

MBA Teaching Note 07-02
Some Problems with the Profitability Index

Finance students are taught that the net present value (NPV) rule is the correct way to analyze a capital investment decision. A project with positive NPV is acceptable and one with a negative NPV should be avoided. A related measure that is always covered is the *profitability index*.¹ In spite of what books teach, this measure is almost totally worthless. There is no more information in the profitability index than there is in the NPV figure. But textbooks tell us that it is the correct measure when capital is limited, the situation referred to as *capital rationing*.

The net present value is defined as below:

$$NPV = PVCF - I,$$

where PVCF is the present value of all cash flows that occur after the project starts. The profitability index is defined as²

$$NPV = \frac{PVCF}{I}.$$

The NPV rule is to accept a project if $NPV > 0$, which is equivalent to $PI > 1$ as shown below:

$$NPV > 0 \Rightarrow PVCF - I > 0$$

$$PVCF - I > 0 \Rightarrow \frac{PVCF - I}{I} > \frac{0}{I}$$

$$\frac{PVCF}{I} - 1 > 0 \Rightarrow \frac{PVCF}{I} > 1$$

Thus, any project with positive NPV will have $PI > 1$. So the profitability index rule will never contradict the NPV rule for analysis of a single project. But a conflict can exist when multiple projects are analyzed. And it is in the analysis of multiple projects under capital rationing that the PI rule is considered to be superior. But that is not always true.

Consider the following three projects and a cost of capital of 12%.

Projects	I_0	C_1	C_2	C_3	C_4	PCVF	NPV	PI
A	\$10,000	\$15,000	\$8,000	\$1,500	\$1,000	\$21,474	\$11,474	2.15
B	\$5,000	\$3,000	\$4,000	\$2,000	\$7,000	\$11,740	\$6,740	2.35
C	\$5,000	\$3,500	\$7,000	\$5,000	\$750	\$12,741	\$7,741	2.55

All three projects are acceptable as they all have positive NPVs. Clearly their PIs are greater than 1. In fact, all are even greater than 2. But suppose we have a limited budget. Let us say that we are willing to spend only \$10,000. The choices are simple: select A, costing \$10,000, or select B and C, costing \$10,000. A simple addition of NPVs shows that

$$NPV \text{ of A} = \$11,474$$

$$NPV \text{ of B and C} = \$6,740 + \$7,741 = \$14,481.$$

¹Before going further, let me note that the terminology of “profitability index” is extremely misleading. In teaching finance, we go to great lengths to avoid focusing on “profit,” noting that it does not account for risk or the time value of money, is easily manipulated through legitimate accounting rules, and is historical rather than anticipatory. Years ago someone named this measure the “profitability index,” in spite of the fact that it is correctly based on NPV and shareholder wealth maximization. Whoever came up with this name should probably be banished to a Finance Hall of Shame.

²Some textbooks define the profitability index as NPV/I in which case, projects should be accepted if PI is more than zero. This definition of PI is $PVCF/I - 1$. Defining PI as NPV/I is probably a poorer way to define the PI because it loses its conventional view of being a benefit/cost ratio.

So if we invest \$10,000, it is far better to take B and C. Standard textbooks tell us that this decision can be made by ranking the projects according to the PI. We first select the project with the highest PI. Then we take the project with the second highest PI. We stop when the next project pushes us over the budget.

Thus, in this problem we would first select C because its PI is the highest at 2.55. We have spent \$5,000. We then select B whose PI is 2.35. We have now spent \$10,000 so we can go no further.

This approach works in situations where combinations of projects exhaust the entire budget, as in this case. When there is money remaining in the budget, however, we ought to take that money into account. What happens to it? Does it just go away? The PI fails to account for this money. Consider the following table, which adds two more projects to the ones above.

Projects	I ₀	C ₁	C ₂	C ₃	C ₄	PCVF	NPV	PI
A	\$10,000	\$15,000	\$8,000	\$1,500	\$1,000	\$21,474	\$11,474	2.15
B	\$5,000	\$3,000	\$4,000	\$2,000	\$7,000	\$11,740	\$6,740	2.35
C	\$5,000	\$3,500	\$7,000	\$5,000	\$750	\$12,741	\$7,741	2.55
D	\$4,000	\$5,000	\$9,000	\$0	\$0	\$11,639	\$7,639	2.91
E	\$3,000	\$2,000	\$1,000	\$7,000	\$0	\$7,565	\$4,565	2.52

Let us sort these projects by PI.

