Multiple Internal Rates of Return - When to Anticipate Multiple IRRs and How to Take Advantage of Them to Perform a Better Evaluation

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Abstract

There are different rules to delimit or exactly determine the number of Internal Rates of Return a project may have or has. These rules show that, when the sequence of signs of the cumulative cash flow vs time function is the normal one - negative figures at the start and then only positive ones - there is only one Internal Rate of Return. There are few projects in which there are multiple intersections of cumulative cash flow with the time axis : a number of acceleration projects, complex financing investments, and a few other serial projects. However, not all of them have multiple Internal Rates of Return. The discussion presented in this paper addresses the question of how to empirically infer the existence of multiple rates, and how to use them for the benefit of the evaluation. Moreover, it demonstrates that all multiple rates have the same physical meaning, which does not vary with respect to the traditional single rate case.

Introduction

The possible existence of projects with multiple Internal Rates of Return has always been a worrisome issue for many evaluators. This problem is frequently associated to oil and gas exploitation, since it frequently occurs in the acceleration projects characteristic of the extraction industries. How to anticipate the potential existence of these rates and what significance they have are questions not yet fully answered, representing a preoccupation for technicians and managers. The objective of this paper is to demystify the problem by demonstrating that, in most cases, the simple observation of the project cash flow sequence will be enough to discard the occurrence of multiple rates. In the few cases where the flow sequence and the nature of the project itself leads one to think of potential rate multiplicity, their existence can be corroborated or once again discarded through more complex mathematical methods. Notwithstanding this, such sophistication is never necessary since the same conclusions can be reached by merely observing the Present Worth Profile drawn using a logical range of rates.

The existence of multiple rates does not introduce variations regarding the intrinsic significance of IRR. Far from complicating the analysis, having multiple rates serves to enrich the evaluation by providing a formally different vision which is clear and elegant at the same time.

Internal Rate Of Return

Definition. The Internal Rate of Return (IRR) is the rate which makes the Present Worth (PW) of a project equal to zero. Assuming that cash flows (CF) are produced at the end of the period, Present Worth is

$$PW = \sum CF_j / (1+i)^j \quad (1)$$

Then,

$$\sum CF_j / (1+IRR)^j = 0 \quad (2)$$

Thus, the IRR is obtained by solving an n grade polynomial. Therefore, mathematically, there will be as many solutions as there are number of periods for the project. Of these solutions, only those with a real and positive rate will have economic significance. This leads to the affirmation that the number of IRRs for a project is given by the number of real and positive solutions in IRR, that is, with $0<x<1$, being $x = 1 / (1+IRR)$.

Meaning of IRR. The Internal Rate of Return is probably the capital yield yardstick most used for project evaluations[1]. However, its physical (economic-financial) meaning is not always fully understood by those who evaluate investments and even less by those who take their decisions based on such evaluations.

As has been fully demonstrated on many occasions [2, 3], the Internal Rate of Return is the rate at which the unrecovered funds that remain in the project work. However, many times the IRR is erroneously associated with the rate at which the whole investment works. This serious conceptual error results in the IRR being used later on for comparing investments, a task for which this yardstick is inappropriate.

The IRR is an excellent indicator for accepting or rejecting projects. It is fair to recognize, however, that it provides nothing that the Present Worth does not, since it is no more than a single point in its profile. Thus, it is equally correct to say that a project is accepted because the Present Worth at the Corporate Cutoff Rate (CCR) is positive, as it is to say that the decision is taken because IRR > CCR.

But the IRR, save for very particular situations, should not be used for comparing projects, since it does not reflect the investment yield but only a portion of it (the unrecovered funds). It is thus possible that a very high IRR investment will have a global yield lower than that of another investment with a more modest IRR, if in the first case a large portion of the investment leaves the project very soon.

Number of IRRs in a project. As stated earlier, a project can have more than one IRR. There are several rules to delimit or determine the number of IRRs of a project[4]:

- Descartes Theorem
- Rinaldi´s Practical Rule
- Boudan-Fourier Theorem
- Sturm-Kaplan Method

The first three methods are used to delimit the number of internal rates, while the Sturm-Kaplan method can be used to determine that number precisely. As will be illustrated later on in this paper, the Descartes Theorem and Rinaldi´s Practical Rule are very easy to use, allowing for a quick estimate of the maximum number of possible rates. In the past, when Descartes and Rinaldi´s Practical Rule indicated the likely existence of multiple rates, it was customary to turn to the complex procedures by Boudan-Fourier and Sturm-Kaplan in order to corroborate or discard the first indication. Today, the extended use of personal computers has replaced such sophisticated and complex mathematical treatment with a more simple and equally efficient procedure: drawing the Present Worth Profile in a range of rates from 0% to an exaggerately high value such as 1000%. It is evident that any rate outside of this interval will lack any economic interest.

