EC334 Second Seminar

Junxi Liu

Recap

- In the last seminar, we talked about:
  - The intuition behind options
  - How to calculate NPV (with infinite periods)
  - How to value an real option
- The solutions to the seminar problem set 1 has been sent to you and uploaded to my website
- The assessment for this module is due in Week 27 (03/04/2023)
- Please note that you can book multiple slots for my office hour, if you think you will need a large amount of time.
- This week we will be discussing
  - Exam questions and seminar questions for real options
  - Risk neutral probabilities
  - Efficient market hypothesis

NPV

$$NPV = -Investment_0 + \sum_{t=1}^{N} \frac{E(FreeCashFlow_t)}{(1+WACC)^t}$$

When $-1 < r < 1$

$$\lim_{n\to\infty} \sum_{k=1}^{n} a * r^k = \lim_{n\to\infty} a * \frac{r(1-r^n)}{1-r} = a * \frac{r}{1-r} = \frac{a}{\frac{1}{r} - 1}$$

$$\sum_{t=1}^{\infty} \frac{a}{(1+WACC)^t} = \frac{a}{WACC}$$

See an real example from 2021 Final Exam

A property developer is considering taking advantage of the current increase in people working from home. It believes that it is possible to create a block of 500 new 'personal distance' offices with high-speed interconnections and 'smart rooms' that will be attractive to employers once the pandemic threat recedes. The current estimate of the rental revenue per office unit per year is £41,250; The cost of servicing each office unit is £20,000 per year. The riskless rate of return – which is used by the project planners to discount all monetary flows - is 5%. If the project is undertaken this year, it will cost £67.5 million and generate revenue starting now. Once built, the offices are expected to generate the same annual costs and revenues forever.

a. What is the NPV if the project is undertaken now? (**10 marks**)
b. Now suppose that next year, when the current uncertainty is resolved, the rental revenue per unit per year is expected either to rise to £90,000 (the recovery state, with probability 25%) or to fall to £25,000 (the 'long Covid' state, probability 75%) – and to remain at that level forever. If the decision is delayed, the project cost will rise to £75 million in the recovery state or fall to £52 million in the long Covid state, but the annual servicing cost will remain at £20,000 per unit per year. What is the NPV if the project is delayed? **(15 marks)**
c. When (if at all) should the project be undertaken and what is the option to delay the project worth to the developer? (**10 marks**)
d. A university student living in the town points out that the project is risky (at least in the first year). How would you take this into account? (be as specific as you can clear about the method and the implications for valuing the option to delay) (**15 marks**)

See an real example from 2021 Final Exam

a. What is the NPV if the project is undertaken now? (**10 marks**)

Say the original estimate is $R_0 = £41250 * 500$

$$NPV = \frac{(1+r)(Rev - MC)Q}{r} - cost = \frac{1.05(41.25K - 20K)500}{0.05} - £67.5m = £155.625m$$

b. Now suppose that next year, when the current uncertainty is resolved, the rental revenue per unit per year is expected either to rise to £90,000 (the recovery state, with probability 25%) or to fall to £25,000 (the 'long Covid' state, probability 75%) – and to remain at that level forever. If the decision is delayed, the project cost will rise to £75 million in the recovery state or fall to £52 million in the long Covid state, but the annual servicing cost will remain at £20,000 per unit per year. What is the NPV if the project is delayed? (**15 marks**)

The NPVs as seen from next period are

$$\frac{1.05 * (90K - 20K) * 500}{0.05} - £75m = £660m \text{ in the recovery state}$$

$$max\left\{0, \frac{1.05 * (25K - 20K) * 500}{0.05} - £52m\right\} = max\{0, £0.5m\} = £0.5m \text{ in long Covid}$$

So the NPV as seen from the present assuming optimal action is

$$\frac{25\% * £625m + 75\% * £0.5m}{1.05} = £157.5m$$

c. When (if at all) should the project be undertaken and what is the option to delay the project worth to the developer? (**10 marks**)

The project should be delayed but will be undertaken regardless of state; the value of the option to delay is worth $£157.5m - £155.625m = £1.875m$.

