Financial Engineering and real options analysis in evaluation of health care technology: a forward approach

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Financial Engineering
and health/medical care project valuation
Some examples

Claxton (1999)
Perlitz, Peske and Schrank (1999)
Palmer and Smith (2000)
van Bekkum, Pennings and Smit (2008)
Magazzini, Pammolli and Riccaboni (2015)
Schwartz (2004)
Kellogg and Charnes (2000)
Nigro, Morreale and Enea (2014)
Levaggi, Moretto and Pertile (2016)
Cassimon, Backer, Engelen, van Wouwe and Yordanov (2011)
Pennings and Sereno (2011)
Hartmann and Hassan (2006)
Cassimon, Engelen, Thomassen and van Wouwe (2004)
Willigers and Hansen (2008)
The trade-off between risk and reward
Linear and non-linear valuation approaches
A toy example

- Project can succeed with probability $\frac{1}{2}$
  Payoff: 60 million
- Project can fail with probability $\frac{1}{2}$
  Loss: $-40$ million
- How much would we pay to finance this project?
- An intuitive, but totally wrong, approach is to value linearly
  
  Project valuation: $\frac{1}{2}60 + \frac{1}{2}(-40) = 10$ (million)

- However this is unrealistic, for a loss of $-40$ million might not be affordable at all!
Approach 2 (Insurance-type valuation)
Risk measures, reserves

Certainty equivalent

Based on "risk aversion" : prefer certainty to uncertainty

Project gives

\[
\begin{cases}
60 \text{ m} & \text{chances 1/2} \\
-40 \text{ m} & \text{chances 1/2}
\end{cases}
\]

Risk aversion

10 with certainty is preferable to 10 "with uncertainty"

\[
\left( \frac{1}{2} \times 60 + \frac{1}{2} \times (-40) = 10 \right)
\]
At current "wealth" level, say 0, reserve/utility is given by $U(10)$

If project is accepted, then its utility becomes

$$\frac{1}{2}U(60) + \frac{1}{2}U(-40) = \text{Average project utility } V(\text{Project})$$

**Risk aversion**

$$U(10) > \frac{1}{2}U(60) + \frac{1}{2}U(-40)$$

Valuation: find the "break-even" amount, $W$, such that

$$U(10) = V(W + \text{Project})$$

It turns out (K. Arrow (Nobel Prize in Economics 1972) that the risk premium (amount we are willing to commit to the project) is given by

$$W(\text{Project}) = -\frac{1}{2} \frac{U''(10)}{U'(10)} \text{Var}(\text{Project})$$

The riskier the project, the higher the risk premium!

Still, this valuation procedure has major deficiencies: difficult to access $U$, static, etc...
Black-Scholes-Merton (Nobel Prize in Economics 1997)

Toy example
Recall that chances of getting 60/−40 are 1/2 for each scenario.
Assume we can do the following:

- Commit 10 million for the project
- Bet in a casino: Project succeeds ←→ Black occurs
  Project fails ←→ Red occurs
- How much to bet:
  -50 million if Black occurs
  +50 million if Red occurs
- We need 0 investment for this bet - feasible
- Net outcome of this strategy

If Black occurs: −10 − 50 : −60 loss - Project gain 60 million
⇒ Net: 0 million
If Red occurs: −10 + 50 : +40 profit - Project loss −40 million
⇒ Net: 0 million

So, by having the ability to bet on uncertainty, we offset the risk no matter what happens.
The price for this project remains 10 as in the very first case
\[ \left( \frac{1}{2} 60 + \frac{1}{2} (-40) = 10 \right) \] but, now, we do not face the dreadful event of loosing 40 million?

This seemingly redundant idea gave birth to the Derivatives Industry
Revolutionary idea of Black-Scholes-Merton

• Casino $\implies$ stock

• Project $\implies$ derivative on the stock (a contract whose payoff depends on what the stock)

• Casino bet $\implies$ hedging strategy

• Value of the project $\implies$ Value of the derivative

Marriage made in (scientific) heaven

Foundational result

• Stock is the "underlying security"
• Contract is written on the stock
• We can trade the stock (the same way we bet in the casino) to form the so-called "replicating strategy" which offsets all risks
• The wealth needed to set up this replicating strategy is then the price of the contract
• Value of the contract completely specified (for all times)

\[
\text{Value of project} = \mathbb{E}_Q (\text{discounted payoff})
\]

• The measure \( \mathbb{Q} \) is of tantamount importance (....long story....)
• Linear in payoff (no "utility" specification needed)
• Dynamic, universal pricing and hedging rule
• A plethora of contracts can be valued this way (good and bad news, if this technology is misused)
So how do we value/finance health care/medical research projects?
Bad news, challenges, great opportunities for cross/trans/inter-disciplinary research
Real-world projects are not written on "financial assets"

- There is no financial asset matching the evolution/outcome of a "clinical trial", or of a "drug development", or of a "hospital operation project"
- Thus, there is no exact matching of "project risks" with "financial risks"
- Financial assets can be "proxies" but catastrophic losses can always occur even with small (but not zero) probability
- The classical risk-free valuation approach collapses
- Risk cannot be offset and thus remaining risks have to be hedged