Projects	I ₀	C ₁	C ₂	C ₃	C ₄	PCVF	NPV	PI	Total spent
D	\$4,000	\$5,000	\$9,000	\$0	\$0	\$11,639	\$7,639	2.91	\$4,000
C	\$5,000	\$3,500	\$7,000	\$5,000	\$750	\$12,741	\$7,741	2.55	\$9,000
E	\$3,000	\$2,000	\$1,000	\$7,000	\$0	\$7,565	\$4,565	2.52	\$12,000
B	\$5,000	\$3,000	\$4,000	\$2,000	\$7,000	\$11,740	\$6,740	2.35	\$17,000
A	\$10,000	\$15,000	\$8,000	\$1,500	\$1,000	\$21,474	\$11,474	2.15	\$27,000

Note that we have added a column on the right that shows the total amount spent on the given project and all projects with higher PI. Using the PI ranking rule, we would select D first, spending \$4,000. The next choice would be C, and the combination of D and C would cost \$9,000. And so on.

Suppose the capital budget is \$15,000. According to the PI rule, we would first select D, then C, then E. These three projects would cost \$12,000. We cannot select B because we would go over the \$15,000 limit. So D, C, and E look like the best combination. *In fact, they are not.* Their combined NPV is $\$7,639 + \$7,741 + \$4,565 = \$19,945$ and a combined PI of $(\$11,639 + \$12,741 + \$7,565)/\$12,000 = 2.66$. But B, C, and D have a combined NPV of $\$6,740 + \$7,741 + \$7,639 = \$22,120$ and cost \$14,000 for a combined PI of $(\$11,740 + \$12,741 + \$11,639)/\$14,000 = 2.58$. In other words, the combination of D, C, and E is best according to the PI but has the lower NPV. Combination B, C, and D creates more shareholder wealth.

The conflict arises because under the PI ranking rule, we spend \$12,000 and generate an NPV of \$19,945, but we could spend another \$2,000 and generate an NPV of \$22,120. Obviously we should do the latter. Who would not invest \$2,000 for an NPV of $\$22,120 - \$19,945 = \$2,175$?³

There are two reasons for the problem: the combinations do not have the same total outlay and the entire budget is not expended. We need a way to resolve the conflict. Let us assume that if we have a budget of \$15,000, then a full \$15,000 is available for investment. If any combination of projects requires less than \$15,000, we should assume that the remainder of the budget would be spent on neutral projects, i.e., those that have an NPV of zero. If any other projects with positive NPV were available, they would be on the list. Zero-NPV projects always

³ Here is another example where incremental analysis, sometimes used to justify the use of the internal rate of return when projects have unequal sizes, will lead to the correct decision.

exist, such as investment in the risk-free asset. So for appropriate comparison, we should assume that all combinations expend the full budget. Therefore, the package of D, C, and E would result in the expenditure of \$12,000 with an NPV of \$19,945. The remaining \$3,000 would be spent to generate zero NPV. So with this combination, we spend \$15,000 for a PVCF of \$31,945 + \$3,000 = \$34,945 and an NPV of \$19,945. The overall PI would be \$34,945/\$15,000 = 2.33. For the combination of B, C, and D, we spend \$14,000 for a PVCF of \$36,120, an NPV of \$22,120 and another \$1,000 for a PVCF of \$1,000 and an NPV of zero. The total expenditure is \$15,000, the total PVCF is \$37,120, the total NPV is \$22,120 and the overall PI is \$37,120/\$15,000 = 2.47. We will refer to the profitability index that accounts for the investment of all remaining funds at zero NPV as the Adjusted-PI.

Note that when we account for the investment of the left-over funds at zero NPV, the PI rule is consistent with the NPV rule. But unfortunately, there is no simple ranking of individual projects that will enable us to see which combination is the best. We must identify every combination and find its total NPV. Then we select the one with highest NPV. Alternatively, we can find the Adjusted-PI and select the one with the highest Adjusted-PI.