EC334 2023 Class problems 1 – Real options

1. Irreversible investment

It costs a risk neutral firm £800 to set up a factory (fixed cost). The factory can produce one unit of output per year forever. The current price of a unit of output is £100. The product price is currently uncertain. In the next period the price will increase or decrease by 50% (with equal probability) and remain fixed forever at the level it has reached. The interest rate is 10%.

a) According to NPV, should the firm invest now? This means spending £800 in the current period and selling the first unit of output for £100 today and either £150 forever afterwards or £50 forever afterwards (with equal probability).

The expected price of output is $0.5 * £150 + 0.5 * £50 = £100$

$$NPV = -£800 + \sum_{t=0}^{\infty} \frac{£100}{(1+10\%)^t} = -£800 + £1100 = £300 > 0$$

So the firm should invest now.

EC334 2023 Class problems 1 – Real options

b) What is the real option value of waiting to see whether the price goes up or down? This means investing £800 next period and getting the appropriate price forever.

Suppose the firm decides to wait and invest only once it knows the price.

If the price goes down, the firm won't invest; the future (period 1) value is

$$-£800 + \sum_{t=1}^{\infty} \frac{£50}{(1+10\%)^{t-1}} = -£800 + £550 = -£250 < 0$$

If the price goes up, the firm will invest; the future (period 1) value is

$$-£800 + \sum_{t=1}^{\infty} \frac{£150}{(1+10\%)^{t-1}} = -£800 + £1650 = £850 > 0$$

The expected present (period 0) value of waiting and the option value are

$$NPV = 0.5 * 0 + 0.5 * \frac{£850}{1.1} = £386.36$$

$$Option\ value = £386.36 - £300 = £86.36$$

EC334 2023 Class problems 1 – Real options

c) If the price for deferred investment is higher (the firm has to invest £I > £800 at the beginning of next period) how high can it be before the firm will choose to invest now?

First, work out whether the firm will invest if the price goes up or down

If the price goes down, the future (period 1) value of revenue is

$$\sum_{t=1}^{\infty} \frac{£50}{(1+10\%)^{t-1}} = £550$$

So the firm will invest after a price fall only if $I \leq £550$. If the price goes up, the future value of revenue is

$$\sum_{t=1}^{\infty} \frac{£150}{(1+10\%)^{t-1}} = £1650$$

So the firm will invest after a price rise only if $I \leq £1650$. If price is any larger, it will never invest tomorrow and will certainly invest today, but this ceiling price is too high. If the firm invests tomorrow only if price goes up, its *present* value of waiting is

$$0.5 * \left[\frac{-I}{1.1} + \sum_{t=1}^{\infty} \frac{£150}{(1+10\%)^{t}}\right] = 0.5 * \left[£1500 - \frac{I}{1.1}\right] = £750 - \frac{I}{2.2}$$

The firm will prefer to invest now if £300 exceeds this amount, i.e. $I \geq £990$.

EC334 2023 Class problems 1 – Real options

d) How would your answers change if the firm could wait for two periods, and if the price could change at the end of period 1 and again at the end of 2 (in each case going up or down by 50% with equal probability) after which it would stay the same forever?

This is a more complex problem, for you to think about as revision. The changes are;

- Price trajectories are different (up or down tomorrow and the next day)
  - Up, up gives prices: £100, £150, £225, £225…: PV=£2281
  - Up, down gives prices £100, £150, £75, £75…: PV=£918
  - Down, up gives prices £100, £50, $75, £75…: PV=£827
  - Down, Down gives prices £100, £50, £25, £25…: PV=£372
  - Expected present value of revenue is still £1100
- by waiting the firm has to discount the cost of investment and the resulting revenues twice. The optimal decision can be found by considering whether the firm would invest in period 2 if the price were £225 (yes, future value in period 2 = £1675), £75 (still yes, though FV is only £25) or £25 (no). The expected value of waiting (in period 0) is therefore

$$PVW = .25 * £1675 + .5 * £25 + .25 * £0 = \frac{£431.25}{(1.1)^2} = £356$$

So the value of this option = £356 − £300 = £56.

EC334 2023 Class problems 1 – Real options

2. HS2 – a more complex option

The price of steel is currently $P_0 = £250$ per ton. Next year it will either increase by 50% to $P_g = £375$ or fall by 25% to $P_b = £187.50$ – these changes are equally likely, and the new price (and the plant) will last forever. Firm A is considering investing in a plant making steel girders for high-rise buildings. The investment must be made today or never, and will cost $I_0^A = £1.05\ billion$. The annual value of the project – starting in the period when the investment is made - is always $\mu = 175000$ times the price of steel. The risk free interest rate is $r_f = 5\%$.

a) Should the firm invest in the plant?