In view of the above, the methodologies based on Boudan-Fourier and Sturm-Kaplan have lost popularity among economic evaluators. On the contrary, the Descartes Theorem and Rinaldi´s Practical Rule are widely in use, fundamentally because their use allows evaluators to discard an important number of projects as potentially having multiple rates.

Descartes Theorem. According to Descartes, the maximum number of real and positive solutions for an n grade polynomial is given by the number of alternations in the signs of the polynomial coefficients. This shows that project cash flows having a "normal sequence of signs" (all negative ones at the start, then only positive ones) can have one, or no IRR, and as can be easily demonstrated, if the project does have a positive economic yield, there will be one and only one IRR. Since approximately 95% of the projects have negative cash flows at the beginning and then only positive flows, they can be discarded as candidates to have more than one IRR. But Rinaldi´s Practical Rule allows the spectrum of likely candidates to multiple rates to be reduced even further.

Rinaldi´s Practical Rule. It establishes that the maximum number of IRRs for a project is given by the number of times the cumulative cash flow function intersects the time axis. Thus, the first thing to do when the project shows an "abnormal sequence of signs" is to observe the evolution of cumulative cash flows in time. This step serves as a further depuration of candidates to multiple rates. Indeed, according to Descartes, the six projects in Table I are potential candidates to having more than one IRR. By applying Rinaldi´s Practical Rule the range of candidates is reduced to three projects: C, E and F. Finally, only E will end up having two IRRs.

Present Worth Profile. Its use in determining the number of IRRs in a project. The foregoing conclusion, that the only project with two IRRs is E, can be reached through at least two different routes: by applying the Sturm-Kaplan method or by building the Present Worth Profile for a sufficiently extended range of rates (for the particular cases of E and F, the IRRs could have been calculated by solving the corresponding second degree equation). Table II shows the Present Worth Profile for the six projects, and Fig. 1 is a graphic representation of the three candidates to having a double rate according to Rinaldi´s Practical Rule. As illustrated, only project E has two IRRs. Later on it will be seen that, had project C been more thoroughly analyzed, it would have been enough to build the Present Worth Profile within a much smaller range in order to discard the existence of two rates.

Multiple Rate Projects

Most frequent cases. Based on the preceding discussion, sign alternation in the function cumulative CF vs time is a necessary, although not sufficient condition for the existence of multiple rates. There are three situations where this alternation appears most frequently:

- Acceleration projects
- Complex financing projects
- Projects in series or with significant interim investments.

Acceleration projects. This is the case most frequently cited by technical literature[5,6]. In the oil industry, the most common acceleration projects are drilling of infill wells, stimulation and change of production equipment. Their main purpose is to speed up the production of an existing flow without generating significant new reserves. The analysis usually centers on the difference between the cash flows prepared for two different situations:

- Production with additional investment (accelerated case)
- Production with no modifications (basic case).

Since there is no increase of reserves, the difference between the accelerated and the basic production prognoses is a series that adds up to zero (or nearly zero). Therefore, it has initial positive values followed by others which are negative and which at least in part compensate the initial production increase. This generally induces a cash flow alternation of signs: negative at the beginning, due to the acceleration investment, positive later as a result of increased production and finally negative again.

The following is an extremely simplified example of this, in order to visualize the situation.

Under the present production conditions, the GBS field will be producing for two more years. The estimated annual profit is 6000 m.u.. An additional investment of 1000 m.u. would reduce production time to just one year, thereby concentrating the 12,000 m.u. of profit. Assuming that cash flows are produced at the end of the period, the convenience of accelerating production is studied. Table III presents the differential cash flow and the two IRRs obtained, while Fig. 2 shows the Present Worth Profile of the differential project (accelerated case minus basic case) and that of the components. It can be observed that both IRRs determine a region where the accelerated project has a better yield than the basic project. If the corporate reinvestment rate is within that interval, the acceleration project would have some advantages over the basic case, at least regarding capital yield.

The same conclusions would have been obtained by comparing the Present Worth of the basic case against that of the accelerated case at the corporate reinvestment rate, since either directly or indirectly the decision to accelerate will be taken only in the case that such acceleration results in an increase of the project Present Worth. In short, the object of comparison is always the Present Worth in both scenarios, by analyzing either the differential profile or both profiles separately.

