOUTHWESTERN ENERGY CO	875	107	12 %
PIONEER NATURAL RESOURC...	726	74	10 %
CABOT OIL & GAS CORP	1429	138	10 %
ENERGEN CORP	316	28	9 %
NOBLE ENERGY INC	1437	117	8 %
ANADARKO PETROLEUM CORP	1722	130	8 %
DENBURY RESOURCES INC	254	15	6 %
RANGE RESOURCES CORP	2012	77	4 %
ANTERO RESOURCES CORP	2564	80	3 %
EOG RESOURCES INC	2147	48	2 %
DEVON ENERGY CORP/DE	1575	-2	0 %
APACHE CORP	1311	-22	-2 %
SM ENERGY CO	396	-7	-2 %
CONTANGO OIL & GAS CO	25	-1	-3 %
CNX RESOURCES CORP	1042	-39	-4 %
QEP RESOURCES, INC.	731	-29	-4 %
BONANZA CREEK ENERGY, INC.	91	-4	-4 %
APPROACH RESOURCES INC	156	-8	-5 %
CONCHO RESOURCES INC	720	-43	-6 %
EP ENERGY CORP	432	-27	-6 %
WPX ENERGY, INC.	347	-22	-6 %
LINN ENERGY, INC.	558	-44	-8 %
WHITING PETROLEUM CORP	616	-52	-8 %
CIMAREX ENERGY CO	482	-41	-9 %
ENCANA CORP	790	-76	-10 %
CONTINENTAL RESOURCES, INC	1275	-124	-10 %
OASIS PETROLEUM INC.	305	-35	-12 %
CHESAPEAKE ENERGY CORP	1708	-327	-19 %
EQT CORP	2251	-507	-23 %

Fig. 5.17—U.S. companies, proved reserves changes (%) - year 2017.

The compilation of results for years 2007 to 2017 is presented in **Table 5.16,** which contains the number of companies with positive ROTP and the fraction of positive ROTP per year. In the U.S., filers are required to report only proved reserves; hence, the table presents only P90 values. The percentage of positive revisions in proved reserves for U.S. filers averaged only 51% for all years, instead of the 90% expected from reserves definitions. **Fig. 5.18** presents a calibration plot with proportion correct of ROTP by year. This calibration plot shows that the assigned P90 corresponds to a proportion correct of 0.51, meaning that on average for this period of time filers in the U.S. overestimate 1P reserves significantly.

Table 5.16—U.S. dataset, proved reserves number and fraction of companies with positive ROTP per year.

Year	Companies Analyzed	Number of Companies with Positive ROTP	Fraction of Positive ROTP
2007	25	18	0.72
2008	27	15	0.56
2009	28	13	0.46
2010	28	15	0.54
2011	32	11	0.34
2012	32	16	0.50
2013	32	16	0.50
2014	32	13	0.41
2015	32	19	0.59
2016	32	21	0.66
2017	32	13	0.41
Total	332	170	**0.51**

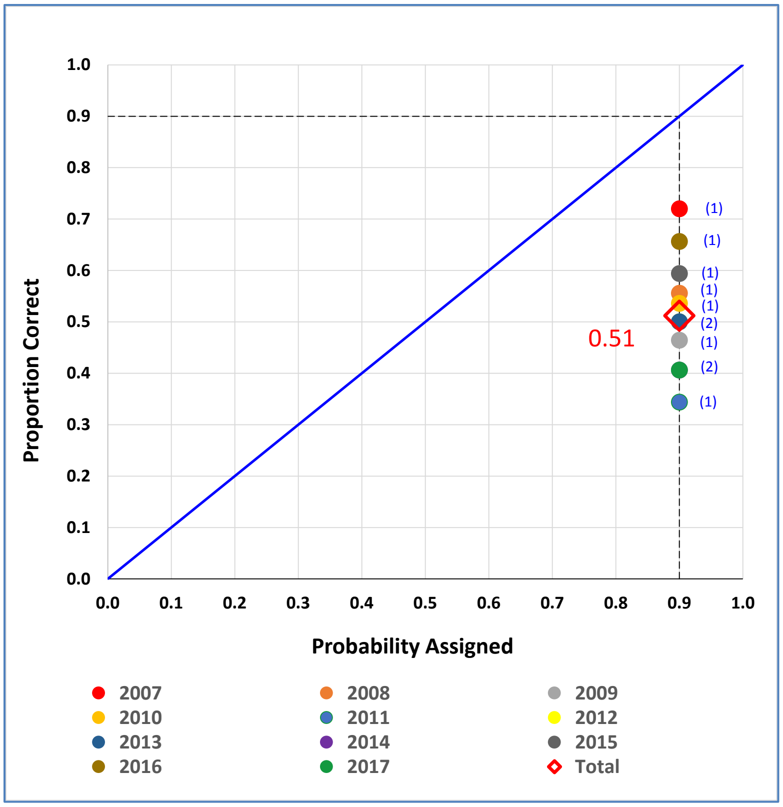


Fig. 5.18—U.S. dataset, proved reserves ROTP calibration plot by year.

Table 5.17 presents the number and fraction of years with positive ROTP in proved reserves for each company. As Table 5.16 and Table 5.17 are analyzing same dataset, the overall results are the same. A calibration plot that represent the fraction of years with positive ROTP per company is presented in **Fig. 5.19.** The number located next to each point represents the number of companies that had a given fraction of positive ROTP.

Table 5.17—U.S. dataset, proved reserves number and fraction of years with positive ROTP per company.

Company Name	Years Analyzed	Number of Years with Positive ROTP	Fraction of Positive ROTP
ANADARKO PETROLEUM CORP	11	11	1.00
ANTERO RESOURCES CORP	7	2	0.29
APACHE CORP	11	4	0.36
APPROACH RESOURCES INC	11	2	0.18
BONANZA CREEK ENERGY, INC.	7	3	0.43
CABOT OIL & GAS CORP	11	10	0.91
CHESAPEAKE ENERGY CORP	11	4	0.36
CIMAREX ENERGY CO	11	6	0.55
CNX RESOURCES CORP	11	5	0.45
CONCHO RESOURCES INC	11	1	0.09
CONTANGO OIL & GAS CO	7	2	0.29
CONTINENTAL RESOURCES, INC	11	6	0.55
DENBURY RESOURCES INC	11	5	0.45
DEVON ENERGY CORP/DE	11	5	0.45
DORCHESTER MINERALS, L.P.	11	11	1.00
ENCANA CORP	11	5	0.45
ENERGEN CORP	11	1	0.09
EOG RESOURCES INC	11	8	0.73
EP ENERGY CORP	7	3	0.43
EQT CORP	11	4	0.36
LINN ENERGY, INC.	11	3	0.27
NEWFIELD EXPLORATION CO /DE/	11	6	0.55
NOBLE ENERGY INC	10	6	0.60
OASIS PETROLEUM INC.	10	4	0.40
PDC ENERGY, INC.	11	5	0.45
PIONEER NATURAL RESOURCES CO	11	6	0.55
QEP RESOURCES, INC.	11	5	0.45
RANGE RESOURCES CORP	11	9	0.82
SM ENERGY CO	11	4	0.36
SOUTHWESTERN ENERGY CO	11	10	0.91
WHITING PETROLEUM CORP	11	10	0.91
WPX ENERGY, INC.	9	4	0.44
Total	332	170	**0.51**

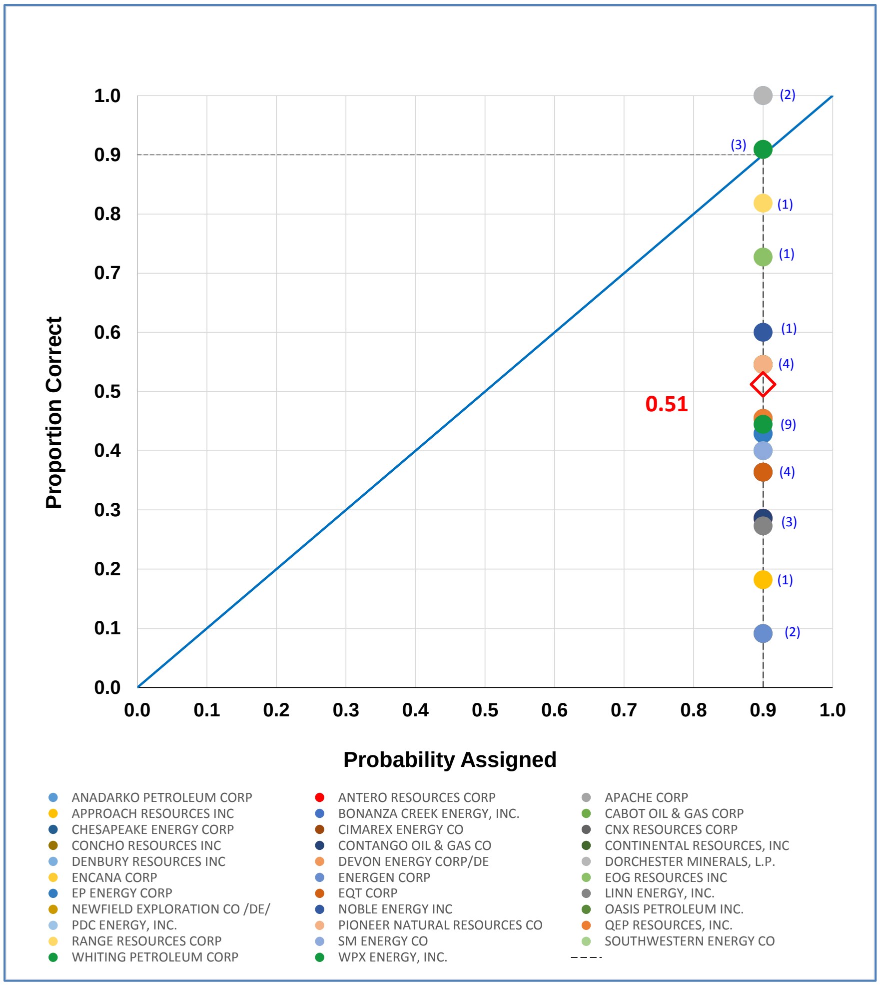


Fig. 5.19—U.S. dataset, proved reserves ROTP calibration plot by company.

In Fig. 5.18, each point represents the fraction of companies with positive ROTP in proved reserves for the respective year. In Fig. 5.19, each point represents the fraction of years with positive ROTP in proved reserves for the respective company. Fig. 5.19 presents more variability than Fig. 5.18. One reason for the differences in the variability of these two representations is that there are more companies (32) than years (11). Another reason could be that it is more likely there will be systematic differences in biases between companies than between years, as mentioned earlier. Because U.S. companies report "revisions of previous estimates" for only proved reserves, there is only one point on the calibration plot and many different lines with different slopes that can pass through this single point. Thus, it is not possible to calculate unique values of actual probability ranges, confidence bias (CB), and directional bias (DB). The interpretation of these biases is non-unique.

To assess the reliability of reserves estimates prepared by U.S. filers, I assumed two extreme scenarios that combine the only measure available (51% positive revisions of ROTP for proved reserves) with extreme values for CB and DB. I also present an intermediate scenario between these two extremes. **Fig. 5.20** presents an interpretation of these three scenarios, assuming the model of Alarfaj and McVay (2016) in which the true and the estimated reserves distributions are continuous normal distributions (Alarfaj and McVay 2016). Fig. 5.20 shows PDFs (left) and inverse-CDF (right) plots, each with four distributions as follows:

- True distribution (perfectly-calibrated),
- Estimate 1 (Est. 1) with maximum overconfidence, CB=1, and almost neutral directional bias, DB= -0.02,
- Estimate 2 (Est. 2) with moderate overconfidence, CB=0.43, and maximum (optimistic) directional bias, DB=1, and
- Estimate 3 (Est. 3) intermediate between the two extreme cases.

All of these interpretations are possible.

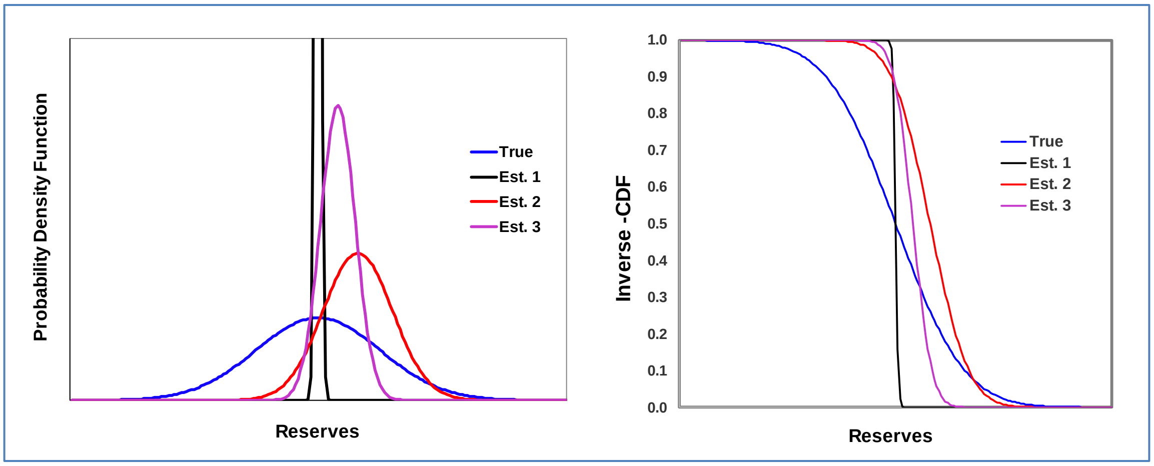


Fig. 5.20—Comparison between the true and estimates 1, 2 and 3 in PDFs (left) and inverse-CDFs (right) representations.

The calibration plot shown in **Fig. 5.21** illustrates the above estimates. Estimate 1 represents maximum CB, and Estimate 2 represents maximum DB. It can be concluded that U.S. filers are overconfident, with biases are somewhere between extreme overconfidence (based on Estimate 1) combined with little directional bias, and moderate overconfidence (based on Estimate 2) combined with moderate-to-high optimism (**Table 5.18**). It is more likely that the reality is somewhere between these two extremes. Estimate 3 is one such possibility.

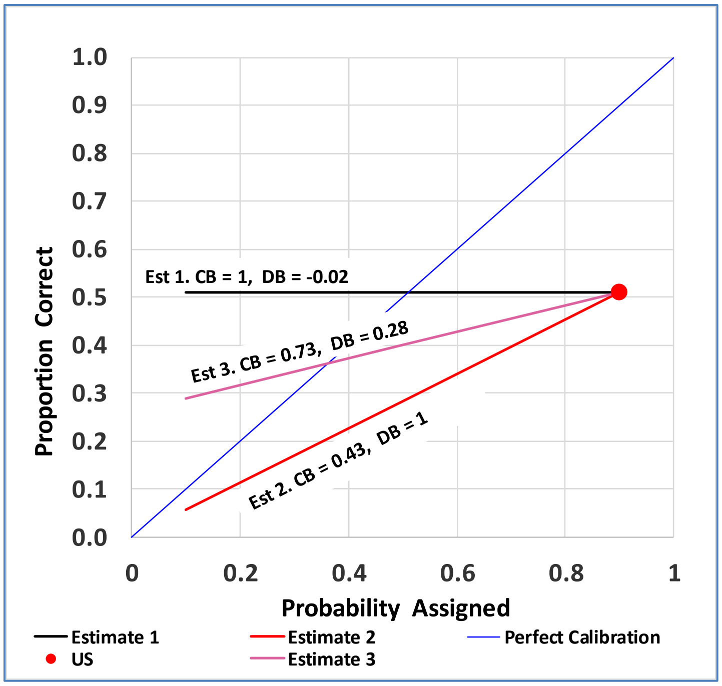


Fig. 5.21—U.S. dataset, calibration plot showing three estimates.

Table 5.18—U.S. dataset, bias calculations for both estimates.

U.S	1P	2P	Slope	Intercept	CB	DB
Estimate 1	0.51	0.51	0.00	0.51	1.00	-0.02
Estimate 2	0.51	0.28	0.57	0.00	0.43	1.00
Estimate 3	0.51	0.40	0.28	0.26	0.73	0.28

5.4 Comparison between U.S. and Canadian Reserves Disclosures

Major differences in Canadian and U.S. reserves estimation and disclosure requirements were presented in Section 2.2.3. As a summary:

- Canadian requirements are unique in the following ways: (1) disclosure of annual reconciliation of changes in estimates of gross 1P and 2P reserves is mandatory; (2) reserves can be estimated using forecasted prices and costs; and (3) reserves reconciliation requires a reserves balance where technical revisions are presented separately from revisions due to economic factors (COGEH 2018).

- Requirements in the United States have the following unique features: (1) disclosure of annual reconciliation of changes in estimates of net 1P reserves is mandatory; (2) estimation of proved oil reserves must be based on a fixed prices and costs under existing economic conditions—the average of prices received from product sales on the first day of each month during the 12-month period immediately preceding disclosure of reserves in a filing with the SEC; and (3) reserves reconciliation requires a reserves balance where "revisions of previous estimates" may include changes caused by economic and technical factors combined, although if important economic factors or significant uncertainties affect changes in proved reserves, an explanation shall be provided (FASB 2010).

For these reasons, it is not possible to perfectly compare the reliability of reserves estimates between filers in these two countries. Nevertheless, a reasonable comparison can be made between the proportion correct of technical revisions in Canada and the proportion correct of ROTP in the U.S. For the U.S., results based on an intermediate estimation (Estimate 3, the line between the two extreme estimates presented in Fig. 5.21) will be used to compare with the detailed Canadian dataset (**Fig. 5.22 and Table 5.19**).