$NPV = \mu P_0 - I_0^A + \frac{0.5*\mu*(P_g + P_b)}{r_f} = -£21.875\ million$; the investment shouldn't be made.

b) Suppose that management has the option to expand the scale of the operation after one year. At that time, it can double the gross value of the project by investing an additional $I_1^A = £800\ million$. What is the value of this option? Should the firm invest in the smelter today?

The decision to make the first investment is taken at $t = 0$. The option must be agreed at $t = 0$ but exercised (expand or not) at $t = 1$. Expected annual revenue after this year is $R^E = 50\% * \mu * 2 * (P_g + P_b) = 49.22\ million = 50\% * 2(R_g + R_b)$.

EC334 2023 Class problems 1 – Real options

If Up	If down	Formula	Value
No	No	$\mu P_0 - I_0^A + \frac{R^E}{r_f}$	-£21.875 m
Yes	No	$\mu P_0 - I_0^A + .5\left[\frac{2R_g - r_f I_1^A}{r_f(1+r_f)}\right]$	£253.42 m
No	Yes	$\mu P_0 - I_0^A + .5\left[\frac{2R_b - r_f I_1^A}{r_f(1+r_f)}\right]$	-£74.7 m
Yes	Yes	$\mu P_0 - I_0^A + \frac{2R^E - r_f I_1^A}{r_f(1+r_f)}$	£200.6 m

The investment should be undertaken. The value of the expansion option is the difference between the NPVs; £253.42 $million - 0$ as the project would not be pursued without this option.

EC334 2023 Class problems 1 – Real options

Now suppose that Firm B has entered a partnership with a foreign steel producer who offers the following opportunity: Firm B can invest in a rail plant using the partner's steel for a current investment of $I_0 = £20\ million$, but must invest a further $I_1 = £85\ million$ next year. The value of the investment depends on whether the firm wins an HS2 contract - it will learn the outcome next year. If the firm wins the contract, the value of the plant will be $V^G = £7.5\ million$ per year from then on but if another firm wins the contract or HS2 is abandoned, the plant will only be worth $V^B = £3.25\ million$ £3.25 million per year. The firm assesses the chances of a successful bid for the HS2 contract at $\pi = 40\%$.

c) Should the firm invest in the plant?

$$NPV = \frac{0.4 * £7.5m + 0.6 * £3.25m - 5\% * £85m}{5 * 1.05} - £30m = -£1.95\ million$$

This is negative, so the answer is again no.

EC334 2023 Class problems 1 – Real options

d) Will the firm invest today, and what is the value of the option to abandon?

Abandon If win	Abandon If lose	Formula	Value
No	No	$\frac{\pi V^G + (1-\pi)V^B - r_f I_1}{r_f(1+r_f)} - I_0$	£-20.00 m
No	Yes	$\frac{\pi(V^G - r_f I_1)}{r_f(1+r_f)} - I_0$	£4.76 m
Yes	No	$\frac{(1-\pi)(V^B - r_f I_1)}{r_f(1+r_f)} - I_0$	£-31.43 m
Yes	Yes	$-I_0$	£-1.95 m

Discussions on Real Options versus NPV

- Note that managers have been observed to accept negative NPV projects.
  - In the previous example, we can also calculate the NPV of £100 state: when discounted to the present at 10% and weighted by its 50% probability, this state contributes to -£318.2 to the NPV, leading the average NPV to be £363.6
- The main difference between NPV methodology and real options is that the former *discounts expected cashflows at a constant discount rate*. NPV implicitly assumes that no decisions will be made in the future— that all expected cashflows are pre-committed.
- A second important difference between NPV and real options is that they deal with *mutually exclusive opportunities* in quite different ways. NPV treats the decision to defer one year as a mutually exclusive alternative from deferring for two years and so on. The NPV of each possible deferral choice is calculated, and we then choose the maximum of the set. In contrast, real options analysis uses a decision tree and works backward through it, from the future to the present, to calculate a single value.