Table IV and Fig. 3 show three projects having a similar structure. However, Case A has two IRRs, B one and C none. Thus, only Project A holds some chance of being economically convenient. For B and C there will be no rates where the accelerated project is better than the basic one. The existence of a range where the Present Worth of the differential project is positive is closely associated to the multiplying power of the investment or the magnitude of the positive cash flows which is equivalent. When the multiplying power is poor, the range is smaller or even non-existent (Projects B and C).

The multiplying power of the investment introduces a different vision regarding acceleration projects. As illustrated by Table IV, they can be considered a self-loan in which some installments have been paid previous to recieving the loan itself (in Argentina this kind of plan is called a "Plan con Ahorro Previo"). Thus, in Case A, some money is initially placed in a financial institution (-1 m.u.), then the institution gives you the loan (6 m.u.) that in the end will be repaid (-6 m.u.). The final result is an economic loss (-1 m.u.) with a possible financial advantage (6 extra m.u. in year 1). It can be demonstrated that the minimum IRR represents the loan rate; if a bank lends the money at a lesser rate and there are neither other reasons for acceleration nor any liability restrictions, the acceleration project should not be undertaken and the funds should be obtained through the bank[7].

Projects with complex financing. In these cases, multiple rates are common but, once again, this circumstance is far from being a complication. Assume a 200 m.u. loan to be returned in three equal installments using the French System. The amount of each installment, including interest, is 100 m.u.. The loan, difficult to obtain, will require an expenditure of 5 m.u. in the period before obtaining the loan. The cash flow series will thus be as follows:

Period	1	2	3	4	5
CF(m.u.)	-5	200	-100	-100	-100

This series has two Internal Rates of Return, 25.5% and 3848%. Again, both rates determine a range within which the corporate reinvestment rate should fall if the loan is to be convenient. Assuming that no better financing is obtainable, a company reinvesting at 50% would find it convenient to take the loan, since the 200 m.u. reinvested would allow to pay for the installments, recover the profit loss of the 5 m.u. spent initially and therefore not reinvested, and there would still be a surplus of 175 m.u. at the end of year 5.

Period	1	2	3	4	5
CF (m.u.)	-5.0	200.0	-100.0	-100.0	-100.0
Net CF reinvested (m.u.)			288.8	283.1	274.7
Expenditure profit loss (m.u.)		-7.5			
Net CF (m.u.)	-5.0	192.5	188.8	183.1	174.7

On the contrary, a company reinvesting at 10% would find that taking the loan is not convenient.

Period	1	2	3	4	5
CF (m.u.)	-5.0	200.0	-100.0	-100.0	-100.0
Net CF reinvested (m.u.)			214.0	125.3	27.9
Expenditure profit loss (m.u.)		-5.5			
Net CF (m.u.)	-5.0	194.5	114.0	25.3	-72.1

By following the same line of reasoning, it would not be convenient to take the financing offered to the company in the event it can reinvest at a rate higher than the maximum IRR, such as 3900%.

Period	1	2	3	4	5
CF (m.u.)	-5	200	-100	-100	-100
Net CF reinvested (m.u.)			0	-4000	-164000
Expenditure profit loss (m.u.)		-200			
Net CF (m.u.)	-5	0	-100	-4100	-164100

The reason why a loan having a nearly 200 times lower rate than the reinvestment rate should be rejected is based on the profit loss resulting from not reinvesting the amounts spent for obtaining the loan. Needless to say, this is just an example. Reinvestment rates such as, in this case, the maximum IRR, are economically unthinkable and therefore, for all practical purposes, it could be said that the cash flow under study has just one IRR.

The following example also shows alternation in the cumulative cash flow signs. This is a project including financing associated to the project itself.

Period	1	2	3	4	5
Project CF (m.u.)	-5	-300	150	150	150
Loan CF (m.u.)		500	-250	-250	-250
Combined CF (m.u.)	-5	200	-100	-100	-100
Combined cum. CF (m.u.)	-5	195	95	- 5	-105

It is apparent from the above that cash flow values are the same as those in the previous example. In order to accept or reject the project-loan combination it should be evaluated whether the surplus funds reinvested are enough to cover future obligations and leave room for some profit at the end. As illustrated before, this will take place when the reinvestment rate falls between both IRRs.

The examples shown illustrate the fact that multiple IRRs do not generate problems when evaluating complex financing projects. On the contrary, as is the case with acceleration, they facilitate the analysis by setting a range within which the reinvestment rate should fall so that a convenient profit is secured for the project.