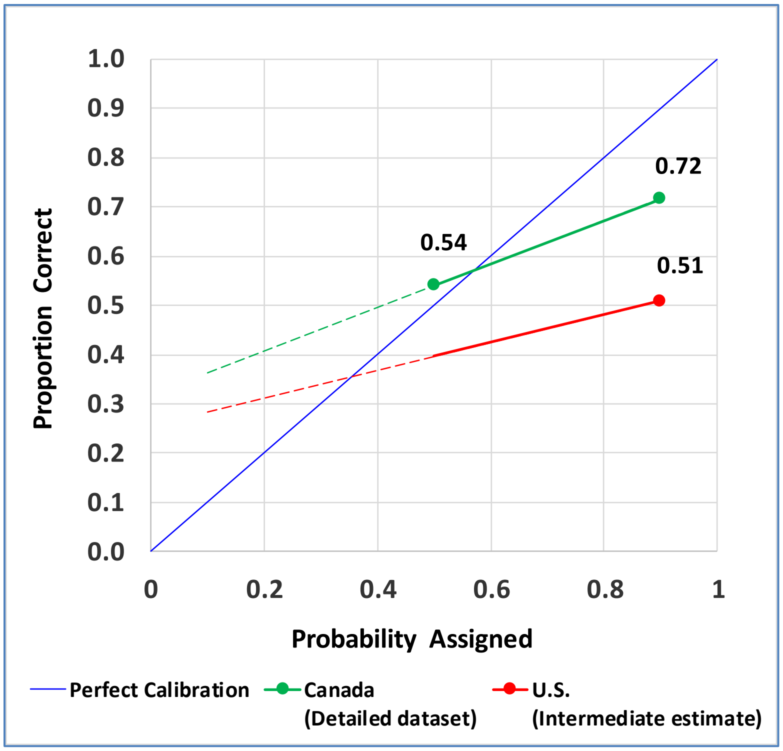


Fig. 5.22—Calibration plot with results from U.S and Canadian filings.

Table 5.19—Comparison of results between U.S. and Canadian filings.

Country	Proportion of Correct		Slope	Intercept	CB	Interpretation	DB	Interpretation
	1P	2P						
Canada (Detailed dataset)	0.72	0.54	0.44	0.32	0.56	Moderate overconfidence	-0.14	Slight pessimism
U.S. (Intermediate estimate)	0.51	0.40	0.28	0.26	0.73	Moderate-to-high overconfidence	0.28	Moderate optimism

By definition, proved reserves are conservative estimates; technical revisions in proved reserves should be positive about 90% of the time. For Canadian companies, the fraction of positive revisions for the P90 is actually 0.72 (72%), indicating that 18% of the time estimations decreased instead of increasing. In other words, 18% of the time previous proved-reserves estimates were higher than they should have been. For 2P reserves, positive technical revisions are expected 50% of the time. The actual fraction of positive revisions in P50 reserves was 0.54 (54%), indicating that 4% of the time estimations increased instead of decreased. Filers in Canada are in need of improvement.

For reserves filers in the U.S., proved ROTP should be positive 90% of the time. However, results for revisions were positive closer to 50% of the time. This indicates that 40% of the time estimates decreased instead of increasing. In other words, 40% of the time, previous proved-reserves estimates were greater than they should have been. Estimates made by filers in the U.S. are significantly further from the assigned probabilities by reserves definitions than Canadian filers.

Canadian reserves filers have a confidence bias of 0.56 on a scale of 0 to 1, where 0 corresponds to no overconfidence (perfectly-calibrated) and 1 corresponds to complete overconfidence. Canadian filers have a directional bias of -0.14 on a scale of -1 to 1, where -1 corresponds to a completely negative directional bias (which is pessimism), 0 means neutral or unbiased directionally, and 1 corresponds to complete positive directional bias (which is optimism). Therefore, Canadian filers are moderately overconfident in their reserves estimates and have a slight directional bias toward pessimism.

U.S. reserves filers have approximately a confidence bias of 0.73 and a directional bias of 0.28. Therefore, U.S. filers are overconfident in their reserves estimates and have a moderate directional bias toward optimism. It should be noted that U.S. biases calculations are approximate values due to the high uncertainty depicted by the three estimates from one single point for proved reserves in the calibration plot (Fig. 5.21). With a more-likely intermediate interpretation for the U.S., the results show that U.S. reserves filers are more overconfident than Canadian filers, and U.S. filers are moderately optimistic, whereas Canadian filers are slightly pessimistic.

The results of this study indicate that companies in Canada are more reliable in estimating reserves than companies in the U.S. One possible explanation of the differences in the reliability of reserves estimates could be that Canadian companies are forced to specify two points on the reserves distribution, P50 and P90, and that they are thus better able to distinguish between these two categories of reserves. Because U.S. companies are not required to distinguish between these two categories, their single reported estimate ends up somewhere in between and, apparently, closer to the P50 value. The U.S. 1P estimates disclosed seemed to satisfy only the certainty criterion for 2P reserves. However, there could be other possible causes that have not been considered.

5.5 Calculation of Confidence Interval

The biases calculations in the estimation of reserves for a sample of Canadian companies and a sample of U.S. companies presented in previous sections were based on the proportion of positive "technical revisions" for Canadian companies and in the proportion of positive ROTP for U.S. companies. The proportions obtained are the means of the mentioned revisions, and there is uncertainty about how far these sample means may be from the means of the entire populations of companies filing in Canada and in the U.S. In this section, a confidence interval around the means of the positive proportions of the revisions is calculated to assess the uncertainty associated with the proportion-correct estimates.

The confidence interval for the mean is an interval that will contain the population mean a specified proportion of the time. The confidence interval is computed based on the mean and the estimated standard error (SE). The SE of the mean measures how far the sample mean of the data is likely to be from the true population mean of the proportion-correct distribution, and it is defined as (Lane 2013):

$$SE(p) = \sqrt{\frac{p(1-p)}{n}} \quad (8)$$

where:

$p = \text{ mean of the estimate}$

$n = \text{ sample size}$

The confidence interval (CI) of the mean is calculated using Eq. 9. Notice that the confidence interval computation does not take into account information regarding the size or mean of the population.

$$CI = p \pm z_\alpha \, SE(p) \quad (9)$$

where:

$\alpha = \text{the significance level}$

z_α = *number of standard deviations extending from the mean of a normal distribution required to contain a specific area* $(1-\alpha)$ *of the normal distribution, and*

$(1-\alpha) = the\ confidence\ level$

For this study, a significance level of 0.05 was selected (this value is at the discretion of the researcher) that corresponds to a confidence level of 0.95 (95%). The interpretation of a 95% confidence level for the mean is that if repeated random samples were taken and the confidence intervals were computed for each sample, 95% of the intervals would contain the population mean. For this statistical method to be valid, the sample must be randomly selected and representative of the population (Lane 2013).

5.5.1 Confidence Interval for the General Canadian Dataset

The sample size of this dataset was 270, which corresponds to the combination of companies and years analyzed. Results of the general dataset plotted in the calibration plot show that the proportion of positive technical revisions is 0.80 for 1P reserves and 0.58 for 2P reserves (Fig. 5.3).

The confidence level selected to calculate the confidence interval is 95%. The z_α value can be found using the standard normal distribution, specifying that the area is 0.95 and indicating that the area is to be between the cut off points. The $z_{0.05}$ value is 1.96.

The mean of the proportion correct for 1P reserves revisions is 0.80, and the standard error is:

$$SE(0.8)\ for\ 1P = \sqrt{\frac{p(1-p)}{n}} = \sqrt{\frac{(0.8*0.2)}{270}} = 0.024$$

The mean of the proportion correct for 2P reserves revisions is 0.58, and the standard error is:

$$SE(0.58)\ for\ 2P = \sqrt{\frac{p(1-p)}{n}} = \sqrt{\frac{(0.58*0.42)}{270}} = 0.03$$

For 1P reserves the confidence interval is:

$$CI\ = p\ \pm z_{0.05} * SE(0.8) = 0.8 \pm 1.96 * 0.024 = (0.75 - 0.85)$$

For 2P reserves the confidence interval is:

$$CI = p\ \pm z_{0.05} * SE(0.58) = 0.58 \pm 1.96 * 0.03 = (0.52 - 0.64)$$

Therefore, it can be stated with 95% confidence that when analyzing the general Canadian dataset, the proportion of positive technical revisions for proved reserves will be between 0.75 and 0.85, and for 2P reserves will be between 0.52 and 0.64, for the population of Canadian filers. Thus, it can be stated with 95% confidence that Canadian filers are overconfident and somewhat pessimistic, as all combinations of proportions of positive technical revisions for P90 and P50 will result in overconfident and pessimistic bias values. Notice that there is a 5% probability that the population mean would not be contain in previous confidence intervals.

5.5.2 Confidence Interval for the Detailed Canadian Dataset

This dataset contained a sample size of 963, which corresponds to the combination of companies, years and products analyzed. The calibration plot of the detailed dataset shows that the proportion of positive technical revisions is 0.72 for 1P reserves and 0.54 for 2P reserves (Fig. 5.5).

The mean of the proportion correct for 1P reserves revisions is 0.72, and the standard error is:

$$SE(0.72)\ for\ 1P = \sqrt{\frac{p(1-p)}{n}} = \sqrt{\frac{(0.72*0.28)}{963}} = 0.014$$

The mean of the proportion correct for 2P reserves revisions is 0.54, and the standard error is:

$$SE(0.54)\ for\ 2P = \sqrt{\frac{p(1-p)}{n}} = \sqrt{\frac{(0.54*0.46)}{963}} = 0.016$$

For 1P reserves revisions the confidence interval is:

$$CI = p\ \pm z_{0.05} * SE(0.72) = 0.72 \pm 1.96 * 0.014 = (0.69 - 0.75)$$

For 2P reserves revisions the confidence interval is:

$$CI = p\ \pm z_{0.05} * SE(0.54) = 0.54 \pm 1.96 * 0.016 = (0.51 - 0.57)$$

Therefore, it can be stated with 95% confidence that when analyzing the detailed Canadian dataset, the proportion of positive technical revisions for proved reserves will be between 0.69 and 0.75 and for the 2P reserves will be between 0.51 and 0.57, for the population of Canadian filers. It can be concluded with 95% confidence that Canadian filers are overconfident and somewhat pessimistic, as all combinations of proportion of positive technical revisions for P90 and P50 will result in overconfident and pessimistic bias values. Again, notice that there is a 5% probability that the population mean would not be contain in previous confidence intervals.

5.5.3 Confidence Interval for the U.S. Dataset

This dataset contained a sample size of 332, which corresponds to the combinations of companies and years analyzed. The calibration plot shows that for proved reserves the proportion of ROTP for U.S. reserves filers is positive 51% of the time (Fig. 5.18).

The mean of the proportion of positive revisions for 1P reserves is 0.51, and the standard error is:

$$SE(0.51)\ for\ 1P\ reserves = \sqrt{\frac{p(1-p)}{n}} = \sqrt{\frac{(0.51*0.49)}{332}} = 0.027$$

For 1P reserves the confidence interval is:

$$CI = p\ \pm z_{0.05} * SE(0.51) = 0.51 \pm 1.96 * 0.027 = (0.46 - 0.56)$$

Therefore, it can be stated with 95% confidence that when analyzing the U.S. dataset, the proportion of positive ROTP for proved reserves for U.S. filers will be between 0.46 and 0.56, for the population of U.S. filers. Thus, it can be stated with 95% confidence that U.S. filers are somewhere between complete overconfidence and slightly pessimistic bias, and moderate overconfidence and complete optimism.

5.6 Discussion

Several authors have reported for years the petroleum industry has underperformed due to overconfidence and optimism in project evaluation procedures (Capen 1976; Rose 2004). I have shown that companies tend to be biased in their reserves estimates. Specifically, filers are overconfident in their estimations, and their tendency to be optimistic is not as dominant as their tendency to be overconfident. At least three groups of professionals can benefit from the methodology presented in this study:

(1) Estimators, who can use this methodology to measure biases in their reserves estimates and use this information to reduce or eliminate biases in future reserves estimates. As determined in this study, the leading bias in reserves estimation is overconfidence, i.e., underestimation of uncertainty. Measurements of biases should make estimators aware that reserves distributions in general have been too narrow and, thus, they need to widen the distributions.

(2) Investors, who can use this methodology to measure the biases in reported reserves estimates and apply external corrections (Capen 1976; Fondren et al. 2013) to compare volumes fairly. If investors do not apply corrections, they could also be overconfident and optimistic, and they could invest in some investments in which they should not. Similarly, if the investors are overconfident and pessimistic, they could choose to not invest in some investments in which they should, resulting in missed opportunities.

(3) Regulators, who can use this methodology to determine if filers are complying with appropriate criteria for 1P and 2P reserves. As this study has shown, reserves estimates made by filers in U.S. and Canada are not consistent with reserves definitions. One way to mitigate this problem over time is to request that filers report their historical record of “technical revisions” in the case of Canada, and ROTP in the case of the U.S., to show how consistent their reserves estimates are consistent

with reserves definitions. The expectation is that awareness of biases will induce operators to reduce their biases over time. Another way to reduce biases in reserves estimates for filers in the U.S. would be to request them to report 2P reserves, as U.S. 1P estimates were significantly more optimistic than those in Canada.

6. LIMITATIONS AND FUTURE WORK

6.1 Limitations

The ideal procedure to select companies for this study is to select them randomly. Canadian companies were randomly selected, while the selection of U.S. companies was not entirely random. U.S companies were "randomly" selected from a pre-defined list of companies that had relevant information available, specifically, information in the reserves-change category "revision of previous estimates" and an explanation of the revisions due to price variations. Thus, the U.S. analysis could be biased towards companies that provided this information.

I also had a limited number of samples for some combinations of companies and years, which made it difficult to calculate meaningful DB values, i.e., in the range of -1 to 1. With only two points in the calibration plot for filers in Canada, sometimes the straight-line approximation was not valid.

6.2 Future Work

This research presents a methodology that others can use to quantify biases in reserves estimates. Since I have shown that companies tend to be biased in their reserves estimates, the next step in this study could be to establish a procedure to apply corrections to reduce or eliminate biases in reserves estimates (Capen 1976; Fondren et al. 2013).

The source of the information for this study was 10-K reports by U.S. companies and AIF reports by Canadian companies. The volumes reported are the result of the addition of volumes of singular entities. In statistical aggregation, the P90 quantities from the aggregate are always greater than the arithmetic sum of the reservoir-level P90 quantities, and the P10 quantities from the aggregate are always less than the arithmetic sum of the reservoir-level P10 quantities. This “portfolio effect” is the result of the central limit theorem in statistical analysis. A portfolio effect should be expected when companies add many entities. Future studies could analyze this topic in more detail.

This study assessed the reliability of reserves estimates by analyzing the proportion of positive “technical revisions.” Another tool to evaluate the reliability of reserves estimates could be to analyze the magnitudes of the “technical revisions.” This information is stored in the database and is available for future studies.

Companies filing in Canada report in the AIF both “technical revisions” and “economic factors.” The “economic factors” were gathered in the database but were not analyzed. Future analysis of this information could help in understanding the impact of economic factors on the reliability of reserves estimates for filers in Canada.

7. CONCLUSIONS

Based on analysis of “technical revisions” of reserves by 34 reserves filers in Canada and “Revisions Other Than Price” (ROTP) of 32 reserves filers in the U.S., for a period from year 2007 to 2017, the following conclusions were drawn:

- Filers in both Canada and the U.S. overestimated proved reserves, and U.S. filers overestimated proved reserves more so than Canadian filers.
- “Technical revisions” reported by the sample of companies filing in Canada were positive an average of 72% for 1P reserves and an average of 54% for 2P reserves, whereas the expected values were 90% and 50%, respectively. Thus, on average over this time period, filers in Canada overestimated 1P reserves and underestimated 2P reserves.
- The ROTP calculated for the sample of companies filing in the U.S. were positive an average of only 51% for 1P reserves, compared to an expected 90%. Thus, on average over this time period, filers in the U.S. overestimated 1P reserves significantly.
- Considering the entire reserves distribution, Canadian filers’ reserves distributions were too narrow (overconfident), with an average overconfidence bias (CB) of 0.56 on a scale of 0 to 1 (corresponding to zero to complete overconfidence). The reserves distributions were shifted negative directionally (pessimism), with an average directional bias (DB) of -0.14 on a scale of -1 to 0 to 1 (corresponding to

complete pessimism to neutral directional bias to complete optimism). Thus, overall, sampled filers in Canada over this time period were moderately overconfident and slightly pessimistic.

- Considering the entire reserves distribution, it is not possible to calculate unique values for confidence and directional biases for filers in the U.S. as they are required to report only 1P reserves. Overall, sampled filers in the U.S. over this time period were somewhere between (1) complete overconfidence and neutral directional bias (CB=1 and DB≈0) and (2) moderate overconfidence and complete optimism (CB=0.43 and DB=1).
- The filers in Canada studied did not demonstrate any apparent improvement in confidence and directional biases during the 11-year period analyzed. Similar analysis cannot be performed for filers in the U.S., as it is not possible to uniquely calculate biases by year.
- For filers in Canada, directional bias decreases (becomes more pessimistic) with increasing company size. Junior-sized companies are optimistic (DB=0.15), intermediate-sized companies are slightly pessimistic (DB=-0.13), and senior-sized companies are the most pessimistic (DB=-0.35).
- For filers in Canada, oil reserves estimates exhibit a positive directional bias (DB=0.16), indicating optimism, while reserves estimates for gas and NGL exhibit negative directional biases (DB=-0.34 and DB=-0.35, respectively), indicating slight pessimism.

- Unconventional-resources reserves estimates in Canada display more overconfidence (CB=0.64) than reserves estimates in conventional resources (CB=0.52). Reserves estimates for unconventional resources (DB=-0.21) are more pessimistic than estimates for conventional resources (DB=-0.09).

NOMENCLATURE

Acronyms

AIF	Annual Information Form
ASC	Alberta Securities Commission
CB	Confidence Bias
CI	Confidence Interval
COGEH	Canadian Oil and Gas Evaluation Handbook
CSA	Canadian Securities Administrators
DB_{OC}	Directional Bias Over-confidence
DB_{UC}	Directional Bias Under-confidence
EDGAR	Electronic Data Gathering Analysis and Retrieval
EUR	Estimated Ultimate Recovery
FASB	Financial Accounting Standards Board
NGL	Natural Gas Liquids
NI	National Instrument
OC	Overconfidence
SE	Standard Error
SEC	Securities & Exchange Commission
SEDAR	System for Electronic Document Analysis and Retrieval
UC	Underconfidence

Symbols - Units

α	Confidence level
a	Intercept
Bcf	Billions of cubic feet
bbls	Barrels
BOE	Barrels of oil equivalent
BOE/D	Barrels of oil equivalent per day
MM	Millions
m	Slope

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APPENDIX A

COMPANY RECONCILIATION SAMPLE FORMS FOR CANADA AND THE U.S.

