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Internal rate of return: Good and bad features, and a new way of interpreting the historic measure

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ABSTRACT

IRR, a widely used profitability measure, is the *Discount Rate* that yields *Net Present Value* (*NPV*) = 0 for a stream of positive and negative cash flows, at least one of each sign and with no explicit financing payments. A big disadvantage is lack of parameters, such as a project finance rate or the enterprise rate (*ER*), i.e., *Return on Investment* of the overarching investment group to serve as a measure of opportunity cost. The coupled metrics proposed earlier by the author— $NPV_{project}$ and $NPV_{\%}$–do not suffer these disadvantages, so *IRR* is analyzed in terms of $NPV_{\%}$. Useful information can be obtained from a projection of *IRR* values onto the $NPV_{\%}$, *ER* plane revealing the sensitivity of *IRR* to risk under meaningful operating conditions.

1. Introduction

The Internal Rate of Return (*IRR*) has been used for years by economists and engineers to estimate the profitability (or potential profitability) of projects. Its definition is rooted in procedures of Discounted Cash Flow (DCF), a methodology that is utilized to "weight" cash flows occurring at the "present time" in some rational way so as to represent their value relative to "future" cash flows in later years. When coupled with *Net Present Value* (*NPV*), *IRR* forms the necessary second measure of profitability. *NPV* is scaled, i.e., with units of dollars, while *IRR* is *un*-scaled or normalized, with units of % or %/time. Two such measures are required to distinguish between projects that may appear to be about equal in terms of profitability but are of different size or scope. Whether the designer prefers a higher profitability or a lower scale of investment can then be considered.

Process Engineers interested in plant design/costing (Douglas, 1988; Edgar et al., 2001; Peters et al., 2003; Ross et al., 2005; Seider et al., 2008; Towler and Sinnott, 2007; Turton et al., 2003; Wells and Rose, 1986) have long used a variation of the *IRR*, now generally referred to as the "hurdle criterion." In this approach, a company will impose a significantly high hurdle rate before approving any conceptual design, in other words, will require that a potential process possess a minimum value of *IRR* as its discount rate, then choose the conceptual process alternative that yields the highest value of *NPV* above this hurdle.

Process engineers are generally satisfied with this approach; and economists view *IRR*/*NPV* as a mature area, another way of saying that the field is "dead" as far as need for additional research. Still, the reexamination of the use of *NPV* methods made earlier by the author (Mellichamp, 2013) and (Mellichamp, 2016) indicated that much more could be accomplished by defining/using a different normalized profitability measure (the normalized *NPV*, referred to as $NPV_{\%}$). It is useful to look at the *IRR* concept again in light of the $NPV_{\%}$ measure, to see what it does and does not provide as an alternative.

First, it is important to note that *IRR* is strictly defined and used only to determine whether a plant or project will be profitable enough to a company (the Enterprise) to build it. The definition specifically does not involve the concept of financing. Thus, for companies large enough to have a group that focuses on financing plants/projects, it is only after a design engineer or group evaluates that it is potentially profitable enough to the company to justify constructing and operating it for its anticipated lifetime that the "finance group" considers what alternative to use— to take on an outside financier, borrow money, sell a bond issue, sell shares of stock—and then how much of any of these is required.