Discussions on Real Options versus Decision Trees

- They both make state-contingent future decisions
- Decision trees assume a constant discount rate — either the risk-free rate or the weighted average cost of capital—throughout the tree.
- Real options analysis uses replicating portfolios and obeys the law of one price. Implicitly, it changes the risk-adjusted discount rate at each branch in the tree.
- If we extend the simple one-period example given above to the two-period example, decision tree may face difficulty on choosing discount rate

Missing discount rate

- The risk-free rate of interest is not equivalent to the discount rate, WACC.
  - Most corporate finance analysts would estimate WACC by finding the beta of a firm whose systematic risk is similar to the project, assuming a market risk premium, a tax rate, a target capital structure, and a risk-adjusted cost of debt.
  - But there is another approach— to find a priced security that has perfectly correlated payouts with the project — a twin security.
  - According to the law of one price, which prevents arbitrage, the current price of the portfolio must equal the present value of our project
- When calculating real option values, twin security don't work
  - These payouts are not perfectly correlated with the twin security or the project itself. However, we can use put-call parity to construct a replicating portfolio that is made up of m shares of the twin security and B default-free bonds

$$m(uV_0) + B(1 + r_f) = C_u,$$
$$m(dV_0) + B(1 + r_f) = C_d.$$

2020 Exam Question 1

The UK is negotiating fishing access in the post-Brexit trade deal. Assuming the deal is signed by 31 December 2020, it is expected to be worth £20 billion to the UK in present value terms.

By December 2021, this expected present value of the deal will either ***increase to £30 billion or fall to £13.33 billion***.

Between the end of 2021 and the end of 2022, this will go up or down again; the deal will ***be £45 billion if the value has increased 2 years running; £20 billion if it has had one rise and one fall (in either order); or £8.88 billion if it has fallen twice in a row.***

The ***objective probability*** of a rise in any given year each year is 70%.

Currently, the deal will cost £21 billion to implement.

- Delaying the decision (extending the negotiation) to the end of 2021 will cost £3.5 billion (whether or not there is a deal) and increase the implementation cost by 10%.
- ***A further extension (to the end of 2022) will cost an additional £0.5 billion and increase implementation cost by a further 10%.*** (Extension costs are paid when the decision to extend is made; implementation costs are incurred when the deal is concluded).
- ***There is a tradeable security that currently (in Year 0) costs £2 billion per unit and follows a binomial lattice with u= 3/2 and d= 2/3*** (meaning the price in any given year is u times the previous price if the asset goes up and d times the previous price if it goes down). It is correlated with the change in the PV of the deal. The riskless rate of interest is 5%.

2020 Exam Question 1

a. What is the trade deal worth today? Should the deal be done? [5 marks]

[All monetary figures in billions]

The value of the deal D is perfectly correlated with the value of the security S (D=10S) so the current PV is $PV(D) = £20$. This is less than the implementation cost, so the deal should not be done:

$$NPV = D - I_0 = -£1 \ < 0$$

b. What would the one-year delay option be worth?

i. Considered as a decision tree? Hint: find WACC that makes the expected present value of the project next year ignoring implementation cost equal to the current expected value (from part a) and compute the option NPV discounted by WACC using the 'objective probabilities' [5 marks]

- If the economy goes up, the deal will be worth $£30 - (1 + 10\%) * £21 = £6.9$ – accept
- If the economy goes down, the deal would be worth $£13.3 - 1.1 * £21 = -£9.766$ – reject

From the DTA perspective, the WACC is 25% since

$$\frac{70\% * £30 + 30\% * £13.3}{1 + WACC} = PV(D) = £20, \text{so}$$

$$WACC = \frac{70\% * £30 + 30\% * £13.3}{PV(D)} - 1 = 1.25 - 1 = 25\%$$

This means that the NPV with the option is

$$NPV = \frac{70\% * £6.9 + 30\% * £0}{1.25} - £3.5 = £0.364 > 0$$

So the option is worth £3.64 (million) and will be exercised only if the market goes up.