This appendix presents a reconciliation snapshot for the company Crescent Point Energy Corp. under Canadian and U.S. regulations for year 2017.

Table A.1—Company reconciliation of changes in reserves AIF - Canadian regulation.

Reconciliations of Changes in Reserves[1]

The following table sets forth a reconciliation of the Corporation's Company Gross reserves by total Proved, total Probable and total Proved plus Probable reserves as at December 31, 2017 against such reserves as at December 31, 2016 based on forecast price and cost assumptions.

TOTAL	Shale Gas [5] (Natural Gas) *(MMcf)*			Conventional Natural Gas [5] (Natural Gas) *(MMcf)*			Total BOE *(Mboe)*		
Factors	Proved	Probable	Proved + Probable	Proved	Probable	Proved + Probable	Proved	Probable	Proved + Probable
December 31, 2016	247,501	138,953	386,455	127,261	67,441	194,702	600,199	358,289	958,489
Discoveries	—	—	—	—	—	—	—	—	—
Extensions and Improved Recovery [2] [7]	30,692	25,512	56,203	859	1,399	2,257	57,559	44,814	102,373
Technical Revisions [3]	29,212	(608)	28,604	(1,284)	(16,304)	(17,588)	31,198	(36,517)	(5,320)
Acquisitions [8]	22,142	9,539	31,681	437	1,477	1,914	22,352	10,922	33,275
Dispositions [6] [9]	(536)	(806)	(1,342)	(1,600)	(781)	(2,380)	(14,317)	(6,561)	(20,878)
Economic Factors	(2,354)	2,433	79	(2,022)	1,463	(560)	(1,477)	2,046	569
Production	(26,398)	—	(26,398)	(12,511)	—	(12,511)	(64,245)	—	(64,245)
December 31, 2017	300,259	175,023	475,281	111,140	54,695	165,834	631,270	372,993	1,004,262

Table A.2—Company reserves changes SEC - U.S. regulations.

Net Proved Reserves [(1)]	Total			
	Crude Oil (Mbbls)	NGLs (Mbbls)	Natural Gas (MMcf)	Total (Mboe)
December 31, 2015	343,187	39,367	216,001	418,554
Revisions of previous estimates	(13,789)	1,269	27,630	(7,915)
Improved recovery	10,981	1,357	6,753	13,464
Purchases of reserves in place	7,225	439	4,183	8,361
Extensions and discoveries	8,794	473	3,040	9,773
Production	(41,474)	(5,682)	(34,027)	(52,827)
Sales of reserves in place	(1,677)	(62)	(4,795)	(2,539)
December 31, 2016	313,246	37,161	218,785	386,872
Revisions of previous estimates	81,960	16,515	83,089	112,323
Improved recovery	3,892	1,564	3,868	6,101
Purchases of reserves in place	13,191	1,841	18,548	18,124
Extensions and discoveries	14,972	1,387	8,802	17,826
Production	(43,630)	(5,978)	(34,269)	(55,319)
Sales of reserves in place	(12,661)	(178)	(1,847)	(13,147)
December 31, 2017	370,971	52,313	296,977	472,780

APPENDIX B

DESCRIPTION OF DATASETS

Table B.1—General Canadian dataset records.

General Canadian Dataset		
Record Title	**Units**	**Comments**
Year End	Year	Year at end of the period analyzed
Company category		Senior, Intermediate or Junior
Company Name		Name of the company as state in the database
Product		Refers to the total volume.
Proved Beginning	MMboe	Proved reserves at Beginning of period analyzed
Proved Technical Revisions	MMboe	Proved technical revisions during the period analyzed
Proved Economic Factors	MMboe	Proved economic factors during the period analyzed
Proved Ending	MMboe	Proved reserves at End of period analyzed
Probable Beginning	MMboe	Probable reserves at Beginning of period analyzed
Probable Technical Revisions	MMboe	Probable technical revisions during the period analyzed
Probable Economic Factors	MMboe	Probable economic factors during the period analyzed
Probable Ending	MMboe	Probable reserves at End of period analyzed
2P Beginning	MMboe	Proved-plus-probable reserves at Beginning of period analyzed
2P Technical Revisions	MMboe	Proved-plus-probable technical revisions during the period analyzed
2P Economic Factors	MMboe	Proved-plus-probable economic factors during the period analyzed
2P Ending	MMboe	Proved-plus-probable reserves at End of period analyzed
Production	MMboe	Cumulative production during the period analyzed
Year Production	BOE/D	Production rate of the year analyzed
Proved Technical Revisions change (%)	%	Ratio Proved technical revision / Proved Beginning
2P Technical Revisions change (%)	%	Ratio 2P technical revision / 2P Beginning
Number of Positive Proved Revisions	Number	Number of positive Proved Technical Revisions
Number of Positive 2P Revisions	Number	Number of positive 2P Technical Revisions

Table B.2—Detailed Canadian dataset records.

Detailed Canadian Dataset		
Record Title	**Units**	**Comments**
Year End	Year	Year at end of the period analyzed
Company category		Senior, Intermediate or Junior
Company Name		Name of the company as state in the database
Product Class		Conventional or Unconventional
Fluid	MMbls	Oil
Fluid	Bcf	Gas
Fluid	MMbls	NGL
Bitumen Proved Beginning	MMbls	Bitumen Proved reserves at Beginning of period analyzed
Bitumen Proved Technical Revisions	MMbls	Bitumen Proved technical revisions during the period analyzed
Bitumen Proved Economic Factors	MMbls	Bitumen Proved economic factors during the period analyzed
Bitumen Proved Ending	MMbls	Bitumen Proved reserves at End of period analyzed
Bitumen Probable Beginning	MMbls	Bitumen Probable reserves at Beginning of period analyzed
Bitumen Probable Technical Revisions	MMbls	Bitumen Probable technical revisions during the period analyzed
Bitumen Probable Economic Factors	MMbls	Bitumen Probable economic factors during the period analyzed
Bitumen Probable Ending	MMbls	Bitumen Probable reserves at End of period analyzed
Bitumen 2P Beginning	MMbls	Bitumen Proved-plus-probable reserves at Beginning of period analyzed
Bitumen 2P Technical Revisions	MMbls	Bitumen Proved-plus-probable technical revisions during the period analyzed
Bitumen 2P Economic Factors	MMbls	Bitumen Proved-plus-probable economic factors during the period analyzed
Bitumen 2P Ending	MMbls	Bitumen Proved-plus-probable reserves at End of period analyzed
Coalbed Methane Proved Beginning	Bcf	Coalbed Methane Proved reserves at Beginning of period analyzed
Coalbed Methane Proved Technical Revisions	Bcf	Coalbed Methane Proved technical revisions during the period analyzed
Coalbed Methane Proved Economic Factors	Bcf	Coalbed Methane Proved economic factors during the period analyzed
Coalbed Methane Proved Ending	Bcf	Coalbed Methane Proved reserves at End of period analyzed
Coalbed Methane Probable Beginning	Bcf	Coalbed Methane Probable reserves at Beginning of period analyzed
Coalbed Methane Probable Technical Revisions	Bcf	Coalbed Methane Probable technical revisions during the period analyzed
Coalbed Methane Probable Economic Factors	Bcf	Coalbed Methane Probable economic factors during the period analyzed
Coalbed Methane Probable Ending	Bcf	Coalbed Methane Probable reserves at End of period analyzed
Coalbed Methane 2P Beginning	Bcf	Coalbed Methane Proved-plus-probable reserves at Beginning of period analyzed
Coalbed Methane 2P Technical Revisions	Bcf	Coalbed Methane Proved-plus-probable technical revisions during the period analyzed
Coalbed Methane 2P Economic Factors	Bcf	Coalbed Methane Proved-plus-probable economic factors during the period analyzed
Coalbed Methane 2P Ending	Bcf	Coalbed Methane Proved-plus-probable reserves at End of period analyzed
Natural Gas Proved Beginning	Bcf	Natural Gas Proved reserves at Beginning of period analyzed
Natural Gas Proved Technical Revisions	Bcf	Natural Gas Proved technical revisions during the period analyzed
Natural Gas Proved Economic Factors	Bcf	Natural Gas Proved economic factors during the period analyzed
Natural Gas Proved Ending	Bcf	Natural Gas Proved reserves at End of period analyzed
Natural Gas Probable Beginning	Bcf	Natural Gas Probable reserves at Beginning of period analyzed
Natural Gas Probable Technical Revisions	Bcf	Natural Gas Probable technical revisions during the period analyzed
Natural Gas Probable Economic Factors	Bcf	Natural Gas Probable economic factors during the period analyzed
Natural Gas Probable Ending	Bcf	Natural Gas Probable reserves at End of period analyzed
Natural Gas 2P Beginning	Bcf	Natural Gas Proved-plus-probable reserves at Beginning of period analyzed
Natural Gas 2P Technical Revisions	Bcf	Natural Gas Proved-plus-probable technical revisions during the period analyzed
Natural Gas 2P Economic Factors	Bcf	Natural Gas Proved-plus-probable economic factors during the period analyzed
Natural Gas 2P Ending	Bcf	Natural Gas Proved-plus-probable reserves at End of period analyzed
Heavy Oil Proved Beginning	MMbls	Heavy Oil Proved reserves at Beginning of period analyzed
Heavy Oil Proved Technical Revisions	MMbls	Heavy Oil Proved technical revisions during the period analyzed
Heavy Oil Proved Economic Factors	MMbls	Heavy Oil Proved economic factors during the period analyzed
Heavy Oil Proved Ending	MMbls	Heavy Oil Proved reserves at End of period analyzed
Heavy Oil Probable Beginning	MMbls	Heavy Oil Probable reserves at Beginning of period analyzed
Heavy Oil Probable Technical Revisions	MMbls	Heavy Oil Probable technical revisions during the period analyzed
Heavy Oil Probable Economic Factors	MMbls	Heavy Oil Probable economic factors during the period analyzed
Heavy Oil Probable Ending	MMbls	Heavy Oil Probable reserves at End of period analyzed
Heavy Oil 2P Beginning	MMbls	Heavy Oil Proved-plus-probable reserves at Beginning of period analyzed
Heavy Oil 2P Technical Revisions	MMbls	Heavy Oil Proved-plus-probable technical revisions during the period analyzed
Heavy Oil 2P Economic Factors	MMbls	Heavy Oil Proved-plus-probable economic factors during the period analyzed
Heavy Oil 2P Ending	MMbls	Heavy Oil Proved-plus-probable reserves at End of period analyzed

Table B.2—Detailed Canadian dataset records. (Continued)

Detailed Canadian Dataset		
Record Title	**Units**	**Comments**
Light & Medium Oil Proved Beginning	MMbls	Light & Medium Oil Proved reserves at Beginning of period analyzed
Light & Medium Oil Proved Technical Revisions	MMbls	Light & Medium Oil Proved technical revisions during the period analyzed
Light & Medium Oil Proved Economic Factors	MMbls	Light & Medium Oil Proved economic factors during the period analyzed
Light & Medium Oil Proved Ending	MMbls	Light & Medium Oil Proved reserves at End of period analyzed
Light & Medium Oil Probable Beginning	MMbls	Light & Medium Oil Probable reserves at Beginning of period analyzed
Light & Medium Oil Probable Technical Revisions	MMbls	Light & Medium Oil Probable technical revisions during the period analyzed
Light & Medium Oil Probable Economic Factors	MMbls	Light & Medium Oil Probable economic factors during the period analyzed
Light & Medium Oil Probable Ending	MMbls	Light & Medium Oil Probable reserves at End of period analyzed
Light & Medium Oil 2P Beginning	MMbls	Light & Medium Oil Proved-plus-probable reserves at Beginning of period analyzed
Light & Medium Oil 2P Technical Revisions	MMbls	Light & Medium Oil Proved-plus-probable technical revisions during the period analyzed
Light & Medium Oil 2P Economic Factors	MMbls	Light & Medium Oil Proved-plus-probable economic factors during the period analyzed
Light & Medium Oil 2P Ending	MMbls	Light & Medium Oil Proved-plus-probable reserves at End of period analyzed
NGL Proved Beginning	MMbls	NGL Proved reserves at Beginning of period analyzed
NGL Proved Technical Revisions	MMbls	NGL Proved technical revisions during the period analyzed
NGL Proved Economic Factors	MMbls	NGL Proved economic factors during the period analyzed
NGL Proved Ending	MMbls	NGL Proved reserves at End of period analyzed
NGL Probable Beginning	MMbls	NGL Probable reserves at Beginning of period analyzed
NGL Probable Technical Revisions	MMbls	NGL Probable technical revisions during the period analyzed
NGL Probable Economic Factors	MMbls	NGL Probable economic factors during the period analyzed
NGL Probable Ending	MMbls	NGL Probable reserves at End of period analyzed
NGL 2P Beginning	MMbls	NGL Proved-plus-probable reserves at Beginning of period analyzed
NGL 2P Technical Revisions	MMbls	NGL Proved-plus-probable technical revisions during the period analyzed
NGL 2P Economic Factors	MMbls	NGL Proved-plus-probable economic factors during the period analyzed
NGL 2P Ending	MMbls	NGL Proved-plus-probable reserves at End of period analyzed
Shale Gas Proved Beginning	Bcf	Shale Gas Proved reserves at Beginning of period analyzed
Shale Gas Proved Technical Revisions	Bcf	Shale Gas Proved technical revisions during the period analyzed
Shale Gas Proved Economic Factors	Bcf	Shale Gas Proved economic factors during the period analyzed
Shale Gas Proved Ending	Bcf	Shale Gas Proved reserves at End of period analyzed
Shale Gas Probable Beginning	Bcf	Shale Gas Probable reserves at Beginning of period analyzed
Shale Gas Probable Technical Revisions	Bcf	Shale Gas Probable technical revisions during the period analyzed
Shale Gas Probable Economic Factors	Bcf	Shale Gas Probable economic factors during the period analyzed
Shale Gas Probable Ending	Bcf	Shale Gas Probable reserves at End of period analyzed
Shale Gas 2P Beginning	Bcf	Shale Gas Proved-plus-probable reserves at Beginning of period analyzed
Shale Gas 2P Technical Revisions	Bcf	Shale Gas Proved-plus-probable technical revisions during the period analyzed
Shale Gas 2P Economic Factors	Bcf	Shale Gas Proved-plus-probable economic factors during the period analyzed
Shale Gas 2P Ending	Bcf	Shale Gas Proved-plus-probable reserves at End of period analyzed
Synthetic Oil Proved Beginning	MMbls	Synthetic Oil Proved reserves at Beginning of period analyzed
Synthetic Oil Proved Technical Revisions	MMbls	Synthetic Oil Proved technical revisions during the period analyzed
Synthetic Oil Proved Economic Factors	MMbls	Synthetic Oil Proved economic factors during the period analyzed
Synthetic Oil Proved Ending	MMbls	Synthetic Oil Proved reserves at End of period analyzed
Synthetic Oil Probable Beginning	MMbls	Synthetic Oil Probable reserves at Beginning of period analyzed
Synthetic Oil Probable Technical Revisions	MMbls	Synthetic Oil Probable technical revisions during the period analyzed
Synthetic Oil Probable Economic Factors	MMbls	Synthetic Oil Probable economic factors during the period analyzed
Synthetic Oil Probable Ending	MMbls	Synthetic Oil Probable reserves at End of period analyzed
Synthetic Oil 2P Beginning	MMbls	Synthetic Oil Proved-plus-probable reserves at Beginning of period analyzed
Synthetic Oil 2P Technical Revisions	MMbls	Synthetic Oil Proved-plus-probable technical revisions during the period analyzed
Synthetic Oil 2P Economic Factors	MMbls	Synthetic Oil Proved-plus-probable economic factors during the period analyzed
Synthetic Oil 2P Ending	MMbls	Synthetic Oil Proved-plus-probable reserves at End of period analyzed
Tight Oil - Shale Oil Proved Beginning	MMbls	Tight Oil - Shale Oil Proved reserves at Beginning of period analyzed
Tight Oil - Shale Oil Proved Technical Revisions	MMbls	Tight Oil - Shale Oil Proved technical revisions during the period analyzed
Tight Oil - Shale Oil Proved Economic Factors	MMbls	Tight Oil - Shale Oil Proved economic factors during the period analyzed
Tight Oil - Shale Oil Proved Ending	MMbls	Tight Oil - Shale Oil Proved reserves at End of period analyzed
Tight Oil - Shale Oil Probable Beginning	MMbls	Tight Oil - Shale Oil Probable reserves at Beginning of period analyzed
Tight Oil - Shale Oil Probable Technical Revisions	MMbls	Tight Oil - Shale Oil Probable technical revisions during the period analyzed
Tight Oil - Shale Oil Probable Economic Factors	MMbls	Tight Oil - Shale Oil Probable economic factors during the period analyzed
Tight Oil - Shale Oil Probable Ending	MMbls	Tight Oil - Shale Oil Probable reserves at End of period analyzed
Tight Oil - Shale Oil 2P Beginning	MMbls	Tight Oil - Shale Oil Proved-plus-probable reserves at Beginning of period analyzed
Tight Oil - Shale Oil 2P Technical Revisions	MMbls	Tight Oil - Shale Oil Proved-plus-probable technical revisions during the period analyzed
Tight Oil - Shale Oil 2P Economic Factors	MMbls	Tight Oil - Shale Oil Proved-plus-probable economic factors during the period analyzed
Tight Oil - Shale Oil 2P Ending	MMbls	Tight Oil - Shale Oil Proved-plus-probable reserves at End of period analyzed

Table B.2—Detailed Canadian dataset records. (Continued)

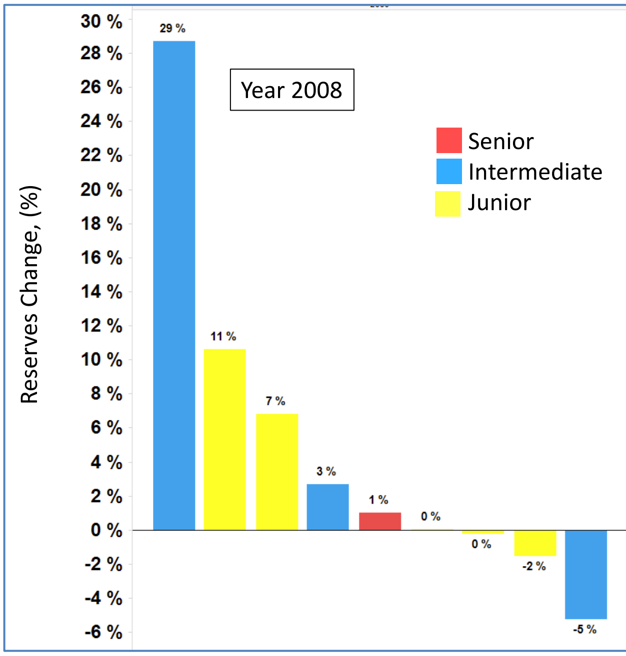
Detailed Canadian Dataset		
Record Title	**Units**	**Comments**
Proved Beginning	MMboe	Total Proved reserves at Beginning of period analyzed
Proved Technical Revisions	MMboe	Total Proved technical revisions during the period analyzed
Proved Economic Factors	MMboe	Total Proved economic factors during the period analyzed
Proved Ending	MMboe	Total Proved reserves at End of period analyzed
Probable Beginning	MMboe	Total Probable reserves at Beginning of period analyzed
Probable Technical Revisions	MMboe	Total Probable technical revisions during the period analyzed
Probable Economic Factors	MMboe	Total Probable economic factors during the period analyzed
Probable Ending	MMboe	Total Probable reserves at End of period analyzed
2P Beginning	MMboe	Total Proved-plus-probable reserves at Beginning of period analyzed
2P Technical Revisions	MMboe	Total Proved-plus-probable technical revisions during the period analyzed
2P Economic Factors	MMboe	Total Proved-plus-probable economic factors during the period analyzed
2P Ending	MMboe	Total Proved-plus-probable reserves at End of period analyzed
Production	MMboe	Cumulative production during the period analyzed
Year Production	BOE/D	Production rate of the year analyzed
Proved Technical Revisions change %	%	Ratio Proved technical revision / Proved Beginning
2P Technical Revisions change %	%	Ratio 2P technical revision / 2P Beginning
Number of Positive Proved Revisions	Number	Number of positive Proved Technical Revisions
Number of Positive 2P Revisions	Number	Number of positive 2P Technical Revisions

Table B.3—U.S. dataset records.