Projects in series or with significant interim investments. When the amounts to be invested in a project exceed the limit of maximum exposure set by the company the project is usually developed in stages, so that the first amounts invested generate income to finance the later stages. This may generate an alternation of cumulative cash flow signs.

As a result, based on Rinaldi´s Practical Rule, multiple IRRs would be feasible. A similar situation occurs in the case of projects which, because of their own nature, require significant investments years after the start. Such is the case of oil fields where enhanced recovery operations are implemented after development, or of gas fields where, at certain time during the life of the field, it is necessary to recompress the gas due to pipeline requirements. In all of the cases, the project is a sum of individual projects, where a project by project analysis is recommended before evaluating the whole. Unless one of them is an acceleration project, each individual project will have a "normal sign sequence" and therefore only one IRR. The Present Worth Profile of the whole project will be the sum of the individual profiles. Thus, within the range of rates defined by the lesser IRR and the higher IRR, some projects will have a positive PW while others will show a negative PW. This may generate a composite profile with multiple IRRs.

Notwithstanding the above, multiple rates are fairly unusual in serial projects due to the projects own nature. To start with, the sum of cash flows (profit) is a positive value, so that the composite profile begins at a positive value and there is no chance that the PW sign changes until after the lesser IRR is surpassed. As has been stated before, multiple IRRs should necessarily occur in the space defined by the lesser IRR and the higher IRR, since for $i <$ lesser IRR all PWs are positive, and for $i >$ higher IRR all values are negative. If this range is thin the probability of multiple rates is small. If the range is big, high rates will appear and the importance of the discounted cash flows that are far in time from the beginning will be reduced. So, the chance of multiple rates appearing will be small. By way of an example, try to draw two conventional PW profiles which, added, result in three IRRs (two is not possible, since for very high rates the PW should be negative). Surely this is no easy task.

As stated before, drawing the PW profile of the project within a range of logical rates would be enough in order to empirically study the existence of multiple rates. For serial projects the "logical range" is defined by the maximum and minimum IRRs of the component projects. But a thorough knowledge of each component project is not a condition in order to define the range. Another possible procedure is to break down the global project into small individual pseudo-projects having a "normal sequence of signs". Breaking down Project C of Table I in this manner:

Period	C	CI	CII
	0	-1000	-1000
	1	1200	1200
	2	-2000	-2000
	3	4000	4000
	4	4000	4000
Total	6200	200	6000
IRR		20%	173.2%

would allow the establishment of a range between 20% and 173.2% to study rate multiplicity. It is obvious that the proposed parting into pseudo-projects serves only to study multiple rates. It is recommendable to know each real particular project individually if a correct evaluation is to be made.

One other possibility for studying multiple rates in the event of serial projects is to divide the project into two, with the initial negatives and all positives on one side, and with the rest of the negatives on the other. The first group would result in a PW profile that is conventional (monotone, decreasing at least down to IRR), while the second group would have a profile with entirely negative values tending to zero for an infinite rate. Changing the signs of the second profile values and representing both in the same graph, the intersections thus obtained will be the project IRRs. It should be noted that it is unnecessary to extend the line of the profiles once the first has changed sign, since new intersections will not be possible. Fig. 4 presents this methodology as applied, once again, to Project C of Table I.

But... what can be said of multiple rates in the very few cases in which they occur?. In this case, the PW profile usually has a shape similar to those in Fig. 5. Although the three IRRs, as will be illustrated further on, maintain their meaning, only the lesser one would be of use in deciding the undertaking of the entire project, since the second leg with a positive PW is in itself unstable and surely the positive amounts will be small and will correspond to rates too high to be real.

Physical Meaning Of Internal Rates Of Return

As expressed before, the IRR is that rate at which the unrecovered balances of the initial investment are put to work. This is demonstrated in Table V for projects having a "normal sign sequence". For multiple rate projects both rates keep the same meaning, as shown in Table VI.

Conclusions

* Multiple IRRs, when they occur, do not pose a problem when evaluating projects. There are different theoretical and empirical methods to detect them.
* Far from complicating the analysis, multiple IRRs in many cases help to enrich it, by supplying a vision that is formally different and at the same time clear and elegant.
* The most common cases of projects having multiple IRRs are acceleration projects and those having complex financing.
* In both cases, in the event of having two IRRs, they define the range within which the corporate reinvestment rate should be for the project to be feasible.
* Serial projects, even though they fulfill the necessary requirements in accordance with Rinaldi´s Practical Rule, usually have only one IRR.
* In the infrequent case of serial projects having more than one IRR, only the minimum one will be compared against the Corporate Cutoff Rate in order to decide on proceeding with the project.
* Under all circumstances, the IRR is the rate at which the unrecovered balances of the initial investment are put to work. In order to prevent its use under inadquate circumstances, such as for comparing projects, it should be kept in mind that it does not constitute the yield of the entire initial investment but only a part of it.
* The occurrence of multiple IRRs does not introduce modifications regarding their physical meaning. All of them represent the same and their meaning remains unaltered with respect to the case of a single IRR.