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Notation

a_i Fraction allocation of *Fixed capital* in year *i* ($i = 0, -1, -2, -3$)
b_j Fraction allocation of $Profit_{BT}$ in year *j* ($j = 1, 2, 3$, etc.)
C Total production costs (Raw materials, utility and labor costs, etc. but not financing costs)
CF Cash flow
CR Interest rate on construction loan. for large loans, multiple banks often are used
D_i *Depreciation allowed* and taken in Year i [= 0.1(*FC* + *SU*) if project operating lifetime is 10 years and depreciation is "straight-line."]
DR *Discount rate* used in present value calculation. In all work by the author, *DR* is taken to be *ER* to impose the loss of Enterprise ROR for all funds taken out of internal investments
DCFROR *Discounted cash flow rate of return* (long name for IRR)
ER *Enterprise rate*, i.e, the long-term rate of earnings generated by the company. A classic measure of *ER* is the average book value of company assets, as maintained by stock analysts. A five-year moving average would be appropriate
FC *Fixed capital* (= *Direct Costs* + *Indirect costs*)
FR Finance (interest) rate on any bond issue used to cover construction costs. In a company with an active Finance Group, this likely would be the *WACC* (Weighted Average Cost of Capital)
IRR *Internal rate of return* (*Discount rate* that makes $NPV_0 = 0$)
N Plant anticipated lifetime ($= N_{Construction} + N_{Operations}$)
NPV *Net present value* (the sum of discounted *Cash flows* over a project's entire lifetime, i.e., design/construction/operations)
NPV_0 *NPV* at the start of process operations [i.e., at end of year(0)]
$NPV_{\%}^{required}$ *NPV* value necessary to obtain a particular value of ROI_{BT} (e.g., $ROI_{\mathrm{BT}}^{required}$)
NPV_{proj} *NPV* at the time a firm decision is made to construct, e.g., EOY(-1), EOY(-2), ... depending on the length of design/construction period. thus: $NPV_{proj} = (1 + DR) - N^{\mathrm{Construction}}\ NPV_0$
NPV_{proj}^{norm} NPV_{proj}/TCI (NPV_{proj} normalized by capital requirement, *TCI*)
$NPV_{proj}^{norm/ann}$ NPV_{proj}^{norm} (NPV_{proj} annualized by total lifetime of the project, i.e., the design/construction/operating period, and normalized by *TCI*)
$NPV_{\%}$ Shorthand for $NPV_{proj}^{norm/ann}$ defined in terms of the project initiation date, not the startup date, thus based on NPV_{proj} not NPV_0 !] note that $NPV_{\%}$ is a linear function of ROI_{BT}. therefore its inverse is proportional to *POT* and serves as a surrogate for short-term risk
$NPV_{\%}^{\min}$ Minimum value of $NPV_{\%}$ that justifies intrinsic risk
P_{BT} *Profit Before Taxes* = *Total Revenues* − *Total Production Costs* = *R* − *C* (Other names used Annual Profits, Gross Profits, or Net Earnings.)
R *Total Revenues* (from operations) = *Production Rate* x *Sales Price*

R *Total revenues* (from operations) = *Production rate* × *Sales price*
POT *Pay-Out* (or *Pay-Back*) *Time*
ROI_{BT} *ROI* before taxes based on *TI* = *FC* + *SU* + *WC* (calculated directly from design cost estimations.)
SU *Start-up Capital* (*SU* is assumed to be partially recovered along with *FC* via depreciation during each year of the project lifetime.)
SV *Salvage value* of the plant (Recovered at end of the project's lifetime.)
TI *Total investment* (=*FC* + *WC* + *SU*)
TCI *Total capitalized investment* ($TCI \neq TI = FC + WC + SU$), i.e., includes construction interest costs, if any.
TR *Tax rate* (The incremental rate paid for federal + state + local taxes expressed as a fraction.)
WC *Working capital* (recovered at the end of project lifetime along with *SV*. taxes are assumed to be paid only on *SV* at that time.)

Greek letters
α_{WC}, α_{SU}, α_{SV} Factored estimate (multiple of *Fixed capital*, e.g., $WC = \alpha_{WC} FC$)

2. The good features underlying *IRR*

Apparently, the original idea of *IRR* was to calculate the annual return on a purchase made with a single-payment of cash, then sold *n* years later for cash, for example, the acquisition of a fine painting. How much it appreciated or depreciated each year that it was owned, the so-called *IRR*, was simply the *n*th root of the quotient of sales and purchase values, thus

$$IRR = \left[\frac{Sales\ Price}{Purchase\ Price}\right]^{1/n} - 1 \quad (1)$$

Notice that no cash flows occur except at times "going in" and "coming out" of the purchase.

Internal Rate of Return represents a similarly simple concept, a single number that does not depend in any way on financing issues (whether money is used to buy the object, if not, what rate of interest might be paid and other terms of a loan, etc.). Investors historically liked the concept and a simple interpretation appears to have been attached to it from the outset, namely, that *IRR* represents the upper limit on the rate of interest that could be paid to purchase an object for later sale and still make a profit.

Later, multi-year projects were considered in which the costs of a project were paid out over several years, then expenses were recovered via after-tax profits earned over a subsequent period of several years. Net Present Value methods were developed to compensate for the different times at which the cash flows occurred, and it seemed natural to find a single number that could characterize an entire stream of cash flows for analysis.

However, the important issue is not whether a project will make a profit, but prospectively whether it will make enough money in early years to return the capital invested, and over its full assumed lifetime, more than enough to justify the intrinsic risks involved. Not every investment returns all the capital invested; some don't return any portion of it. An investor wants to obtain both sunk capital and sufficiently enough beyond that to compensate (at least statistically and over a long period of experience) for the known and unknown risks the investments will be exposed to.

In the process world, plant designers would like to know, well before building and starting-up a plant, just how profitable the designed project must be to justify its intrinsic risks. For this pur-