U.S Dataset		
Record Title	**Units**	**Comments**
Year End	Year	Year at end of the period analyzed
Company Category		Senior, Intermediate or Junior
Company Name		Name of the company as state in the database
Proved at Beginning	MMboe	Total Proved reserves at Beginning of period analyzed
Proved Natural Gas	Bcf	Proved Natural Gas reserves at end of period analyzed
Proved Oil and Condensate	MMbls	Proved Oil and Condensate reserves at end of period analyzed
Proved NGL	MMbls	Proved NGL reserves at end of period analyzed
Proved at End	MMboe	Total Proved reserves at End of period analyzed
Production	MMboe	Cumulative production during the period analyzed
Production	BOE/D	Production rate of the year analyzed
Revisions Natural Gas	Bcf	Proved revisions of Natural Gas during the period analyzed
Revisions Oil and Condensate	MMbls	Proved revisions of Oil and Condensate during the period analyzed
Revisions NGL	MMbls	Proved revisions of NGL during the period analyzed
Total Revisions	MMboe	Total Proved revisions during the period analyzed
Revisions due Price	MMboe	Total Proved revisions due price during the period analyzed
Total Revisions other than price	MMboe	Difference between Total Revisions and Revisions due Price
Total Revisions % change	%	Ratio Total Revisions / Proved at Beginning
Revisions Other than price % change	%	Ratio Total Revisions Other than Price / Proved at Beginning
Number of Positive Total Revisions	Number	Number of positive Total Revisions
Number of Positive Revisions Other than price	Number	Number of positive Total Revisions other than price

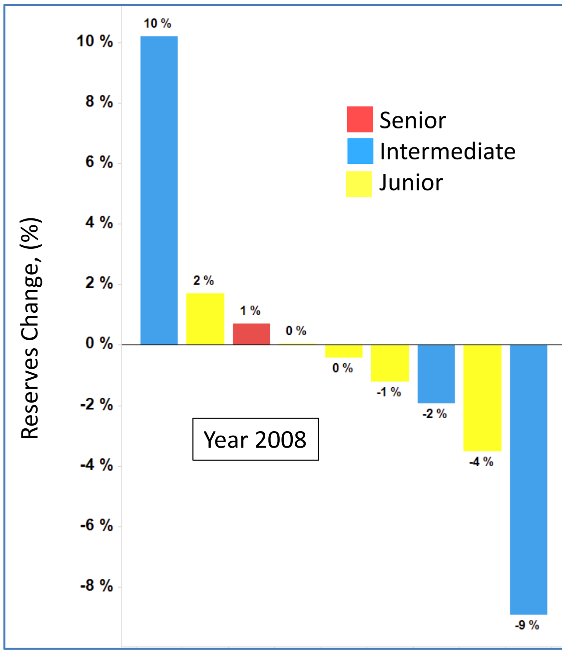
APPENDIX C

CANADIAN COMPANIES 1P AND 2P RESERVES CHANGES (%) BY YEAR



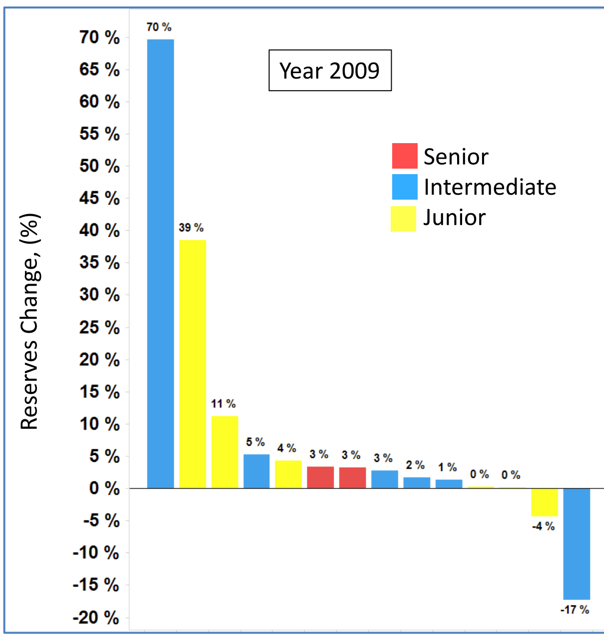
Company Name	Proved Initial Reserves	Technical Revisions	Reserves (%) Change
TransGlobe Energy Corporation	9.86	2.83	29 %
Iron bridge -former RMP Energy Inc	7.41	0.79	11 %
Delphi Energy Corp	11.28	0.77	7 %
NuVista Energy Ltd	28.02	0.75	3 %
ARC Resources Ltd.	222.59	2.28	1 %
Granite Oil Corp	0.07	0.00	0 %
Connacher Oil and Gas Limited	59.86	-0.10	0 %
Niko Resources Ltd	199.71	-3.03	-2 %
Paramount Resources Ltd	26.06	-1.37	-5 %

Fig. C.1—Canadian companies proved reserves changes (%) for year 2008.



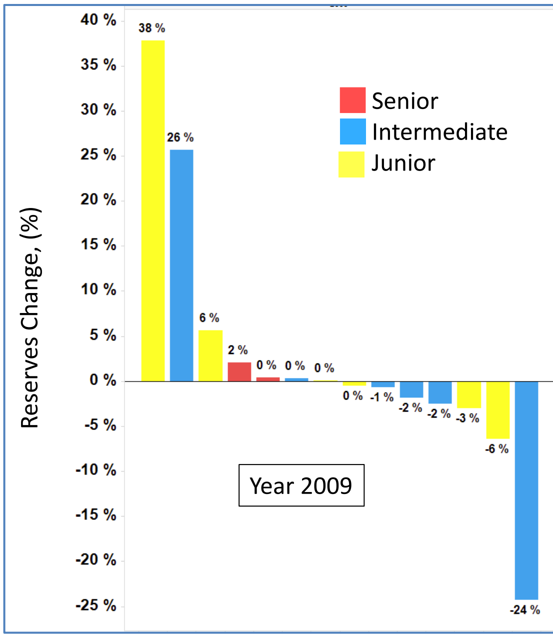
Company Name	2P Initial Reserves	Technical Revisions	2P Reserves (%) Change
TransGlobe Energy Corporation	13.24	1.35	10.2 %
Delphi Energy Corp	17.18	0.29	1.7 %
ARC Resources Ltd.	283.55	2.11	0.7 %
Granite Oil Corp	0.09	0.00	0.0 %
Connacher Oil and Gas Limited	187.25	-0.82	-0.4 %
Niko Resources Ltd	284.70	-3.31	-1.2 %
NuVista Energy Ltd	39.62	-0.74	-1.9 %
Iron bridge -former RMP Energy Inc	13.72	-0.47	-3.5 %
Paramount Resources Ltd	41.27	-3.68	-8.9 %

Fig. C.2—Canadian companies proved-plus-probable reserves changes (%) for year 2008.



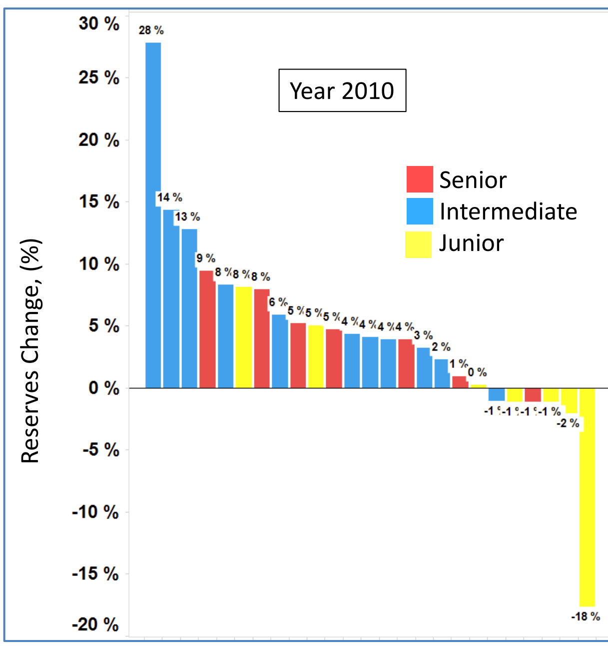
Company Name	Proved Initial Reserves	Technical Revisions	Reserves (%) Change
TransGlobe Energy Corporation	12.61	8.77	70 %
Granite Oil Corp	0.95	0.37	39 %
Terra Energy Corp	24.09	2.70	11 %
Paramount Resources Ltd	22.24	1.19	5 %
Delphi Energy Corp	15.06	0.65	4 %
Crescent Point Energy Corp	132.15	4.55	3 %
ARC Resources Ltd.	241.15	7.60	3 %
Bellatrix Exploration Ltd.	23.31	0.64	3 %
NuVista Energy Ltd	52.71	0.89	2 %
Advantage Oil	101.37	1.31	1 %
Connacher Oil and Gas Limited	182.84	0.53	0 %
Niko Resources Ltd	190.36	0.04	0 %
Iron bridge -former RMP Energy Inc	10.49	-0.45	-4 %
Canacol Energy Ltd	0.35	-0.06	-17 %

Fig. C.3—Canadian companies proved reserves changes (%) for year 2009.



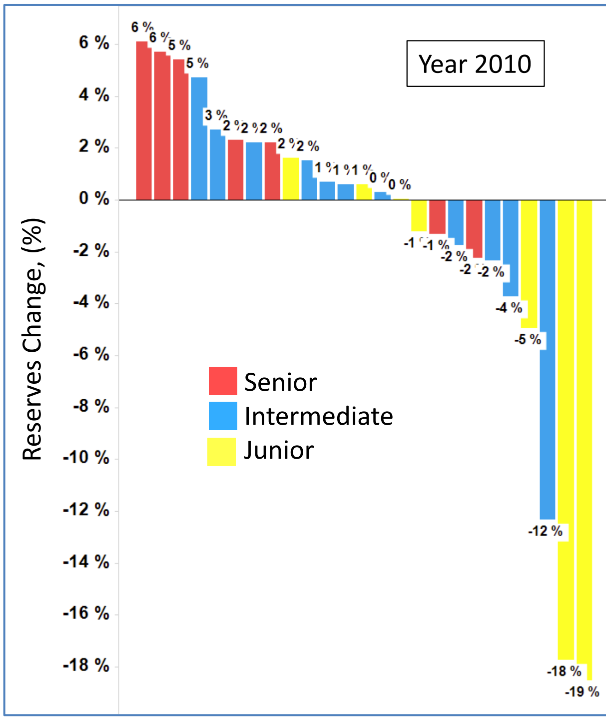
Company Name	2P Initial Reserves	Technical Revisions	2P Reserves (%) Change
Granite Oil Corp	1.18	0.44	37.8 %
TransGlobe Energy Corporation	19.79	5.09	25.7 %
Terra Energy Corp	31.24	1.75	5.6 %
ARC Resources Ltd.	319.11	6.65	2.1 %
Crescent Point Energy Corp	190.95	0.73	0.4 %
Paramount Resources Ltd	36.38	0.09	0.3 %
Niko Resources Ltd	275.08	0.04	0.0 %
Delphi Energy Corp	21.91	-0.09	-0.4 %
Bellatrix Exploration Ltd.	39.28	-0.23	-0.6 %
Advantage Oil	173.42	-3.10	-1.8 %
NuVista Energy Ltd	77.51	-1.88	-2.4 %
Connacher Oil and Gas Limited	379.47	-11.12	-2.9 %
Iron bridge -former RMP Energy Inc	17.75	-1.12	-6.3 %
Canacol Energy Ltd	1.34	-0.32	-24.2 %

Fig. C.4—Canadian companies proved-plus-probable reserves changes (%) for year 2009.



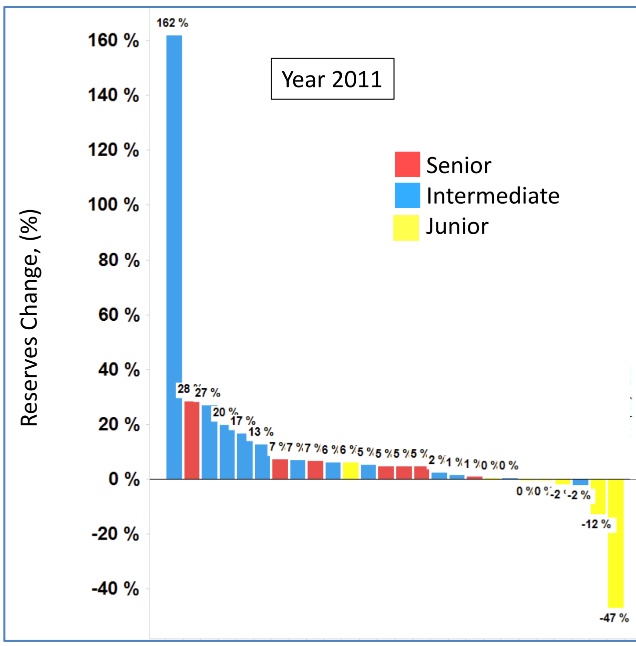
Company Name	Proved Initial Reserves	Technical Revisions	Reserves (%) Change
Advantage Oil	107.87	29.95	28 %
Canacol Energy Ltd	2.65	0.38	14 %
Whitecap Resources Inc.	2.83	0.36	13 %
Crescent Point Energy Corp	185.69	17.42	9 %
Paramount Resources Ltd	21.33	1.77	8 %
Terra Energy Corp	25.33	2.06	8 %
ARC Resources Ltd.	267.54	21.16	8 %
Bonavista Energy Corporation	193.19	11.46	6 %
Canadian Natural	4167.33	217.50	5 %
Surge Energy Inc	6.84	0.34	5 %
Cenovus Energy Inc	1415.17	66.00	5 %
TransGlobe Energy Corporation	19.25	0.83	4 %
NuVista Energy Ltd	67.84	2.79	4 %
Pengrowth Energy Corporation	215.55	8.50	4 %
Tourmaline Oil Corp	34.85	1.35	4 %
Vermilion Energy Inc	94.79	3.00	3 %
Peyto Exploration & Development Corp	148.86	3.48	2 %
Suncor Energy Inc.	1245.83	11.50	1 %
Connacher Oil and Gas Limited	180.16	0.38	0 %
Bellatrix Exploration Ltd.	16.49	-0.17	-1 %
Delphi Energy Corp	17.92	-0.19	-1 %
Husky Energy Inc	1004.32	-11.53	-1 %
Niko Resources Ltd	179.98	-2.00	-1 %
Iron bridge -former RMP Energy Inc	11.33	-0.22	-2 %
Granite Oil Corp	1.71	-0.30	-18 %

Fig. C.5—Canadian companies proved reserves changes (%) for year 2010.