2020 Exam Question 1

ii. From a real options perspective? Hint: use the risk-neutral probabilities and the riskless discount rate. [10 marks]

First compute the risk-neutral probability of a favourable change:

$$\frac{p^{rn} * £30 + (1 - p^{rn}) * £13.3}{1.05} = £20 \text{ or } p^{rn} = 46\%$$

Hence the correct NPV is

$$NPV = \frac{46\% * £6.9 + 54\% * £0}{1.05} - £3.5 = -£0.47714 < 0$$

c. Why is the decision tree inappropriate in this case? [5 marks]

The PV of the *project* is $-£0.47714 + £3.5 = £3.0229$. Computing the replicating portfolio (D=10S),

$$\frac{\Delta D}{\Delta S} = \frac{£6.9 - £0}{£3 - £1.33} = 4.14$$

The replicating portfolio thus includes 4.14 units of S, costing £8.28 billion; there must also be -5.25714 billion units of the money market asset M, priced at 1 ($8.28 - 5.25714 = 3.0229$ as required). This portfolio will be worth £6.9 billion or 0 in Year 1, depending on whether the market goes up or down, this pattern of returns exactly matches the project with the delay option.

If someone using the decision tree approach thought the correct PV was $£0.364 + £3.5 = £3.864$, you could sell them a similar deal for £3.864 and buy the replicating portfolio for £3.0229; this would fully hedge your position and leave you with a risk-free profit of $£3.864 - £3.0229 = £0.841143$.

The economic intuition is that the decision tree method only works if you correctly adjust the WACC. Using the objective probabilities the deal next year is worth $0.7 * £6.9 + 0.3 * £0 = £4.83$. Using $\widehat{WACC} = 59.79\%$ would give the correct PV of £3.0229. But it is hard to compute the 'correct' WACC for each state. In this case, to compute WACC you could calculate the replicating portfolio weights for the stock (S) and the money market bond (M) using

$$w_S = \frac{2 * 4.14}{3.02287} = 2.7392$$

$$w_M = \frac{-5.25714}{3.02287} = -1.7392$$

Since the rates of return are $r_s = 25\%$ and $r_M = 5\%$, the expected return on the portfolio is

$$w_S * r_S + w_M * r_M = (2.739 * 25\% - 1.739 * 5\%) * 2 = 1.19565$$

2020 Exam Question 1

d. What would the 2-year delay option be worth? Would it be accepted? [15 marks]

Start by identifying the underlying tradeable security – it is easiest to exploit the marketable asset disclaimer to use the deal without flexibility. Its values are

20	30	45
		20
	13.33	8.88

As we saw, when the market goes down, the deal will not be made. To work out the correct value of the deal when the market has gone up, note making the deal now will be worth £6.9 (as above). If the deal is delayed one more year, the discounted project value (using the riskless rate of 5% and the risk-neutral probability of 46% for a favourable outcome) is

$$\frac{46\%[1.5 * £30 - 1.1^2 * £21]}{1.05} - 0.5 = 0.46 * (£45 - £25.41)/(1 + 0.05) - £0.5 = £8.08228 > £6.9$$

so if the market goes up it will be optimal to delay till Year 2. This tells us that the value of the deal in Year 1 is £8.08228 if the market goes up and £0 if the market goes down. Computing the NPV as of year 0 gives

$$NPV = \frac{46\% * £8.08228 + 54\% * £0}{1.05} - £3.5 = £0.0408 > 0$$

So the deal with a 2-year delay should (just) be accepted.

e. How does this compare to a fixed ('European') option to extend the negotiation period (delay decision) by exactly 2 years, assuming that costs would stay the same (£3.5 billion immediately and £0.5 billion next year, with an implementation cost of £25.41 billion in year 2 if a deal is accepted then)? Intuitively, how (if at all) would expect the 'American' option considered above or this 'European' option to affect the value of the eventual deal? [10 marks]

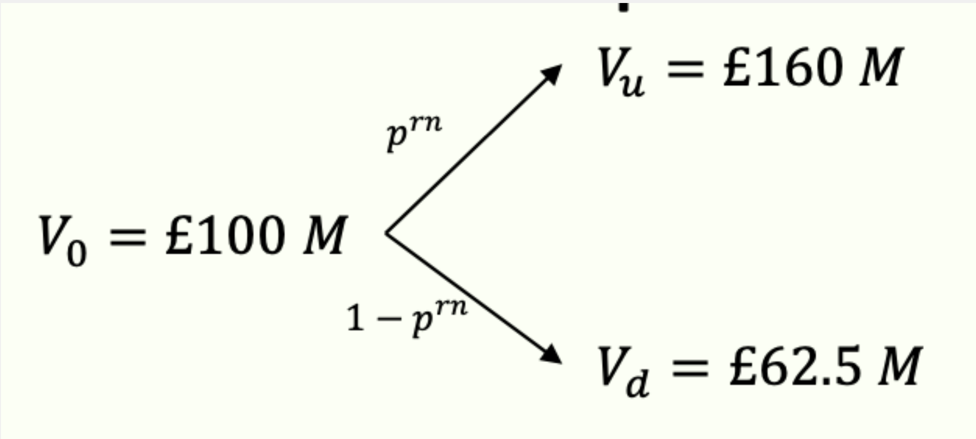
Students need not compute this exactly, but should notice that it is less valuable (e.g. because an unfavourable outcome next year allows the UK to save the second extension cost (£0.5 billion) if and only if they choose the American option. They should also note that the European option reduces UK bargaining power and flexibility.