Nomenclature

CF = *Cash Flow*
CCR = *Corporate Cutoff Rate*
IIR = *Internal Rate of Return*
PW = *Present Worth*
i = *discount rate*

Subscript

j = *period number*

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TABLE I - PROJECTS WITH ABNORMAL SEQUENCE OF SIGN CASH FLOWS

Period	PROJECT A		PROJECT B		PROJECT C	
	CF (m.u.)	Cum. CF (m.u.)	CF (m.u.)	Cum. CF (m.u.)	CF (m.u.)	Cum. CF (m.u.)
0	-1000	-1000	-1000	-1000	-1000	-1000
1	900	-100	1200	200	1200	200
2	-2000	-2100	-100	100	-2000	-1800
3	4000	1900	4000	4100	4000	2200
4	4000	5900	4000	8100	4000	6200

Period	PROJECT D		PROJECT E		PROJECT F	
	CF (m.u.)	Cum. CF (m.u.)	CF (m.u.)	Cum. CF (m.u.)	CF (m.u.)	Cum. CF (m.u.)
0	-1000	-1000	-1000	-1000	-1000	-1000
1	1200	200	6000	5000	2000	1000
2	2000	2200	-6000	-1000	-2000	-1000
3	4000	6200				
4	-4000	2200				

TABLE II - PROJECTS WITH ABNORMAL SEQUENCE OF SIGN CASH FLOWS - PRESENT WORTH PROFILE

RATE (%)	PRESENT WORTH (m.u.)					
	A	B	C	D	E	F
0	5900.0	8100.0	6200.0	2200.0	-1000.0	-1000.0
20	2170.8	3478.7	2379.1	1478.9	-138.9	-601.9
40	801.0	1646.5	954.1	924.3	160.3	-422.7
60	230.1	811.2	347.3	560.9	253.9	-332.0
80	-28.0	390.4	64.6	327.1	267.5	-281.2
100	-150.0	162.5	-75.0	175.0	250.0	-250.0
120	-208.1	32.4	-146.1	74.4	221.6	-229.2
140	-234.3	-44.8	-182.2	6.7	191.0	-214.1
160	-244.1	-91.6	-199.7	-39.4	161.6	-202.5
180	-245.1	-120.3	-206.9	-71.1	134.8	-193.1
200	-241.6	-137.9	-208.2	-93.0	111.1	-185.2
220	-235.6	-148.3	-206.3	-108.1	90.3	-178.2
240	-228.4	-154.1	-202.5	-118.3	72.3	-172.0
260	-220.8	-156.9	-197.6	-125.1	56.6	-166.3
280	-213.0	-157.6	-192.3	-129.5	43.0	-161.1
300	-205.5	-157.0	-186.7	-132.0	31.3	-156.3
320	-198.2	-155.5	-181.1	-133.3	21.1	-151.7
340	-191.2	-153.4	-175.7	-133.6	12.2	-147.4
360	-184.5	-150.8	-170.4	-133.1	4.5	-143.4
380	-178.3	-148.0	-165.2	-132.2	-2.2	-139.6
400	-172.3	-145.1	-160.3	-130.9	-8.0	-136.0
420	-166.7	-142.1	-155.6	-129.3	-13.1	-132.6
440	-161.4	-139.1	-151.2	-127.5	-17.5	-129.3
1000	-84.7	-80.8	-82.2	-79.2	-45.8	-75.9

TABLE III - ACCELERATION PROJECT – GBS Field

YEAR	CF (m.u.)		
	ACCELERATED	BASIC	DIFFERENTIAL
0	-1000		-1000
1	12000	6000	6000
2		6000	-6000
Profit (m.u.)	11000	12000	-1000

Differential Project
Minimum IRR 26.8%
Maximum IRR 373.2%

TABLE IV - ACCELERATION PROJECTS WITH SIMILAR STRUCTURE AND DIFFERENT NUMBER OF IRR

YEAR	A	B	C
0	-1000	-1000	-1000
1	6000	4000	2000
2	-6000	-4000	-2000
Profit (m.u.)	-1000	-1000	-1000
# of IRR	2	1 (2 coincidental)	0
Minimum IRR	26.8%	100%	imag.
Maximum IRR	373.2%	100%	imag.