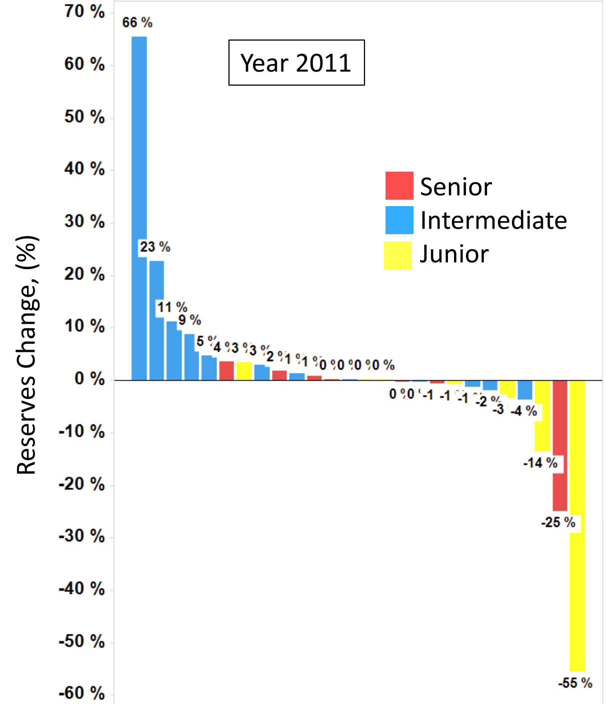
Company Name	2P Initial Reserves	Technical Revisions	2P Reserves (%) Change
ARC Resources Ltd.	376.53	23.12	6.1 %
Suncor Energy Inc.	3434.33	194.83	5.7 %
Tourmaline Oil Corp	59.36	3.21	5.4 %
Whitecap Resources Inc.	5.08	0.24	4.7 %
Peyto Exploration & Development ...	199.89	5.43	2.7 %
Canadian Natural	6345.67	146.33	2.3 %
Bonavista Energy Corporation	271.91	6.01	2.2 %
Crescent Point Energy Corp	281.64	6.21	2.2 %
Delphi Energy Corp	27.27	0.44	1.6 %
Pengrowth Energy Corporation	294.47	4.29	1.5 %
NuVista Energy Ltd	97.63	0.71	0.7 %
Paramount Resources Ltd	34.50	0.20	0.6 %
Terra Energy Corp	35.82	0.21	0.6 %
TransGlobe Energy Corporation	24.18	0.06	0.3 %
Connacher Oil and Gas Limited	388.91	0.05	0.0 %
Niko Resources Ltd	259.76	-3.12	-1.2 %
Husky Energy Inc	2410.68	-30.85	-1.3 %
Vermilion Energy Inc	138.02	-2.29	-1.7 %
Cenovus Energy Inc	2129.50	-46.67	-2.2 %
Advantage Oil	232.26	-5.32	-2.3 %
Bellatrix Exploration Ltd.	25.75	-0.96	-3.7 %
Surge Energy Inc	9.90	-0.48	-4.9 %
Canacol Energy Ltd	6.73	-0.83	-12.3 %
Iron bridge -former RMP Energy Inc	19.90	-3.53	-17.7 %
Granite Oil Corp	2.06	-0.38	-18.5 %

Fig. C.6—Canadian companies proved-plus-probable reserves changes (%) for year 2010.



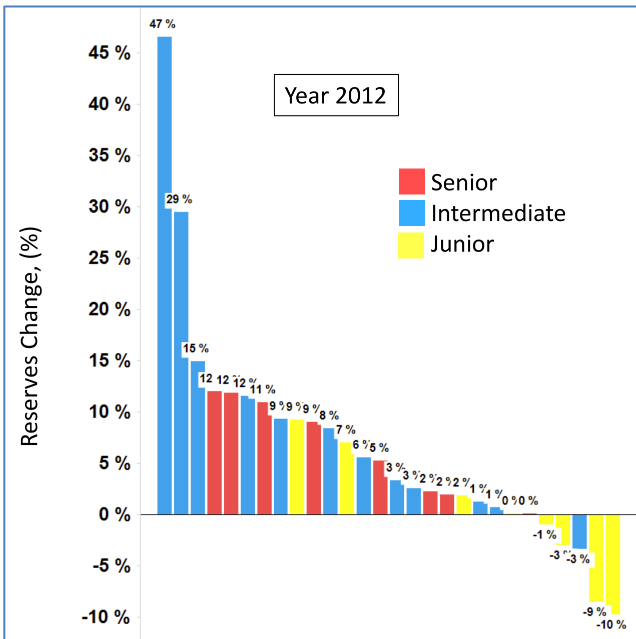
Company Name	Proved Initial Reserves	Technical Revisions	Reserves (%) Change
Canacol Energy Ltd	2.96	4.78	162 %
Suncor Energy Inc.	993.00	281.10	28 %
Whitecap Resources Inc.	8.26	2.22	27 %
Bellatrix Exploration Ltd.	24.84	4.88	20 %
Advantage Oil	143.37	23.85	17 %
TransGlobe Energy Corporation	20.46	2.58	13 %
ARC Resources Ltd.	334.44	23.96	7 %
Pengrowth Energy Corporation	220.32	15.48	7 %
Canadian Natural	4505.33	291.33	7 %
Paramount Resources Ltd	25.57	1.57	6 %
Delphi Energy Corp	22.64	1.34	6 %
Vermilion Energy Inc	96.42	4.92	5 %
Crescent Point Energy Corp	250.81	11.80	5 %
Tourmaline Oil Corp	93.01	4.36	5 %
Cenovus Energy Inc	1665.67	76.83	5 %
NuVista Energy Ltd	73.81	1.75	2 %
Bonavista Energy Corporation	222.91	3.07	1 %
Husky Energy Inc	1081.47	9.77	1 %
Niko Resources Ltd	128.05	0.15	0 %
Parex Resources Inc.	1.07	0.00	0 %
Connacher Oil and Gas Limited	186.67	-0.31	0 %
Granite Oil Corp	1.32	-0.01	0 %
Surge Energy Inc	14.36	-0.23	-2 %
Peyto Exploration & Development Corp	179.70	-3.64	-2 %
Terra Energy Corp	28.58	-3.55	-12 %
Iron bridge -former RMP Energy Inc	10.53	-4.92	-47 %

Fig. C.7—Canadian companies proved reserves changes (%) for year 2011.



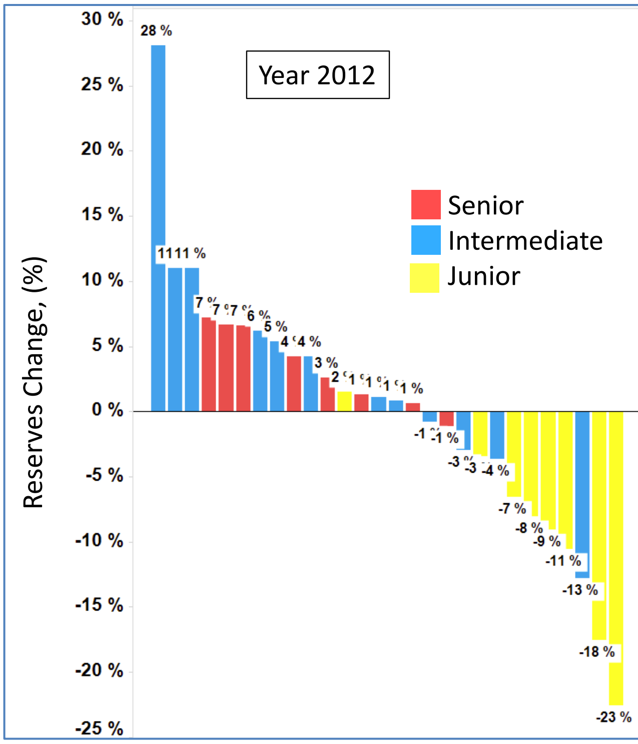
Company Name	2P Initial Reserves	Technical Revisions	2P Reserves (%) Change
Canacol Energy Ltd	8.13	5.33	65.5 %
Parex Resources Inc.	5.85	1.33	22.7 %
TransGlobe Energy Corporation	30.44	3.42	11.2 %
Whitecap Resources Inc.	13.68	1.19	8.7 %
Advantage Oil	243.66	11.76	4.8 %
ARC Resources Ltd.	485.13	17.22	3.6 %
Granite Oil Corp	1.59	0.05	3.4 %
Pengrowth Energy Corporation	317.51	9.24	2.9 %
Canadian Natural	6902.17	122.17	1.8 %
Vermilion Energy Inc	142.33	1.80	1.3 %
Tourmaline Oil Corp	158.18	1.44	0.9 %
Cenovus Energy Inc	2403.00	4.33	0.2 %
Bonavista Energy Corporation	310.74	0.39	0.1 %
Niko Resources Ltd	198.06	0.14	0.1 %
Delphi Energy Corp	34.41	0.01	0.0 %
Husky Energy Inc	2398.85	-3.47	-0.1 %
NuVista Energy Ltd	112.82	-0.35	-0.3 %
Crescent Point Energy Corp	379.54	-2.01	-0.5 %
Connacher Oil and Gas Limited	509.43	-2.91	-0.6 %
Bellatrix Exploration Ltd.	42.44	-0.45	-1.1 %
Peyto Exploration & Development ...	259.68	-4.45	-1.7 %
Surge Energy Inc	21.21	-0.68	-3.2 %
Paramount Resources Ltd	40.08	-1.43	-3.6 %
Terra Energy Corp	39.40	-5.31	-13.5 %
Suncor Energy Inc.	3315.70	-817.57	-24.7 %
Iron bridge -former RMP Energy Inc	16.68	-9.23	-55.4 %

Fig. C.8—Canadian companies proved-plus-probable reserves changes (%) for year 2011.



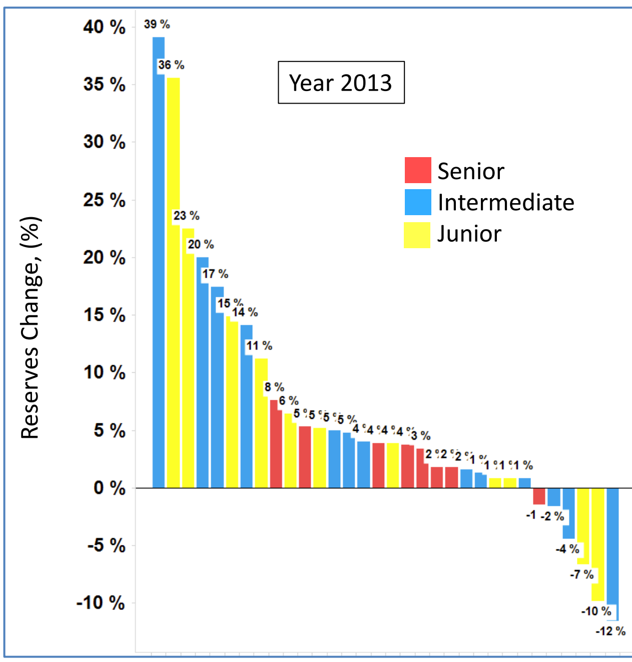
Company Name	Proved Initial Reserves	Technical Revisions	Reserves (%) Change
Canacol Energy Ltd	6.16	2.86	47 %
TransGlobe Energy Corporation	28.15	8.28	29 %
Advantage Oil	161.14	23.93	15 %
ARC Resources Ltd.	359.63	43.20	12 %
Suncor Energy Inc.	1299.68	153.13	12 %
Bellatrix Exploration Ltd.	41.76	4.82	12 %
Tourmaline Oil Corp	148.85	16.26	11 %
Whitecap Resources Inc.	25.62	2.39	9 %
Strategic Oil & Gas Ltd	3.22	0.30	9 %
Crescent Point Energy Corp	281.03	25.29	9 %
Paramount Resources Ltd	35.67	2.99	8 %
Niko Resources Ltd	35.14	2.45	7 %
Vermilion Energy Inc	96.50	5.30	6 %
Canadian Natural	4831.17	253.33	5 %
Pengrowth Energy Corporation	234.27	7.64	3 %
Bonavista Energy Corporation	231.76	5.79	3 %
Cenovus Energy Inc	1945.50	42.50	2 %
Husky Energy Inc	1172.30	22.35	2 %
Iron bridge -former RMP Energy Inc	14.40	0.26	2 %
Parex Resources Inc.	4.95	0.06	1 %
NuVista Energy Ltd	69.46	0.52	1 %
Connacher Oil and Gas Limited	176.99	0.00	0 %
Repsol Oil & Gas Canada Inc. ("ROGCI")	1487.22	0.62	0 %
Surge Energy Inc	20.52	-0.19	-1 %
Terra Energy Corp	28.13	-0.82	-3 %
Peyto Exploration & Development Corp	225.17	-7.37	-3 %
Granite Oil Corp	7.40	-0.63	-9 %
Delphi Energy Corp	25.01	-2.42	-10 %

Fig. C.9—Canadian companies proved reserves changes (%) for year 2012.



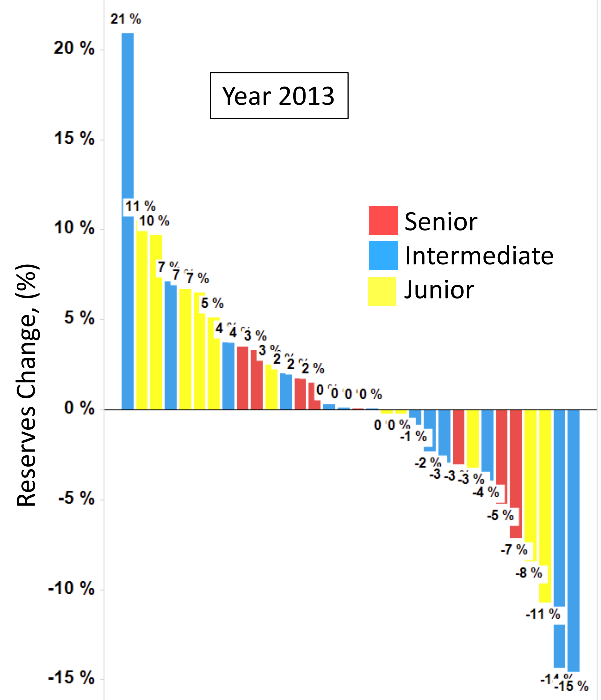
Company Name	2P Initial Reserves	Technical Revisions	2P Reserves (%) Change
Canacol Energy Ltd	10.93	3.08	28.1 %
Advantage Oil	255.44	28.16	11.0 %
TransGlobe Energy Corporation	44.21	4.86	11.0 %
ARC Resources Ltd.	572.37	41.30	7.2 %
Tourmaline Oil Corp	269.80	18.09	6.7 %
Suncor Energy Inc.	2553.85	167.67	6.6 %
Bellatrix Exploration Ltd.	67.44	4.19	6.2 %
Vermilion Energy Inc	146.23	7.96	5.4 %
Crescent Point Energy Corp	424.78	17.69	4.2 %
Whitecap Resources Inc.	38.58	1.62	4.2 %
Cenovus Energy Inc	2660.67	68.50	2.6 %
Iron bridge -former RMP Energy Inc	22.68	0.34	1.5 %
Canadian Natural	7537.83	101.33	1.3 %
Pengrowth Energy Corporation	329.69	3.53	1.1 %
Bonavista Energy Corporation	341.39	2.72	0.8 %
Husky Energy Inc	2850.68	17.18	0.6 %
NuVista Energy Ltd	109.66	-0.75	-0.7 %
Repsol Oil & Gas Canada Inc. ("R...	2222.22	-24.20	-1.1 %
Paramount Resources Ltd	53.02	-1.53	-2.9 %
Strategic Oil & Gas Ltd	5.27	-0.18	-3.4 %
Peyto Exploration & Development ...	322.26	-11.63	-3.6 %
Granite Oil Corp	9.69	-0.63	-6.5 %
Delphi Energy Corp	40.10	-3.22	-8.0 %
Connacher Oil and Gas Limited	503.75	-45.11	-9.0 %
Terra Energy Corp	41.15	-4.31	-10.5 %
Parex Resources Inc.	10.71	-1.36	-12.7 %
Surge Energy Inc	32.21	-5.62	-17.5 %
Niko Resources Ltd	62.31	-14.01	-22.5 %

Fig. C.10—Canadian companies proved-plus-probable reserves changes (%) for year 2012.



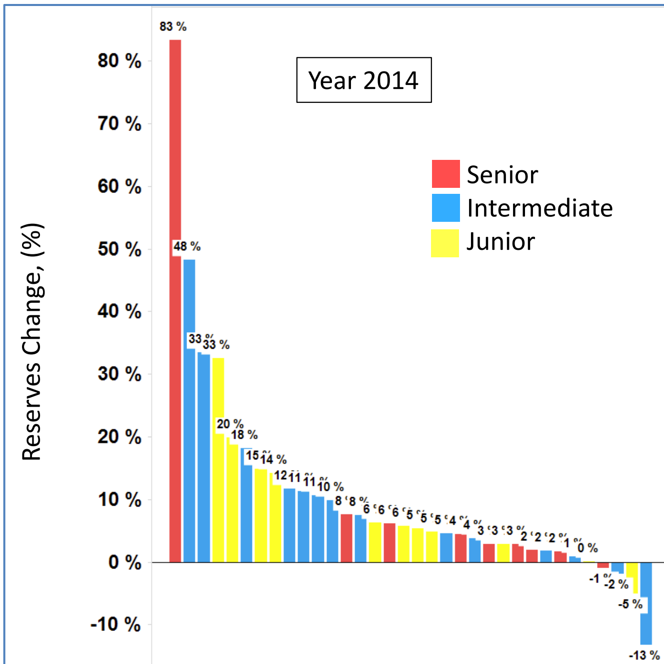
Company Name	Proved Initial Reserves	Technical Revisions	Reserves (%) Change
Parex Resources Inc.	10.06	3.93	39 %
Strategic Oil & Gas Ltd	4.02	1.43	36 %
Granite Oil Corp	14.36	3.23	23 %
Bellatrix Exploration Ltd.	55.22	11.05	20 %
Vermilion Energy Inc	105.26	18.35	17 %
Niko Resources Ltd	61.14	9.08	15 %
Paramount Resources Ltd	50.85	7.18	14 %
PetroShale Inc	0.35	0.04	11 %
Crescent Point Energy Corp	400.37	30.35	8 %
Delphi Energy Corp	23.74	1.52	6 %
ARC Resources Ltd.	363.91	19.18	5 %
Terra Energy Corp	33.13	1.72	5 %
Advantage Oil	193.94	9.73	5 %
NuVista Energy Ltd	59.15	2.82	5 %
Whitecap Resources Inc.	60.89	2.45	4 %
Husky Energy Inc	1192.00	46.98	4 %
Iron bridge -former RMP Energy Inc	14.86	0.58	4 %
Suncor Energy Inc.	1469.17	54.33	4 %
Canadian Natural	5018.33	170.83	3 %
Cenovus Energy Inc	2175.17	38.67	2 %
Tourmaline Oil Corp	249.08	4.58	2 %
Pengrowth Energy Corporation	299.25	4.85	2 %
Bonavista Energy Corporation	248.41	3.24	1 %
Connacher Oil and Gas Limited	214.01	1.79	1 %
Jura Energy Corp.	10.59	0.09	1 %
Raging River Exploration Inc.	11.54	0.10	1 %
Repsol Oil & Gas Canada Inc. ("ROGCI")	1090.72	-15.78	-1 %
TransGlobe Energy Corporation	32.77	-0.50	-2 %
Peyto Exploration & Development Corp	276.35	-12.26	-4 %
Cardinal Energy Inc	2.68	-0.18	-7 %
Surge Energy Inc	28.14	-2.77	-10 %
Canacol Energy Ltd	11.31	-1.30	-12 %

Fig. C.11—Canadian companies proved reserves changes (%) for year 2013.