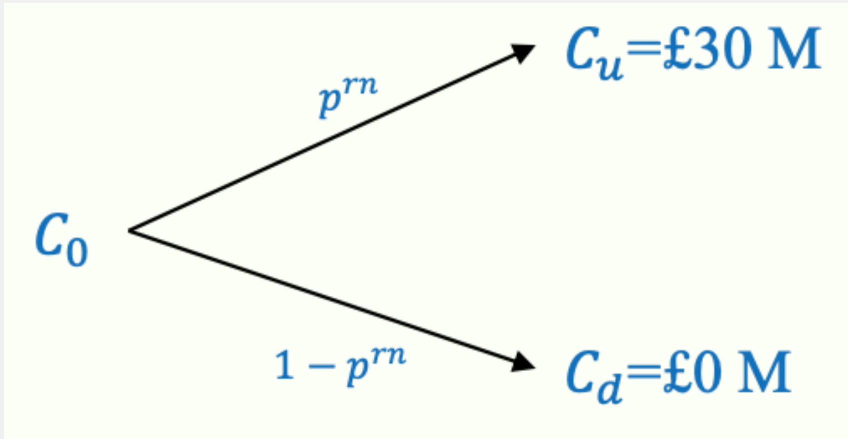
2019 Exam Question 1

1. The UK is considering a post-Brexit trade deal. If the deal is signed in Year 0, by Year 1 the expected present value of the deal will change from today's expectation, to £1500 billion if the world economy goes up or £667 billion if the world economy goes down. Between Year 1 and Year 2, the world economy will change again; the expected present value of the deal will be £2250 billion if the economy goes up 2 years running; £1000 billion if it goes down in Year 1 and up in Year 2 or up in Year 1 and Down in year 2; or £444 billion if it goes down 2 years in a row. The probability of the world economy improving in any given year each year is 70%. The initial implementation cost of the deal is £1050 billion. Delaying decision from Year 0 to Year 1 will cost £175 billion and increase the implementation cost by 10%. Delaying decision from Year 1 to Year 2 will cost an additional £25 billion and increase the implementation cost by a further 10%. (Implementation costs are incurred when the decision to take the deal is made). There is a tradeable security that currently (in Year 0) costs £100 billion per unit and follows a binomial lattice with $u = \frac{3}{2}$ and $d = \frac{2}{3}$ (meaning the price in any given year is u times the previous price if the asset goes up and d times the previous price if it goes down). It is correlated with the world economy. The riskless rate of interest is 5%.

Risk-neutral probabilities

$$\frac{p^{RN}R_{+}+(1-p^{RN})R_{-}}{(1+r_f)}=R_0 \quad p^{RN}=\frac{(1+r_f)R_0-R_{-}}{R_{+}-R_{-}}$$





$$C=\frac{p^{rn}C_u+(1-p^{rn})C_d}{1+r_f}=\frac{p^{rn}£30\ M+(1-p^{rn})£0}{1.05}=12.45$$

- Note: risk-neutral probabilities are not “real” probabilities; they don’t reflect the actual odds of any particular cash flow. They are simply another way of determining the project’s market value.