TABLE V - IRR MEANING - ONE IRR PROJECT

Period	CF (m.u.)	Reinvested unrecoverd funds before CF (m.u.)	Unrecovered funds after CF (m.u.)
0	-1000		1000.0
1	500	1349.0	849.0
2	500	1145.4	645.4
3	500	870.6	370.6
4	500	500.0	0.0
Profit (m.u.)	1000		
IRR	34.90%		

TABLE VI - IRR MEANING - TWO IRR PROJECT

a - Minimum IRR

Period	CF (m.u.)	Reinvested unrecovered funds before CF (m.u.)	Unrecovered funds after CF (m.u.)
0	-1000.0		1000.0
1	6000.0	1267.9	-4732.1
2	-6000.0	-6000.0	0.0
Profit (m.u.)	1000		
IRR	26.80%		

b - Maximum IRR

Period	CF (m.u.)	Reinvested unrecovered funds before CF (m.u.)	Unrecovered funds after CF (m.u.)
0	-1000.0	1000.0	
1	6000.0	4732.1	-1267.9
2	-6000.0	-6000.0	0.0
Profit (m.u.)	1000		
IRR	373.20%		

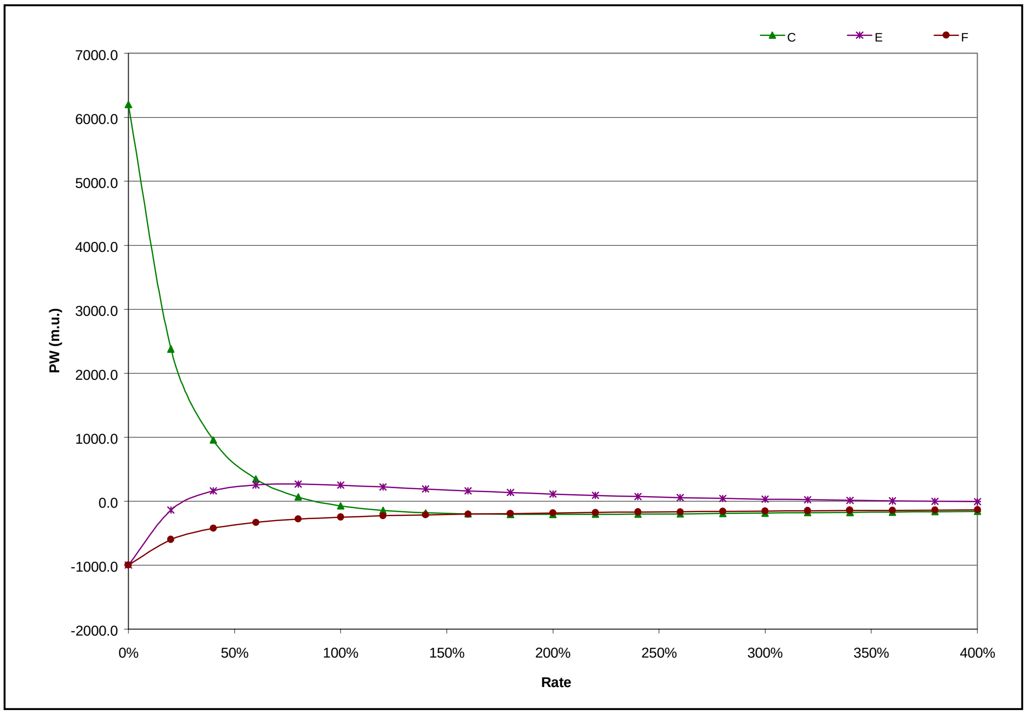