How do then price and hedge?
Real options, Risk measures
Indifference Valuation
Develop valuation hybrids between the risk-free dynamic (across times) and the utility-based static valuation approaches

- Choose a financial proxy that can be traded
- Develop a dynamic portfolio on it
- Develop dynamic optimization criteria without the project \((W = \text{"wealth"})\)

\[
\max_{\text{portfolios}} \left( E(U(W_T)) \right) = \max_{\text{portfolios}} \left( \text{Average Utility (outcomes of trading strategies)} \right)
\]

- Develop dynamic optimization criteria with the project (liability) at time \(T\)

\[
\max_{\text{portfolios}} \left( E(U(W_T - P_T)) \right)
\]

\[
= \max_{\text{portfolios}} \left( \text{Average Utility (outcomes of trading strategies-project liability)} \right)
\]

- Find the cost at initial time, \(C_0\), that is the break-even point

\[
\max_{\text{portfolios}} \left( E(U(W_T)) \right) = \max_{\text{portfolios}} \left( E(U(C_0 + W_T - P_T)) \right)
\]

Easier said than done!
Many challenges

Recall: Value of the project $C_0$ is found endogenously by solving

$$\max_{\text{portfolios}} (E(U(W_T))) = \max_{\text{portfolios}} (E(U(C_0 + W_T - P_T)))$$

- How do we model the random $P_T$ (project)?
- How do we model the utility?
- How do we choose the proxy financial asset on which we trade? What is a good match (familiarity/diversification)?
- How do we choose the underlying models?
  We need a model for the evolution of the financial proxy
  We need a model for the evolution of the clinical trial, the R&D project, etc...
- Model selection is one of the biggest challenges
- What if we have sequential projects? (Phases of drug development, clinical trials, ..?)
Model selection, model adaptation
Data and learning
Challenges

• The existing optimization methods are based on pre-selecting a model (or a family of models) for both the financial asset (proxy) and the evolution of the project during the project’s horizon $[0, T]$ - backwards optimization

• What happens if market conditions change in the mean time and the original model of the financial proxy turns out to be wrong?

• What happens if the model for the project evolution turns out to be inadequate?

• Models can be reasonable but exogenous unpredictable events may occur

• Also, learning takes place through incoming data. Classical methods cannot be applied?

• How do we adapt our models in practice and in theory?
Practice
KEEP CALM AND MODEL ON
Consequences of adapting to a new model(s)

- Classical theoretical optimization results fail
- Time-inconsistencies
- Practical difficulties if other components in the general project valuation scheme remain time-consistent
- In general, what happens in practice is ad hoc!
- Very little in common with the sound results in derivative valuation!
Theoretical advances
Forward-in-time valuation approach

Musiela, Z. (2003-), Nadtochiy, Tehranchi, Berrier et al., El Karoui and M’rad, Shkolnikov, Sircar, Leung, ...

- Extend the classical optimization theory forward-in-time
- Allow for model adaptation
- Allow for risk-preference profile adaptation
- Preserve time-consistency
- Universal, model free approach
Classical approach

- Projects valuation horizon $[0, T]$ prescribed at $t = 0$

- A full model (deterministic or probabilistic) for describing payoffs of all (possibly) involved projects during $[0, T]$ needs to be specified at $t = 0$, and fixed thereafter

- Solution is obtained backwards in time; valuation of first project depends on the accurate model for all future projects during $[0, T]$ (e.g., arriving times, payoff functions, underlying financial market, etc)

- Model/project commitment; no model flexibility for unanticipated market change beyond $t = 0$, and no project flexibility for newly arising R&D opportunities

- Breaking the commitment leads to not well-defined valuation problems (i.e., time-inconsistency, loss of classical optimality, etc)
Forward approach

- Flexible projects valuation horizons; not necessarily "definite"
- Flexible model revision; an accurate model is only needed for a (small) period ahead, and then model revision is done sequentially (e.g., on-line learning)
- Solution is constructed forward in time along with forward moving market and newly incoming R&D opportunities
- Valuation of current project only depends on already known risk exposures; no need to model all possible extra risks (because they may not be able to be predicted-modeled)
- Valuation criteria adapt to changes in model/projects profile as they occur; inter-temporal consistency across different project valuation periods is preserved
In a much bigger picture
Securitize health care/medical research
• Recall that financial assets cannot match the "real projects"
• But what if new financial securities are build for such projects?
• Should we securitize medical research?
• How do we do this then?

Pioneering work of A. Lo and his research group at MIT

Financial Engineering and Cancer Research
Main idea

- In Credit Risk (a very important area in finance), the main objects are defaults.
- Defaults are undesirable and typically rare events.
- Defaults also cluster (systemic risks).
- However, medical breakthroughs are "good, desirable" rare events.

Medical breakthrough $\leftrightarrow$ Financial default
Main idea

- If we securitize medical research, then the powerful classical Black-Scholes theory can apply
- Risks of funding medical research can be offset, or at least minimized in an efficient way
- The powerful machinery of Derivative Valuation can be applied
- Financial technology already in place
Summary

- Valuation and risk management of health care/medical research can be done more efficiently using Financial Engineering.
- Existing methods and techniques are readily available.
- New developments in forward project valuation can accommodate learning, incoming data, model adaptation, sequential projects, etc.
- For scalable projects, financial securitization can be put in place.