2021 Exam Question 1

d. A university student living in the town points out that the project is risky (at least in the first year). How would you take this into account? (be as specific as you can clear about the method and the implications for valuing the option to delay) (**15 marks**)

The basic answer is to do one of two things. One is to compute the WACC for the decision tree (noting that the revenue streams after next period are riskless) using the objective probabilities and use the WACC to discount the NPVs used to value the project and the option. The other is to compute the risk-neutral probabilities for the original project and use these together with the riskless discount rate. This is worth 8 marks; a further 7 marks should be given for accurate calculations. The high revenue is $R_+ = £90000 * 500$; low revenue is $R_- = £25000 * 500$;

$$p^{RN} = \frac{(1 + r_f)R_0 - R_-}{R_+ - R_-} = \frac{(1 + 0.05) * 20625000 - 12500000}{45000000 - 12500000} = 28.17\%$$

$$NPV = \frac{p^{RN} * NPVH + (1 - p^{RN}) * NPVL}{1 + r_f} = £177.43m$$

Option value increases to $£177.43m - £155.625m = £21.8m$

Efficient Market Hypothesis (EMH)

- A critical and dubious assumption is that we can describe the process behind the value of an underlying objectively and clearly – this effectively states that properly- anticipated prices will vary randomly (exogenously)
- But will this hold?
  - Apple's stock price might be correlated with other tech companies
  - Apple's stock performance today might be related to its performance yesterday
  - Apple's stock may fluctuate around a mean value

The signal $E(\omega)$ has *prior probability* $\mathrm{p}(E(\omega))$

For any state ω', the *posterior probability* of ω' given the message E is $\mathrm{p}(\omega'|E)$

$U(a,\omega)$ is the *utility* of taking an action a in state ω

V_0 is the *utility of taking the 'optimal' action* without knowing anything

The *value of the information structure* Π is

$$V(\Pi) = \sum_{E=\Pi_1}^{\Pi_K} p(E)\left[\max_a \int \mathrm{p}(\omega|E)U(a,\omega)\right] - V_0$$

It measures the increase in expected utility from having access to the information in Π and thus being able to adjust action a.

Fama versus Samuelson

- Fama saw financial markets as competitive, so price fluctuations must converge to the 'true' value.
- Fama's "Prices fully reflect all available information" lacks a clear definition of things like 'prices', 'information' and 'reflect' – it is also not clear *how* this has to happen (what 'efficient' really means).
- Samuelson believed randomness and unpredictability arise from competition among investors, independent of 'true value'.
- In informationally efficient markets, price changes must be unforecastable if they fully incorporate the information and expectations of all market participants.
- The more efficient the market, the more random the sequence of price changes it generates

Implications

- *Weak form*: current price reflects the information contained in *all past prices*, so charts and technical analyses that use past prices alone would not consistently outperform the market.

- *Semi-strong form*: current price reflects the information contained in *all public information* (including financial statements and news reports), so no strategy predicated on using and massaging this information can consistently outperform the market.

- *Strong form*: current price reflects *all information*, private and public, so no investor can consistently beat the market.

- No group of investors should be able consistently to beat the market using a common investment strategy.

- An efficient market would also carry very negative implications for many investment strategies and actions that are taken for granted -

2021 Exam Question 2

- “The growing availability of data and the use of technical and ‘big data’ analysis tools will make capital markets (strong-form) efficient.” Discuss whether this is true and the implications for market regulation. (50 marks)
- Should ***discuss the efficient markets hypothesis conclusion*** that no strategy can ‘beat the market’ consistently and forever; thus technical analysis will not (under ideal conditions) pay off. But trades made in this way will ***reflect a broader set of relevant information*** which are then embedded in market prices. A second point concerns ***the set of information used***; there is a potential issue of endogeneity that suggests that not all data will be available to all potential investors – as a result of this asymmetry, the market may be incomplete. Another question is whether ‘big data’ tools can ***identify technical vs. fundamental divergence*** (treating all data as unstructured). A further uncertainty is whether sophisticated (next-gen) algorithms will succeed or be driven out by fast/stupid ones. The computational disadvantages and noisiness of analytics applied to unstructured data – and the widespread availability of computing platforms to the public - may lead such models to incorporate only publicly-available data and thus to generate at best semi-strong efficiency. ***A good answer might also discuss whether strong efficiency necessarily implies semi-strong efficiency or vice versa***. The regulatory implications are that market behaviour may become less predictable and more chaotic, that linkages between the real and financial economies may ‘rewire’ and that control of data (and markets in data) may overlay both real and financial economies. This may mean that we need to consider information flow and access regulation, algorithmic regulation, structural regulation, etc.