Fig 1 – Present Worth Profile and IRR

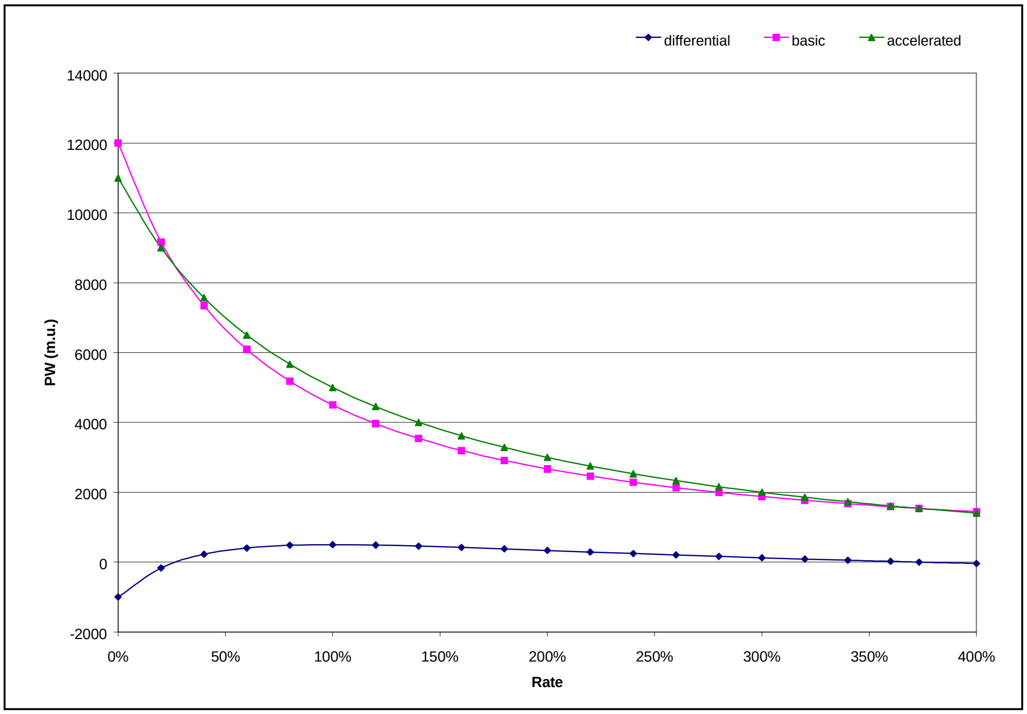

Fig 2 – Acceleration Project GBS Field

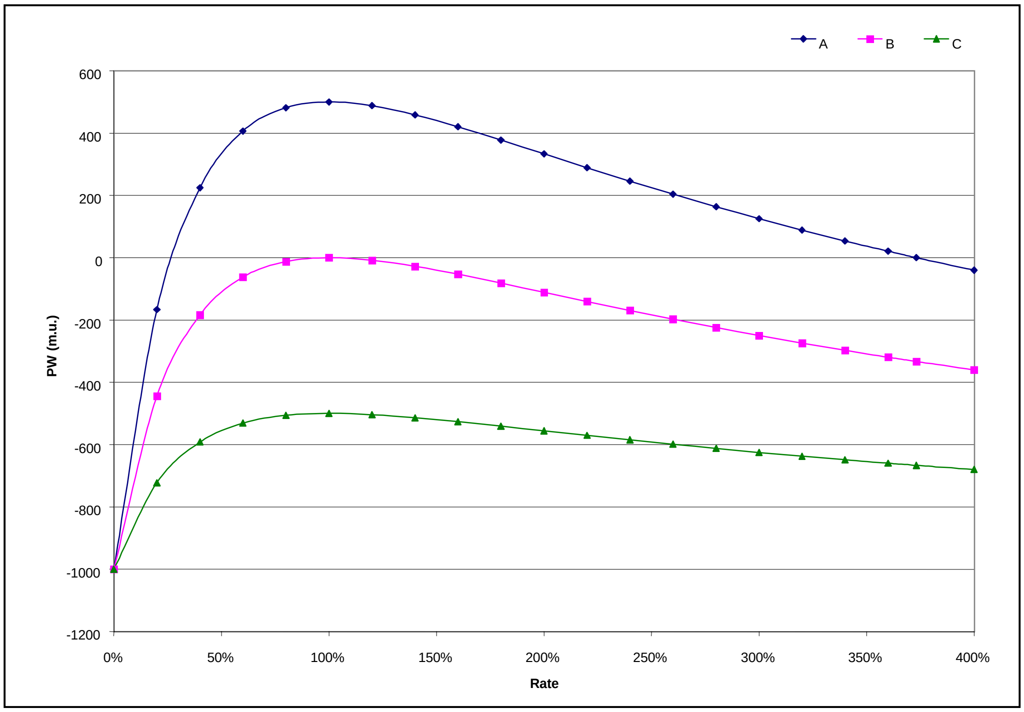

Fig 3 – Acceleration Projects with Similar Structure and Different Number of IRR

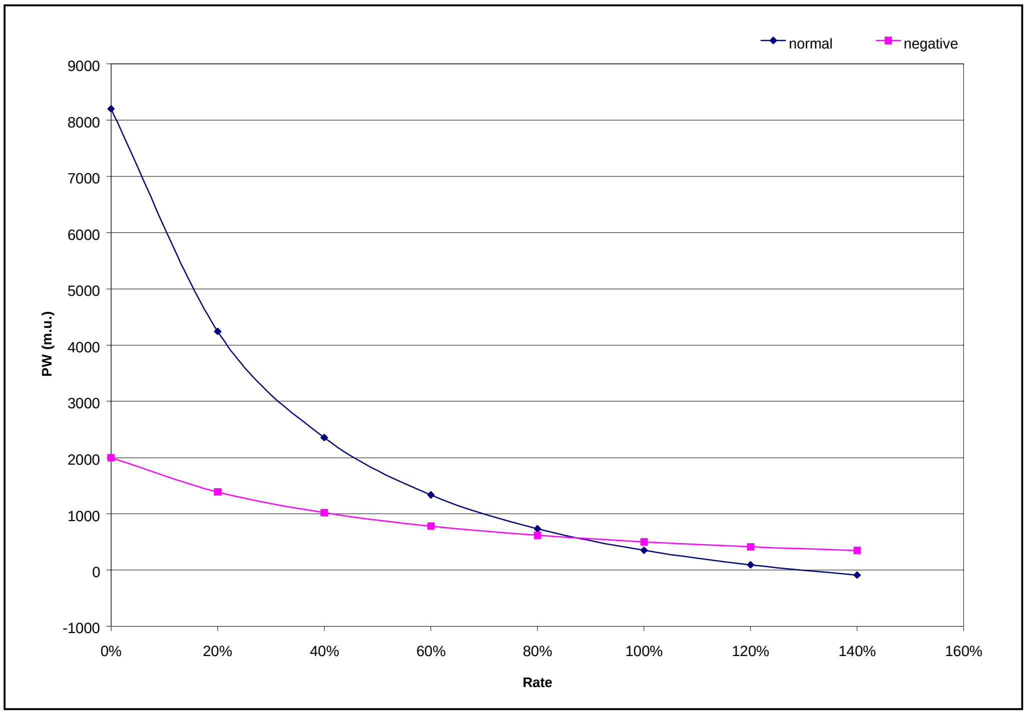

Fig 4 – Number of IRR Determination

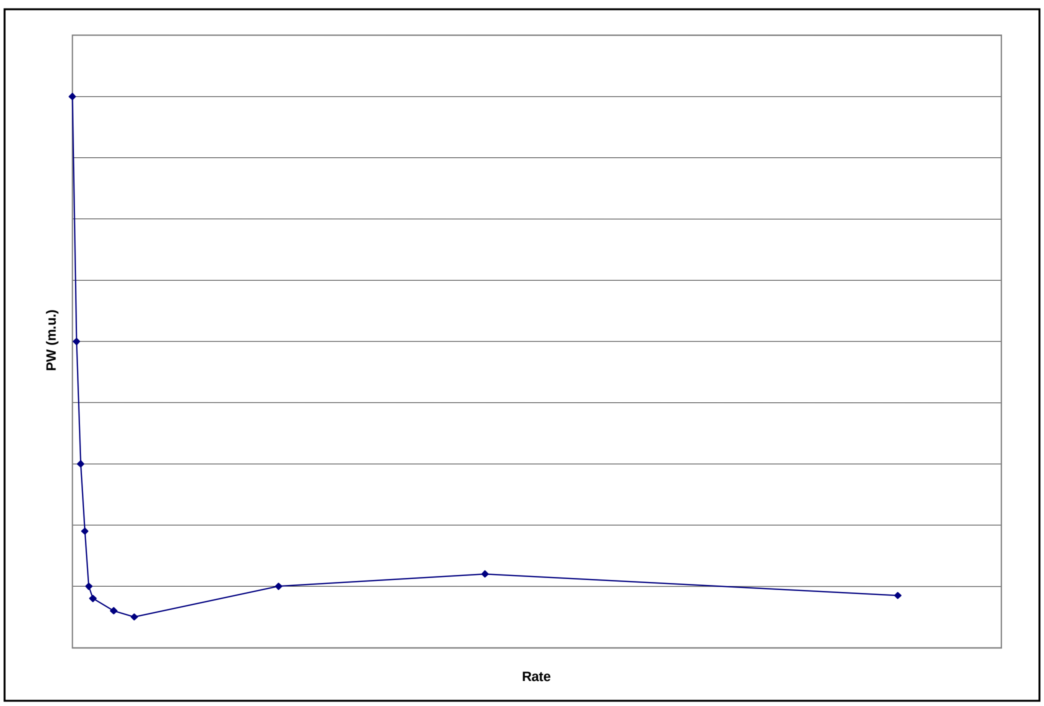

Fig 5 – Serial Project – Probable PW Profile