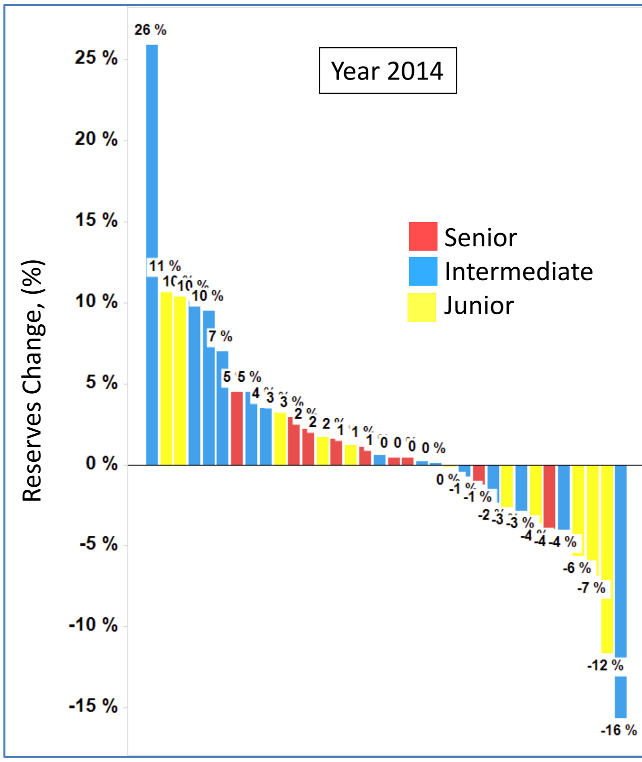
Company Name	2P Initial Reserves	Technical Revisions	2P Reserves (%) Change
Parex Resources Inc.	16.10	3.36	20.9 %
PetroShale Inc	0.37	0.04	10.5 %
Granite Oil Corp	20.19	1.96	9.7 %
Vermilion Energy Inc	164.87	11.77	7.1 %
Iron bridge -former RMP Energy Inc	26.79	1.80	6.7 %
Delphi Energy Corp	42.99	2.78	6.5 %
Niko Resources Ltd	97.74	5.01	5.1 %
Advantage Oil	310.05	11.47	3.7 %
ARC Resources Ltd.	606.98	21.34	3.5 %
Crescent Point Energy Corp	608.80	20.10	3.3 %
Terra Energy Corp	45.03	1.11	2.5 %
NuVista Energy Ltd	94.07	1.85	2.0 %
Husky Energy Inc	2915.28	48.55	1.7 %
Tourmaline Oil Corp	437.87	6.43	1.5 %
Raging River Exploration Inc.	17.16	0.05	0.3 %
Whitecap Resources Inc.	87.45	0.05	0.1 %
Canadian Natural	7885.50	0.83	0.0 %
Pengrowth Energy Corporation	510.91	0.09	0.0 %
Connacher Oil and Gas Limited	451.40	-0.70	-0.2 %
Jura Energy Corp.	32.36	-0.07	-0.2 %
Bonavista Energy Corporation	372.22	-3.14	-0.8 %
Paramount Resources Ltd	179.93	-4.16	-2.3 %
Peyto Exploration & Development ...	391.99	-11.55	-2.9 %
Cenovus Energy Inc	3068.50	-91.50	-3.0 %
Strategic Oil & Gas Ltd	8.18	-0.27	-3.2 %
Bellatrix Exploration Ltd.	103.73	-4.05	-3.9 %
Suncor Energy Inc.	2640.83	-137.17	-5.2 %
Repsol Oil & Gas Canada Inc. ("R...	1709.68	-121.47	-7.1 %
Cardinal Energy Inc	3.52	-0.29	-8.4 %
Surge Energy Inc	46.12	-4.94	-10.7 %
Canacol Energy Ltd	17.79	-2.55	-14.3 %
TransGlobe Energy Corporation	48.72	-7.16	-14.7 %

Fig. C.12—Canadian companies proved-plus-probable reserves changes (%) for year 2013.



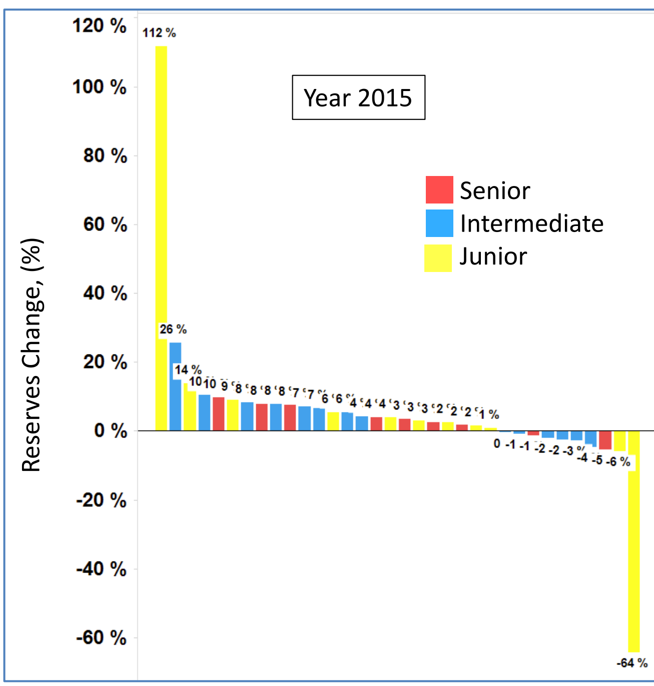
Company Name	Proved Initial Reserves	Technical Revisions	Reserves (%) Change
Seven Generations Energy Ltd.	107.22	89.33	83 %
Parex Resources Inc.	17.16	8.27	48 %
Canacol Energy Ltd	24.85	8.29	33 %
PetroShale Inc	0.55	0.18	33 %
Strategic Oil & Gas Ltd	6.69	1.33	20 %
Kelt Exploration Ltd.	35.18	6.36	18 %
Cardinal Energy Inc	13.75	2.03	15 %
Iron bridge -former RMP Energy Inc	19.76	2.81	14 %
Advantage Oil	178.47	20.95	12 %
Bellatrix Exploration Ltd.	124.11	14.07	11 %
NuVista Energy Ltd	80.46	8.59	11 %
Raging River Exploration Inc.	31.38	3.06	10 %
Crescent Point Energy Corp	432.77	32.69	8 %
Vermilion Energy Inc	128.95	9.64	8 %
Surge Energy Inc	43.50	2.76	6 %
Tourmaline Oil Corp	316.29	19.58	6 %
Delphi Energy Corp	36.09	2.04	6 %
Niko Resources Ltd	64.50	3.49	5 %
Jura Energy Corp.	10.75	0.53	5 %
Paramount Resources Ltd	87.67	4.07	5 %
ARC Resources Ltd.	373.98	16.50	4 %
Bonavista Energy Corporation	256.22	9.68	4 %
Cenovus Energy Inc	2284.17	67.33	3 %
Terra Energy Corp	54.10	1.58	3 %
Suncor Energy Inc.	1966.50	55.83	3 %
Canadian Natural	5137.50	95.50	2 %
Pengrowth Energy Corporation	306.45	5.65	2 %
Husky Energy Inc	1264.70	21.68	2 %
Whitecap Resources Inc.	94.58	0.84	1 %
Connacher Oil and Gas Limited	212.06	0.13	0 %
Repsol Oil & Gas Canada Inc. ("ROGCI")	1104.43	-8.43	-1 %
Peyto Exploration & Development Corp	304.44	-5.55	-2 %
Granite Oil Corp	26.29	-1.28	-5 %
TransGlobe Energy Corporation	31.63	-4.14	-13 %

Fig. C.13—Canadian companies proved reserves changes (%) for year 2014.



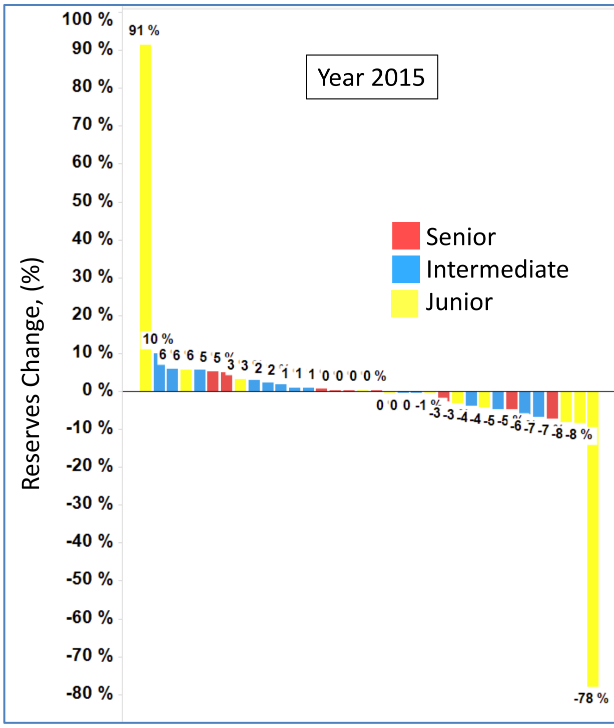
Company Name	2P Initial Reserves	Technical Revisions	2P Reserves (%) Change
Parex Resources Inc.	31.43	8.15	25.9 %
Iron bridge -former RMP Energy Inc	31.67	3.57	11.3 %
PetroShale Inc	0.70	0.07	10.4 %
Canacol Energy Ltd	37.86	3.81	10.1 %
Kelt Exploration Ltd.	59.03	5.61	9.5 %
NuVista Energy Ltd	139.23	9.70	7.0 %
Tourmaline Oil Corp	589.90	26.28	4.5 %
Vermilion Energy Inc	200.25	8.95	4.5 %
Advantage Oil	289.84	10.04	3.5 %
Delphi Energy Corp	61.60	1.95	3.2 %
Seven Generations Energy Ltd.	283.25	8.33	2.9 %
Crescent Point Energy Corp	663.76	14.75	2.2 %
Jura Energy Corp.	32.38	0.54	1.7 %
ARC Resources Ltd.	633.87	9.93	1.6 %
Strategic Oil & Gas Ltd	12.71	0.15	1.2 %
Cenovus Energy Inc	3207.17	34.50	1.1 %
Whitecap Resources Inc.	132.30	0.75	0.6 %
Canadian Natural	7991.17	29.83	0.4 %
Husky Energy Inc	3126.73	11.00	0.4 %
Pengrowth Energy Corporation	476.64	1.11	0.2 %
Bonavista Energy Corporation	398.53	0.36	0.1 %
Connacher Oil and Gas Limited	446.38	-0.29	-0.1 %
Raging River Exploration Inc.	42.73	-0.31	-0.7 %
Repsol Oil & Gas Canada Inc. ("R...	1640.37	-19.95	-1.2 %
Peyto Exploration & Development ...	467.76	-10.59	-2.3 %
Cardinal Energy Inc	21.16	-0.54	-2.6 %
Bellatrix Exploration Ltd.	211.48	-5.86	-2.8 %
Surge Energy Inc	73.46	-2.61	-3.6 %
Suncor Energy Inc.	3108.33	-122.67	-3.9 %
Paramount Resources Ltd	227.28	-9.02	-4.0 %
Niko Resources Ltd	98.56	-5.48	-5.6 %
Terra Energy Corp	74.98	-5.08	-6.8 %
Granite Oil Corp	39.41	-4.55	-11.6 %
TransGlobe Energy Corporation	45.28	-7.06	-15.6 %

Fig. C.14—Canadian companies proved-plus-probable reserves changes (%) for year 2014.



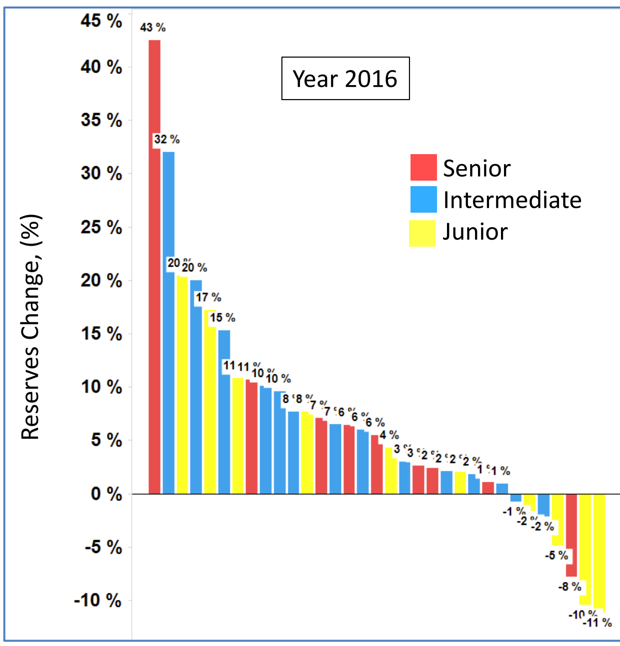
Company Name	Proved Initial Reserves	Technical Revisions	Reserves (%) Change
PetroShale Inc	6.60	7.37	112 %
Parex Resources Inc.	40.42	10.36	26 %
Niko Resources Ltd	36.26	4.99	14 %
Kelt Exploration Ltd.	61.10	6.34	10 %
ARC Resources Ltd.	382.07	37.37	10 %
Cardinal Energy Inc	32.08	2.91	9 %
Advantage Oil	192.06	15.76	8 %
Tourmaline Oil Corp	471.99	37.32	8 %
Paramount Resources Ltd	226.82	17.68	8 %
Seven Generations Energy Ltd.	420.66	31.49	8 %
TransGlobe Energy Corporation	22.14	1.54	7 %
Canacol Energy Ltd	49.36	3.31	7 %
Strategic Oil & Gas Ltd	7.20	0.40	6 %
Vermilion Energy Inc	151.50	8.40	6 %
Whitecap Resources Inc.	154.23	6.34	4 %
Crescent Point Energy Corp	528.12	21.21	4 %
Iron bridge -former RMP Energy Inc	25.61	1.00	4 %
Cenovus Energy Inc	2378.67	80.17	3 %
Granite Oil Corp	35.29	1.01	3 %
Repsol Oil & Gas Canada Inc. ("ROGCI")	871.88	21.43	3 %
Terra Energy Corp	62.80	1.52	2 %
Canadian Natural	5511.17	94.00	2 %
Surge Energy Inc	68.33	1.12	2 %
Connacher Oil and Gas Limited	219.29	1.74	1 %
Peyto Exploration & Development Corp	347.42	-1.45	0 %
Bellatrix Exploration Ltd.	160.59	-0.77	-1 %
Husky Energy Inc	1278.83	-13.50	-1 %
Bonavista Energy Corporation	275.73	-5.15	-2 %
Pengrowth Energy Corporation	309.54	-6.86	-2 %
Raging River Exploration Inc.	49.93	-1.28	-3 %
NuVista Energy Ltd	110.54	-4.87	-4 %
Suncor Energy Inc.	1956.33	-101.17	-5 %
Delphi Energy Corp	42.90	-2.46	-6 %
Jura Energy Corp.	12.60	-8.07	-64 %

Fig. C.15—Canadian companies proved reserves changes (%) for year 2015.



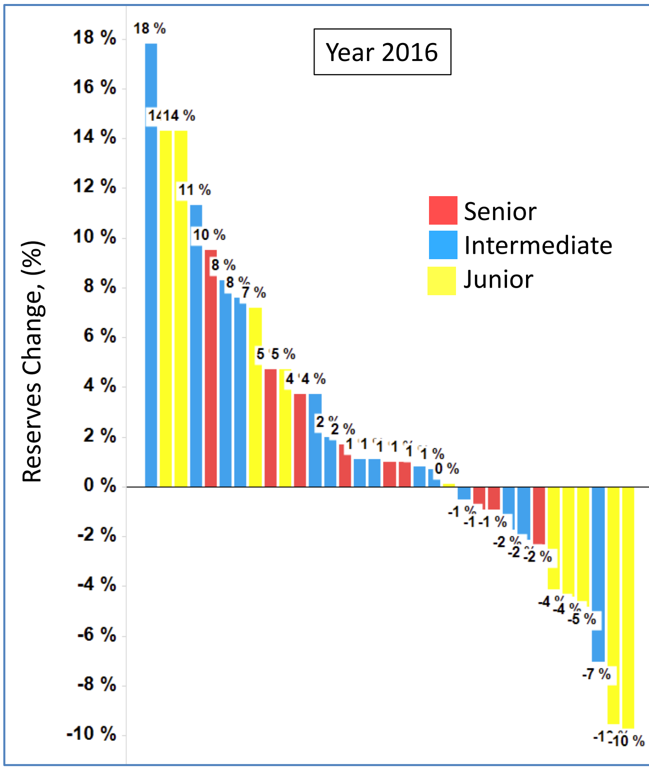
Company Name	2P Initial Reserves	Technical Revisions	2P Reserves (%) Change
PetroShale Inc	10.26	9.38	91.4 %
Parex Resources Inc.	68.42	6.81	10.0 %
Kelt Exploration Ltd.	99.11	5.92	6.0 %
Cardinal Energy Inc	43.03	2.42	5.6 %
TransGlobe Energy Corporation	33.48	1.88	5.6 %
ARC Resources Ltd.	672.74	35.95	5.3 %
Tourmaline Oil Corp	855.41	42.52	5.0 %
Iron bridge -former RMP Energy Inc	41.97	1.31	3.1 %
Advantage Oil	300.56	8.98	3.0 %
Canacol Energy Ltd	76.68	1.68	2.2 %
Paramount Resources Ltd	440.55	8.06	1.8 %
Vermilion Energy Inc	246.88	2.02	0.8 %
Whitecap Resources Inc.	218.18	1.68	0.8 %
Seven Generations Energy Ltd.	788.63	5.20	0.7 %
Repsol Oil & Gas Canada Inc. ("R...	1381.20	4.43	0.3 %
Canadian Natural	8891.33	15.50	0.2 %
Connacher Oil and Gas Limited	441.03	1.06	0.2 %
Crescent Point Energy Corp	807.39	-0.31	0.0 %
Granite Oil Corp	51.70	-0.06	-0.1 %
Peyto Exploration & Development ...	531.44	-0.62	-0.1 %
NuVista Energy Ltd	218.81	-0.60	-0.3 %
Terra Energy Corp	80.25	-0.38	-0.5 %
Husky Energy Inc	3149.20	-77.45	-2.5 %
Niko Resources Ltd	91.04	-2.61	-2.9 %
Bonavista Energy Corporation	426.77	-15.19	-3.6 %
Surge Energy Inc	112.04	-4.67	-4.2 %
Raging River Exploration Inc.	63.56	-2.89	-4.5 %
Cenovus Energy Inc	3921.00	-180.83	-4.6 %
Pengrowth Energy Corporation	556.65	-33.16	-6.0 %
Bellatrix Exploration Ltd.	248.87	-16.43	-6.6 %
Suncor Energy Inc.	2926.33	-204.67	-7.0 %
Strategic Oil & Gas Ltd	13.93	-1.11	-8.0 %
Delphi Energy Corp	74.33	-6.03	-8.1 %
Jura Energy Corp.	35.17	-27.35	-77.8 %

Fig. C.16—Canadian companies proved-plus-probable reserves changes (%) for year 2015.