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- Discuss the differences between the Fama and Samuelson approaches to the efficient market hypothesis. What are the different types of market efficiency, and how might they be affected by e.g. better and more accessible market data, enhanced computation methods (such as machine learning) and regulation? Do you agree with the statement that "financial regulation should seek to make markets as efficient as possible, and nothing more" – explain your answer. [50 marks]
- Fama saw financial markets as competitive, so ***price fluctuations must converge to the 'true' value***. He sought to reconcile technical and fundamental market analysis; given a single 'grounded truth', technical analysis is the means by which the fundamentals are identified and recognised; the random fluctuations are around this convergence, not the convergence itself. Fama's "Prices fully reflect all available information" lacks a clear definition of things like 'prices', 'information' and 'reflect' – it is also not clear how this has to happen (what 'efficient' really means). For Samuelson, **randomness and unpredictability arise from competition between investors, independent of 'true value'.** Price changes In informationally efficient markets must be unforecastable if they are properly anticipated (fully incorporate the information and expectations of all market participants). In other words, the more efficient the market, the more random the sequence of price

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- changes it generates - the most efficient market is one in which price changes are completely random and unpredictable. This is not an accident, but the direct result of many active market participants attempting to profit from their information. An army of investors pounce on even the smallest informational advantages at their disposal; thus their information is incorporated into market prices and quickly eliminates the profit opportunities that first motivated their trades. If this occurs instantaneously, which it must in an idealized world of ‘frictionless’ markets and costless trading, then prices must always fully reflect all available information. Therefore, no profits can be garnered from information-based trading because such profits must have already been captured. In mathematical terms, prices follow martingales.
- Students should differentiate efficiency with respect to different information sets (weak=past prices; semi-strong=public information; strong=all relevant information) and (optionally) informational, operational etc. efficiencies. Better data may bring markets closer to efficiency w.r.t. that data set, but possibly produce responses that are not efficient w.r.t. subsets (if data are not common knowledge). The speed and completeness with which data are spread and priced in may discourage investors from bringing them (esp. to public exchanges). Machine learning can improve efficiency, but can also lead to herding and/or algorithmic departures from the competitive ideal (as algorithms respond to each other, or as speed premium encourages fast/stupid models). Regulation that does not distinguish good from bad motives for a given behaviour (e.g. quote cancellation or naked short sales) can produce new forms of market manipulation or even drive economic activity away from markets. It can limit the speed of trade discovery and execution, inhibit abuses like quote-stuffing or obfuscation, and mandate even disclosure and verification of data. Efficiency may be an inadequate goal (it may stop markets from doing a second-best job of identifying and supplying capital to the best ‘real economy’ ventures, etc.

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- "The random walk hypothesis" states that stock market prices evolve according to a random walk - so price changes are random - and thus cannot be predicted. The efficient markets hypothesis states that asset prices fully reflect all available information (implying that it is impossible consistently to "beat the market" on a risk-adjusted basis since market prices only react to new information). What, if any, is the relation between these two hypotheses (Does either imply the other? How can they be tested?)
- These hypotheses are not directly related – ***neither strictly implies the other***. The EMH says that the information available to the market at time t-1 and at time t is the same unless something happens outside the market. Effectively, you cannot test market efficiency without knowing how the market uses information to set prices. So you can either assume a mechanism for price setting and use this to test efficiency or assume efficiency and test market behavior – but not both at once. That's why Fama says that the EMH is too general to be tested. The RWH is an assumption about how the joint distribution of prices evolves; to get from the EMH to the RWH we'd need to assume something like competitive markets.
- A further refinement is that prices are pretty simple compared to the possible range of 'all information' (semi-strong and strong forms of EMH). This in turn means that there is no obvious reason why weak-conclusion that the expectation conditioned on all past information is the best predictor is valid: if $p_t = E\left(p_t \mid I_t^{\text{market}}\right) + \varepsilon_t$, where $E\left(\varepsilon_t \mid I_t^{\text{market}}\right) = 0$, then EMH implies $E\left(\varepsilon_t \mid I_{t-1}^{\text{market}}\right) = 0$
- Students should note that EMH is a statement about aggregates or averages. A good answer will note that computing a conditional expectation does not necessarily say anything about how the market behaves. As for RWH, it says that discounted returns are unpredictable after corrections for dividends; but prices or returns themselves might be predictable. In particular, CAPM modelling shows that long-run excess returns are quite predictable. What is not predictable are attitudes towards risk – the 'price of risk'.