The number of combinations of projects is potentially quite large. For N possible projects, the number of combinations is given by the factorial expression:

$$\sum_{i=1}^N \frac{N!}{i!(N-i)!}$$

In our example, N = 5. This expression is, therefore,

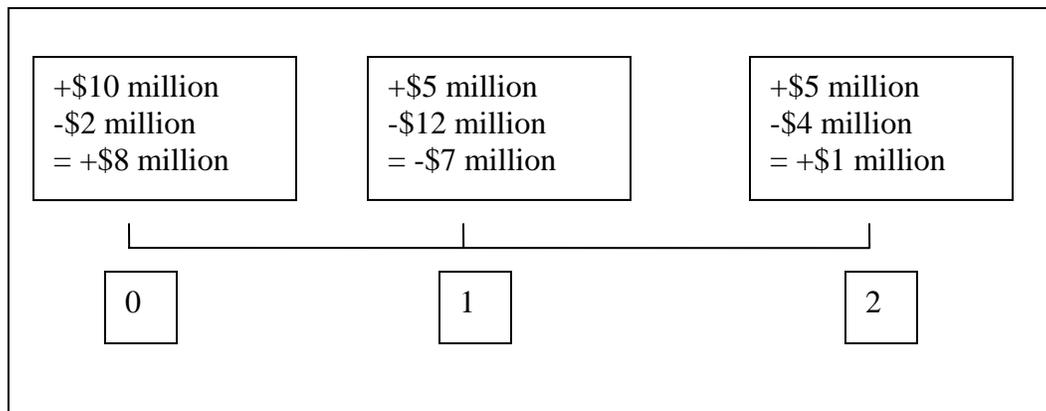
$$\begin{aligned} \sum_{i=1}^5 \frac{5!}{i!(5-i)!} &= \frac{5!}{1!(4!)} + \frac{5!}{2!(3!)} + \frac{5!}{3!(2!)} + \frac{5!}{4!(1!)} + \frac{5!}{5!(0!)} \\ &= 5 + 10 + 10 + 5 + 1 = 31 \end{aligned}$$

This rule tells us that there are five combinations of one project, 10 combinations of two, 10 combinations of three, five combinations of four, and 1 combination of all five. The combinations are listed below with the combined cash flows, NPVs, and adjusted-PIs. The ninth column contains the words “over budget” for projects that cannot be considered because they go over the budget. There are 19 combinations out of 31 that do not exceed the budget. The ranking of these combinations is the same using NPV or the Adjusted PI.