Company Name	Proved Initial Reserves	Technical Revisions	Reserves (%) Change
Seven Generations Energy Ltd.	423.96	180.19	43 %
TransGlobe Energy Corporation	17.50	5.60	32 %
PetroShale Inc	19.45	3.97	20 %
Parex Resources Inc.	46.01	9.22	20 %
Cardinal Energy Inc	43.99	7.59	17 %
Advantage Oil	213.19	32.66	15 %
Strategic Oil & Gas Ltd	6.53	0.71	11 %
ARC Resources Ltd.	393.33	42.04	11 %
Vermilion Energy Inc	160.70	16.24	10 %
Kelt Exploration Ltd.	83.83	8.08	10 %
Canacol Energy Ltd	50.75	3.92	8 %
Terra Energy Corp	70.68	5.46	8 %
Husky Energy Inc	1324.10	93.55	7 %
Bellatrix Exploration Ltd.	143.50	9.30	7 %
Canadian Natural	5712.67	364.17	6 %
Paramount Resources Ltd	226.35	13.60	6 %
Crescent Point Energy Corp	592.06	32.43	6 %
Granite Oil Corp	11.17	0.48	4 %
Pengrowth Energy Corporation	251.75	7.61	3 %
Cenovus Energy Inc	2546.17	67.17	3 %
Tourmaline Oil Corp	644.06	15.71	2 %
Whitecap Resources Inc.	199.61	4.12	2 %
Surge Energy Inc	52.78	1.04	2 %
NuVista Energy Ltd	117.89	2.11	2 %
Repsol Oil & Gas Canada Inc. ("ROGCI")	798.95	8.87	1 %
Peyto Exploration & Development Corp	374.80	3.53	1 %
Bonavista Energy Corporation	262.22	-1.79	-1 %
Iron bridge -former RMP Energy Inc	25.27	-0.41	-2 %
Raging River Exploration Inc.	57.39	-1.23	-2 %
Delphi Energy Corp	23.89	-1.15	-5 %
Suncor Energy Inc.	2029.67	-156.00	-8 %
Jura Energy Corp.	4.00	-0.42	-10 %
Niko Resources Ltd	27.14	-3.00	-11 %

Fig. C.17—Canadian companies proved reserves changes (%) for year 2016.

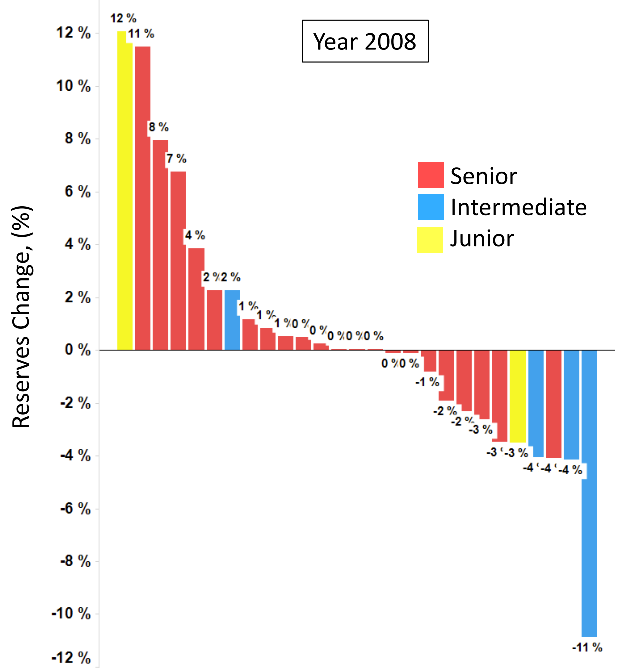


Company Name	2P Initial Reserves	Technical Revisions	2P Reserves (%) Change
TransGlobe Energy Corporation	28.70	5.10	17.8 %
Cardinal Energy Inc	59.53	8.48	14.3 %
PetroShale Inc	25.48	3.63	14.3 %
Parex Resources Inc.	81.68	9.22	11.3 %
Seven Generations Energy Ltd.	859.12	81.72	9.5 %
Kelt Exploration Ltd.	150.51	12.46	8.3 %
Advantage Oil	325.35	24.65	7.6 %
Strategic Oil & Gas Ltd	12.74	0.91	7.2 %
ARC Resources Ltd.	686.84	32.55	4.7 %
Terra Energy Corp	90.62	4.26	4.7 %
Husky Energy Inc	2912.23	106.60	3.7 %
Vermilion Energy Inc	260.89	9.73	3.7 %
Paramount Resources Ltd	431.09	8.62	2.0 %
Canadian Natural	9041.00	157.17	1.7 %
Bellatrix Exploration Ltd.	222.63	2.37	1.1 %
Pengrowth Energy Corporation	568.70	6.48	1.1 %
Crescent Point Energy Corp	935.66	9.50	1.0 %
Tourmaline Oil Corp	1108.28	10.66	1.0 %
NuVista Energy Ltd	252.73	1.90	0.8 %
Peyto Exploration & Development ...	589.81	4.12	0.7 %
Granite Oil Corp	17.70	0.02	0.1 %
Whitecap Resources Inc.	278.39	-1.45	-0.5 %
Repsol Oil & Gas Canada Inc. ("R...	1237.22	-10.65	-0.9 %
Suncor Energy Inc.	3088.83	-28.67	-0.9 %
Canacol Energy Ltd	75.97	-1.28	-1.7 %
Bonavista Energy Corporation	406.49	-8.48	-2.1 %
Cenovus Energy Inc	3830.83	-87.17	-2.3 %
Iron bridge -former RMP Energy Inc	38.54	-1.56	-4.1 %
Jura Energy Corp.	7.25	-0.32	-4.4 %
Surge Energy Inc	85.84	-4.10	-4.8 %
Raging River Exploration Inc.	76.36	-5.38	-7.0 %
Delphi Energy Corp	45.46	-4.31	-9.5 %
Niko Resources Ltd	47.67	-4.62	-9.7 %

Fig. C.18—Canadian companies proved-plus-probable reserves changes (%) for year 2016.

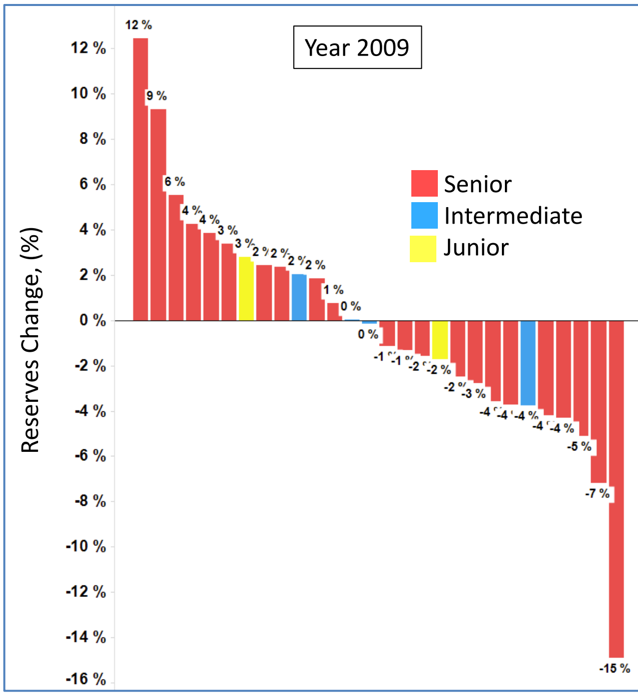
APPENDIX D

U.S. COMPANIES 1P RESERVES CHANGES (%) BY YEAR



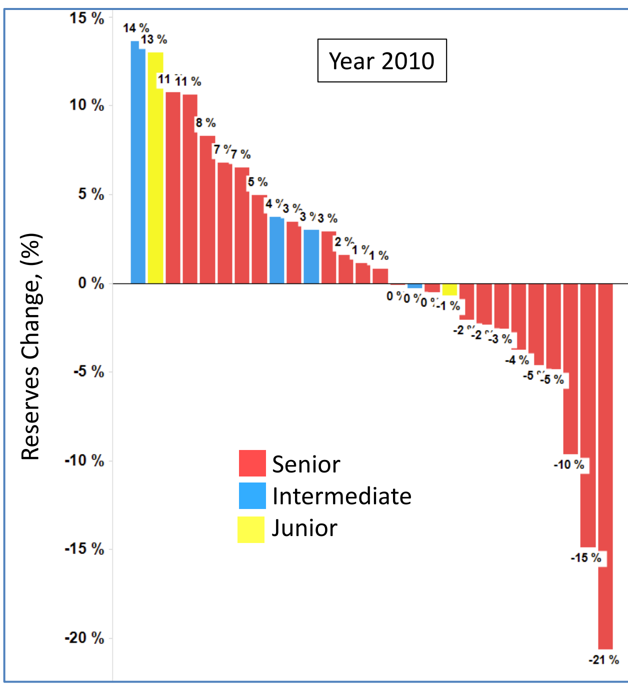
Company Name	1P Initial	ROTP	ROTP % change
DORCHESTER MINERALS, L.P.	14	2	12 %
CHESAPEAKE ENERGY CORP	1813	208	11 %
ANADARKO PETROLEUM CORP	2431	193	8 %
SOUTHWESTERN ENERGY CO	242	16	7 %
PIONEER NATURAL RESOURC...	964	37	4 %
WHITING PETROLEUM CORP	251	6	2 %
PDC ENERGY, INC.	114	3	2 %
DEVON ENERGY CORP/DE	2496	29	1 %
ENCANA CORP	2548	21	1 %
EOG RESOURCES INC	1291	7	1 %
QEP RESOURCES, INC.	311	2	0 %
NOBLE ENERGY INC	880	2	0 %
EQT CORP	447	0	0 %
CABOT OIL & GAS CORP	269	0	0 %
CONTINENTAL RESOURCES, INC	135	0	0 %
NEWFIELD EXPLORATION CO /...	416	0	0 %
LINN ENERGY, INC.	236	0	0 %
CIMAREX ENERGY CO	245	-2	-1 %
RANGE RESOURCES CORP	372	-7	-2 %
CNX RESOURCES CORP	223	-5	-2 %
APACHE CORP	2446	-64	-3 %
CONCHO RESOURCES INC	91	-3	-3 %
APPROACH RESOURCES INC	30	-1	-3 %
DENBURY RESOURCES INC	195	-8	-4 %
SM ENERGY CO	181	-7	-4 %
ENERGEN CORP	292	-12	-4 %
OASIS PETROLEUM INC.	4	0	-11 %

Fig. D.1—U.S. companies proved reserves changes (%) for year 2008.



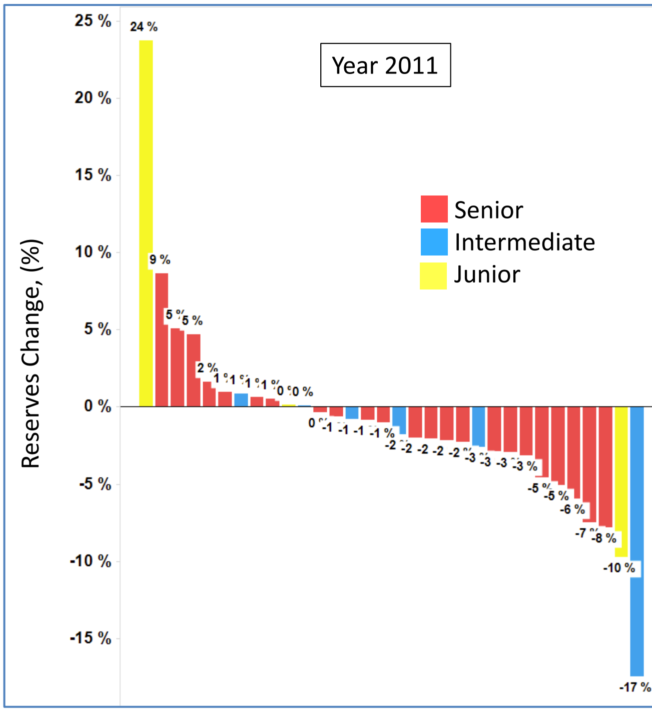
Company Name	1P Initial	ROTP	ROTP % change
CNX RESOURCES CORP	237	30	12 %
ANADARKO PETROLEUM CORP	2277	212	9 %
CIMAREX ENERGY CO	223	12	6 %
SOUTHWESTERN ENERGY CO	364	15	4 %
PIONEER NATURAL RESOURC...	960	37	4 %
RANGE RESOURCES CORP	442	15	3 %
DORCHESTER MINERALS, L.P.	14	0	3 %
WHITING PETROLEUM CORP	239	6	2 %
LINN ENERGY, INC.	277	7	2 %
PDC ENERGY, INC.	126	3	2 %
DEVON ENERGY CORP/DE	1999	37	2 %
CONTINENTAL RESOURCES, INC	159	1	1 %
OASIS PETROLEUM INC.	2	0	0 %
DENBURY RESOURCES INC	250	0	0 %
EOG RESOURCES INC	1448	-16	-1 %
EQT CORP	518	-7	-1 %
APACHE CORP	2401	-37	-2 %
APPROACH RESOURCES INC	35	-1	-2 %
CONCHO RESOURCES INC	137	-3	-2 %
ENCANA CORP	2617	-72	-3 %
QEP RESOURCES, INC.	370	-13	-4 %
CHESAPEAKE ENERGY CORP	2008	-74	-4 %
ENERGEN CORP	264	-10	-4 %
NEWFIELD EXPLORATION CO /...	492	-20	-4 %
NOBLE ENERGY INC	864	-37	-4 %
CABOT OIL & GAS CORP	324	-16	-5 %
SM ENERGY CO	144	-10	-7 %
WPX ENERGY, INC.	760	-113	-15 %

Fig. D.2—U.S. companies proved reserves changes (%) for year 2009.



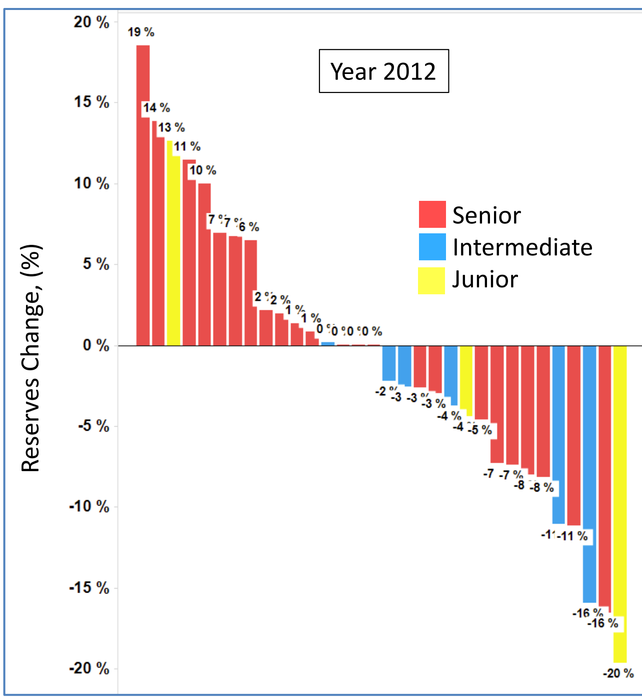
Company Name	1P Initial	ROTP	ROTP % change
OASIS PETROLEUM INC.	13	2	14 %
DORCHESTER MINERALS, L.P.	13	2	13 %
CONTINENTAL RESOURCES, INC	257	28	11 %
ANADARKO PETROLEUM CORP	2304	245	11 %
SOUTHWESTERN ENERGY CO	609	51	8 %
CIMAREX ENERGY CO	256	17	7 %
ENCANA CORP	1920	125	7 %
CABOT OIL & GAS CORP	343	17	5 %
PDC ENERGY, INC.	120	4	4 %
RANGE RESOURCES CORP	521	18	3 %
DENBURY RESOURCES INC	208	6	3 %
QEP RESOURCES, INC.	458	13	3 %
WHITING PETROLEUM CORP	275	4	2 %
DEVON ENERGY CORP/DE	2330	26	1 %
PIONEER NATURAL RESOURC...	899	7	1 %
CHESAPEAKE ENERGY CORP	2376	-1	0 %
ENERGEN CORP	258	-1	0 %
APACHE CORP	2367	-11	0 %
APPROACH RESOURCES INC	36	0	-1 %
WPX ENERGY, INC.	793	-16	-2 %
SM ENERGY CO	129	-3	-2 %
CONCHO RESOURCES INC	212	-5	-3 %
EOG RESOURCES INC	1796	-66	-4 %
LINN ENERGY, INC.	285	-13	-5 %
NOBLE ENERGY INC	820	-40	-5 %
NEWFIELD EXPLORATION CO /...	603	-58	-10 %
EQT CORP	678	-101	-15 %
CNX RESOURCES CORP	319	-66	-21 %

Fig. D.3—U.S. companies proved reserves changes (%) for year 2010.



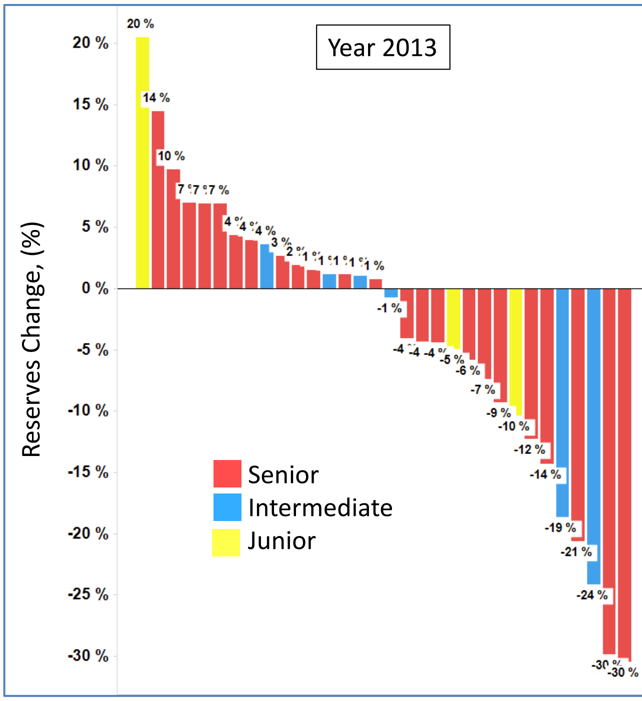
Company Name	1P Initial	ROTP	ROTP % change
DORCHESTER MINERALS, L.P.	14	3	24 %
ANADARKO PETROLEUM CORP	2422	210	9 %
RANGE RESOURCES CORP	740	37	5 %
WHITING PETROLEUM CORP	305	14	5 %
SM ENERGY CO	164	3	2 %
CABOT OIL & GAS CORP	450	4	1 %
EP ENERGY CORP	528	5	1 %
CONTINENTAL RESOURCES, INC	365	2	1 %
SOUTHWESTERN ENERGY CO	823	4	1 %
APPROACH RESOURCES INC	51	0	0 %
BONANZA CREEK ENERGY, INC.	33	0	0 %
CHESAPEAKE ENERGY CORP	2849	-9	0 %
CIMAREX ENERGY CO	314	-2	-1 %
OASIS PETROLEUM INC.	40	0	-1 %
QEP RESOURCES, INC.	505	-4	-1 %
PIONEER NATURAL RESOURC...	1011	-10	-1 %
DENBURY RESOURCES INC	398	-7	-2 %
CNX RESOURCES CORP	622	-12	-2 %
APACHE CORP	2953	-59	-2 %
DEVON ENERGY CORP/DE	2434	-52	-2 %
EOG RESOURCES INC	1950	-43	-2 %
ENERGEN CORP	303	-8	-3 %
ENCANA CORP	2309	-65	-3 %
WPX ENERGY, INC.	772	-22	-3 %
CONCHO RESOURCES INC	323	-10	-3 %
NOBLE ENERGY INC	1092	-49	-5 %
ANTERO RESOURCES CORP	539	-27	-5 %
LINN ENERGY, INC.	433	-25	-6 %
EQT CORP	870	-65	-7 %
NEWFIELD EXPLORATION CO /...	619	-48	-8 %
CONTANGO OIL & GAS CO	50	-5	-10 %
PDC ENERGY, INC.	143	-25	-17 %

Fig. D.4—U.S. companies proved reserves changes (%) for year 2011.



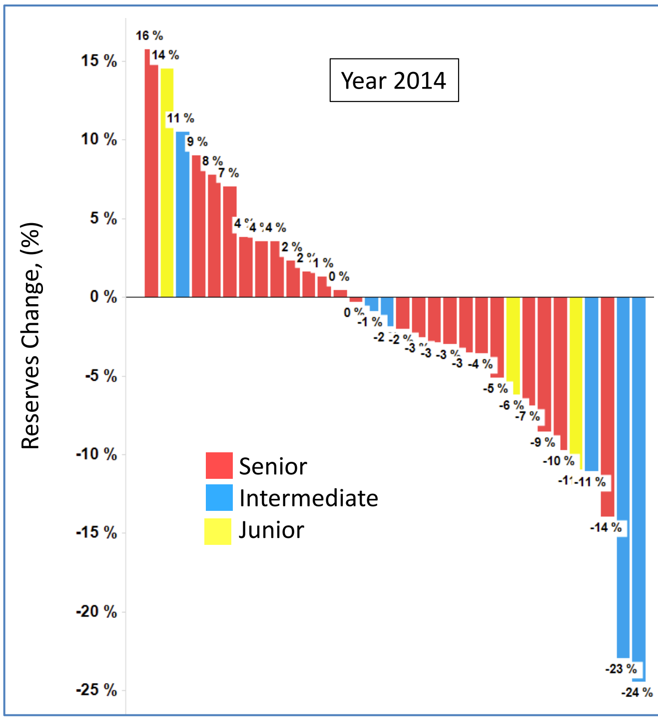
Company Name	1P Initial	ROTP	ROTP % change
QEP RESOURCES, INC.	602	112	19 %
ANADARKO PETROLEUM CORP	2539	352	14 %
DORCHESTER MINERALS, L.P.	15	2	13 %
ENCANA CORP	2273	261	11 %
CABOT OIL & GAS CORP	505	50	10 %
CNX RESOURCES CORP	580	40	7 %
EOG RESOURCES INC	2054	138	7 %
ANTERO RESOURCES CORP	836	54	6 %
RANGE RESOURCES CORP	842	18	2 %
NEWFIELD EXPLORATION CO /...	652	13	2 %
WHITING PETROLEUM CORP	345	5	1 %
CONTINENTAL RESOURCES, INC	508	4	1 %
EP ENERGY CORP	620	1	0 %
APACHE CORP	2990	0	0 %
EQT CORP	894	0	0 %
WPX ENERGY, INC.	845	0	0 %
DENBURY RESOURCES INC	462	-10	-2 %
OASIS PETROLEUM INC.	79	-2	-3 %
PIONEER NATURAL RESOURC...	1063	-27	-3 %
DEVON ENERGY CORP/DE	2548	-74	-3 %
ENERGEN CORP	343	-13	-4 %
CONTANGO OIL & GAS CO	43	-2	-4 %
CONCHO RESOURCES INC	387	-18	-5 %
CHESAPEAKE ENERGY CORP	3131	-226	-7 %
SM ENERGY CO	210	-15	-7 %
NOBLE ENERGY INC	1210	-96	-8 %
CIMAREX ENERGY CO	341	-28	-8 %
PDC ENERGY, INC.	169	-19	-11 %
SOUTHWESTERN ENERGY CO	982	-109	-11 %
BONANZA CREEK ENERGY, INC.	44	-7	-16 %
LINN ENERGY, INC.	562	-92	-16 %
APPROACH RESOURCES INC	77	-15	-20 %

Fig. D.5—U.S. companies proved reserves changes (%) for year 2012.



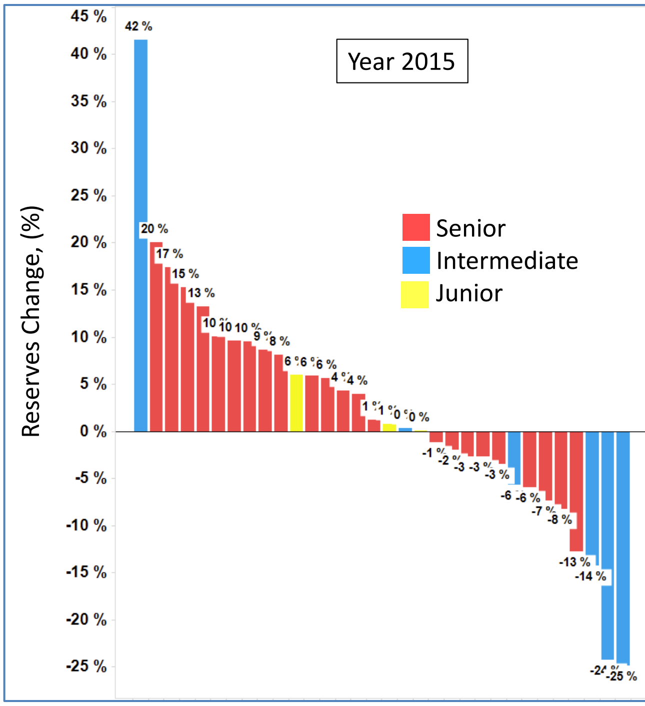
Company Name	1P Initial	ROTP	ROTP % change
DORCHESTER MINERALS, L.P.	14	3	20 %
ANADARKO PETROLEUM CORP	2560	370	14 %
CABOT OIL & GAS CORP	640	62	10 %
SOUTHWESTERN ENERGY CO	670	47	7 %
NOBLE ENERGY INC	1184	82	7 %
RANGE RESOURCES CORP	1084	75	7 %
CNX RESOURCES CORP	666	29	4 %
WPX ENERGY, INC.	748	29	4 %
OASIS PETROLEUM INC.	143	5	4 %
EOG RESOURCES INC	1811	48	3 %
WHITING PETROLEUM CORP	379	7	2 %
SM ENERGY CO	293	4	1 %
DENBURY RESOURCES INC	409	5	1 %
APACHE CORP	2852	33	1 %
EP ENERGY CORP	578	6	1 %
NEWFIELD EXPLORATION CO /...	567	4	1 %
ENERGEN CORP	346	-2	-1 %
CONCHO RESOURCES INC	447	-18	-4 %
DEVON ENERGY CORP/DE	2435	-104	-4 %
LINN ENERGY, INC.	799	-35	-4 %
APPROACH RESOURCES INC	95	-5	-5 %
EQT CORP	1001	-58	-6 %
CHESAPEAKE ENERGY CORP	2615	-191	-7 %
CIMAREX ENERGY CO	376	-35	-9 %
CONTANGO OIL & GAS CO	37	-4	-10 %
CONTINENTAL RESOURCES, INC	785	-96	-12 %
ANTERO RESOURCES CORP	822	-117	-14 %
BONANZA CREEK ENERGY, INC.	53	-10	-19 %
QEP RESOURCES, INC.	656	-135	-21 %
PDC ENERGY, INC.	193	-46	-24 %
ENCANA CORP	1675	-499	-30 %
PIONEER NATURAL RESOURC...	1086	-330	-30 %

Fig. D.6—U.S. companies proved reserves changes (%) for year 2013.



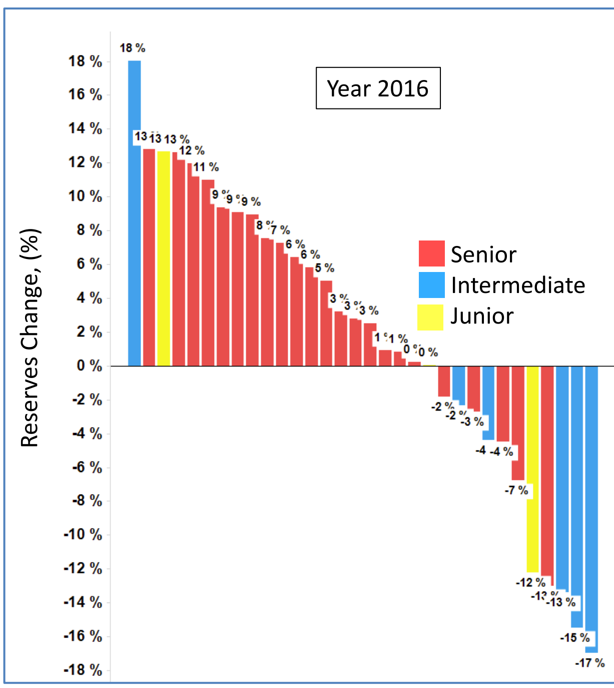
Company Name	1P Initial	ROTP	ROTP % change
ANADARKO PETROLEUM CORP	2792	440	16 %
DORCHESTER MINERALS, L.P.	15	2	14 %
BONANZA CREEK ENERGY, INC.	70	7	11 %
CABOT OIL & GAS CORP	909	82	9 %
NEWFIELD EXPLORATION CO /...	613	48	8 %
SOUTHWESTERN ENERGY CO	1163	81	7 %
CNX RESOURCES CORP	955	36	4 %
CIMAREX ENERGY CO	416	15	4 %
WHITING PETROLEUM CORP	439	16	4 %
EOG RESOURCES INC	2119	49	2 %
SM ENERGY CO	429	7	2 %
NOBLE ENERGY INC	1406	18	1 %
APACHE CORP	2646	11	0 %
QEP RESOURCES, INC.	677	-2	0 %
DENBURY RESOURCES INC	468	-4	-1 %
EP ENERGY CORP	547	-10	-2 %
RANGE RESOURCES CORP	1367	-27	-2 %
CONCHO RESOURCES INC	503	-13	-3 %
ENCANA CORP	1529	-43	-3 %
CHESAPEAKE ENERGY CORP	2678	-78	-3 %
DEVON ENERGY CORP/DE	2411	-84	-3 %
EQT CORP	1391	-49	-4 %
LINN ENERGY, INC.	1067	-54	-5 %
APPROACH RESOURCES INC	115	-7	-6 %
WPX ENERGY, INC.	794	-54	-7 %
PIONEER NATURAL RESOURC...	845	-72	-9 %
CONTINENTAL RESOURCES, INC	1084	-105	-10 %
CONTANGO OIL & GAS CO	52	-6	-11 %
OASIS PETROLEUM INC.	228	-25	-11 %
ANTERO RESOURCES CORP	1274	-177	-14 %
ENERGEN CORP	348	-80	-23 %
PDC ENERGY, INC.	266	-65	-24 %

Fig. D.7—U.S. companies proved reserves changes (%) for year 2014.



Company Name	1P Initial	ROTP	ROTP % change
BONANZA CREEK ENERGY, INC.	90	37	42 %
CNX RESOURCES CORP	1138	228	20 %
NEWFIELD EXPLORATION CO /...	645	112	17 %
SOUTHWESTERN ENERGY CO	1791	273	15 %
ANADARKO PETROLEUM CORP	2858	378	13 %
PIONEER NATURAL RESOURC...	799	80	10 %
RANGE RESOURCES CORP	1718	165	10 %
CABOT OIL & GAS CORP	1233	117	10 %
CHESAPEAKE ENERGY CORP	2469	214	9 %
WPX ENERGY, INC.	727	59	8 %
DORCHESTER MINERALS, L.P.	15	1	6 %
WHITING PETROLEUM CORP	780	46	6 %
NOBLE ENERGY INC	1404	79	6 %
EOG RESOURCES INC	2497	107	4 %
CIMAREX ENERGY CO	522	20	4 %
EQT CORP	1790	21	1 %
APPROACH RESOURCES INC	146	1	1 %
DENBURY RESOURCES INC	438	1	0 %
CONTANGO OIL & GAS CO	46	0	0 %
APACHE CORP	2396	-26	-1 %
ENCANA CORP	1277	-24	-2 %
CONCHO RESOURCES INC	637	-16	-3 %
DEVON ENERGY CORP/DE	2233	-58	-3 %
CONTINENTAL RESOURCES, INC	1351	-46	-3 %
ENERGEN CORP	373	-21	-6 %
SM ENERGY CO	548	-32	-6 %
LINN ENERGY, INC.	938	-69	-7 %
QEP RESOURCES, INC.	655	-53	-8 %
ANTERO RESOURCES CORP	2114	-268	-13 %
EP ENERGY CORP	622	-88	-14 %
PDC ENERGY, INC.	250	-60	-24 %
OASIS PETROLEUM INC.	272	-67	-25 %

Fig. D.8—U.S. companies proved reserves changes (%) for year 2015.



Company Name	1P Initial	ROTP	ROTP % change
OASIS PETROLEUM INC.	218	39	18 %
QEP RESOURCES, INC.	603	77	13 %
DORCHESTER MINERALS, L.P.	14	2	13 %
ANADARKO PETROLEUM CORP	2057	260	13 %
EOG RESOURCES INC	2118	253	12 %
SOUTHWESTERN ENERGY CO	1036	114	11 %
DEVON ENERGY CORP/DE	1662	155	9 %
CIMAREX ENERGY CO	485	44	9 %
NEWFIELD EXPLORATION CO /...	509	45	9 %
CHESAPEAKE ENERGY CORP	1504	114	8 %
NOBLE ENERGY INC	1421	103	7 %
PIONEER NATURAL RESOURC...	664	43	6 %
WPX ENERGY, INC.	583	34	6 %
CABOT OIL & GAS CORP	1365	69	5 %
ENCANA CORP	799	26	3 %
RANGE RESOURCES CORP	1649	46	3 %
LINN ENERGY, INC.	540	14	3 %
CONCHO RESOURCES INC	624	6	1 %
APACHE CORP	1564	13	1 %
WHITING PETROLEUM CORP	821	2	0 %
CONTANGO OIL & GAS CO	31	0	0 %
CNX RESOURCES CORP	940	-17	-2 %
DENBURY RESOURCES INC	289	-7	-2 %
ANTERO RESOURCES CORP	2202	-59	-3 %
ENERGEN CORP	355	-15	-4 %
EQT CORP	1663	-74	-4 %
CONTINENTAL RESOURCES, INC	1226	-82	-7 %
APPROACH RESOURCES INC	167	-20	-12 %
SM ENERGY CO	471	-61	-13 %
BONANZA CREEK ENERGY, INC.	101	-14	-13 %
PDC ENERGY, INC.	273	-42	-15 %
EP ENERGY CORP	546	-92	-17 %

Fig. D.9—U.S. companies proved reserves changes (%) for year 2016.