Combos	I ₀	C ₁	C ₂	C ₃	C ₄	PCVF	NPV	Adjusted PI
A	\$10,000	\$15,000	\$8,000	\$1,500	\$1,000	\$21,474	\$11,474	1.76
B	\$5,000	\$3,000	\$4,000	\$2,000	\$7,000	\$11,740	\$6,740	1.45
C	\$5,000	\$3,500	\$7,000	\$5,000	\$750	\$12,741	\$7,741	1.52
D	\$4,000	\$5,000	\$9,000	\$0	\$0	\$11,639	\$7,639	1.51
E	\$3,000	\$2,000	\$1,000	\$7,000	\$0	\$7,565	\$4,565	1.30
AB	\$15,000	\$18,000	\$12,000	\$3,500	\$8,000	\$33,213	\$18,213	2.21
AC	\$15,000	\$18,500	\$15,000	\$6,500	\$1,750	\$34,214	\$19,214	2.28
AD	\$14,000	\$20,000	\$17,000	\$1,500	\$1,000	\$33,113	\$19,113	2.27
AE	\$13,000	\$17,000	\$9,000	\$8,500	\$1,000	\$29,039	\$16,039	2.07
BC	\$10,000	\$6,500	\$11,000	\$7,000	\$7,750	\$24,480	\$14,480	1.97
BD	\$9,000	\$8,000	\$13,000	\$2,000	\$7,000	\$23,379	\$14,379	1.96
BE	\$8,000	\$5,000	\$5,000	\$9,000	\$7,000	\$19,305	\$11,305	1.75
CD	\$9,000	\$8,500	\$16,000	\$5,000	\$750	\$24,380	\$15,380	2.03
CE	\$8,000	\$5,500	\$8,000	\$12,000	\$750	\$20,306	\$12,306	1.82
DE	\$7,000	\$7,000	\$10,000	\$7,000	\$0	\$19,204	\$12,204	1.81
ABC	\$20,000	\$21,500	\$19,000	\$8,500	\$8,750	\$45,954	\$25,954	over budget
ABD	\$19,000	\$23,000	\$21,000	\$3,500	\$8,000	\$44,852	\$25,852	over budget
ABE	\$18,000	\$20,000	\$13,000	\$10,500	\$8,000	\$40,779	\$22,779	over budget
ACD	\$19,000	\$23,500	\$24,000	\$6,500	\$1,750	\$45,854	\$26,854	over budget
ACE	\$18,000	\$20,500	\$16,000	\$13,500	\$1,750	\$41,780	\$23,780	over budget
ADE	\$17,000	\$22,000	\$18,000	\$8,500	\$1,000	\$40,678	\$23,678	over budget
BCD	\$14,000	\$11,500	\$20,000	\$7,000	\$7,750	\$36,119	\$22,119	2.47
BCE	\$13,000	\$8,500	\$12,000	\$14,000	\$7,750	\$32,046	\$19,046	2.27
BDE	\$12,000	\$10,000	\$14,000	\$9,000	\$7,000	\$30,944	\$18,944	2.26
CDE	\$12,000	\$10,500	\$17,000	\$12,000	\$750	\$31,945	\$19,945	2.33
ABCD	\$24,000	\$26,500	\$28,000	\$8,500	\$8,750	\$57,593	\$33,593	over budget
ABCE	\$23,000	\$23,500	\$20,000	\$15,500	\$8,750	\$53,519	\$30,519	over budget
ABDE	\$22,000	\$25,000	\$22,000	\$10,500	\$8,000	\$52,418	\$30,418	over budget
ACDE	\$22,000	\$25,500	\$25,000	\$13,500	\$1,750	\$53,419	\$31,419	over budget
BCDE	\$17,000	\$13,500	\$21,000	\$14,000	\$7,750	\$43,685	\$26,685	over budget
ABCDE	\$27,000	\$28,500	\$29,000	\$15,500	\$8,750	\$65,158	\$38,158	over budget

Thus, we see that there is no real advantage to the PI or even the Adjusted-PI. The NPV rule tells us all we need to know. The PI ranking rule, so commonly taught in textbooks works only in limited situations.

Another type of situation when the profitability index will break down is for projects that do not involve an initial outlay followed by a stream of mostly positive cash flows. For example, assume that a construction firm wins a contract to build a building that will require two years of work. The firm will be paid \$20 million in installments of \$10 million up front, \$5 million in one year if the project is on schedule, and the remaining \$5 million a year later upon completion of the project. The firm will incur up-front costs of \$2 million, costs at the end of the first year of \$12 million, and costs at the end of the second year of \$4 million. The cash flows look like this.



The cost of capital is 12%. The NPV is

$$NPV = +\$8,000,000 - \frac{\$7,000,000}{(1.12)^1} + \frac{\$1,000,000}{(1.12)^2} = \$2,547,194.$$

So how could we construct a profitability index? This is not the more conventional type of project in which there is an initial outlay followed by a series of mostly positive cash flows. This type of project is oftentimes referred to as a *borrowing project* when illustrating the internal rate of return. It is a project in which most of the positive cash flow occurs at the start, which makes it more like a loan.⁴ If one insists on using tools other than NPV, it requires a different way of thinking. All in all, it is best to scrap the PI as a capital investment decision tool. Like the IRR, there are too many exceptions in which the rule simply does not work.⁵

There is yet another problem with the profitability index and that lies in what we call it. I reserve those thoughts for TN07-04, which deals with problems in capital budgeting terminology.

⁴Because of a positive cash flow followed by a negative cash flow followed by another positive flow means that this type of project is also a good example of the case of multiple internal rates of return.

⁵In a borrowing project like this one, a PI could be constructed by finding the present value of the cash outflows and treating that like the initial outlay. Then divide that number into the present value of the cash inflows. But of course, by that time you have effectively calculated the NPV.