The impact of external market conditions on real options valuation

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How do macroeconomic or industry factors influence R&D project’s

1. value (NPV)
2. success
3. failure

... over time?
We present a novel valuation model based on real options

1. that incorporates the impact of external forces, such as market conditions, economic uncertainty, innovation, firm competition on the cash flow generation

2. that features an option to abandon

3. that enables to estimate the impact of these external conditions on the optimal launching time for the project as well as on success or failure rates of the project

Our practical case covers a pharmaceutical R&D project, but the model and methodology can be easily extrapolated to any industry.
The literature has shown the economic and social impact of R&D projects as well as the impact of the economic and social context on R&D spending:

- International context, GDP as determinants of public spending in research and developments (Hammadou et al., 2014, RP)
- Effect of public funding on innovative projects (Lanahan and Feldman, 2017, RES)
- Productivity growth and R&D expenses (e.g. Kancs an Siliverstovs, 2016, RP)
- Social and economic impact of R&D (e.g. Brautzsch et al., 2015, RP; Ugur et al., 2016, RP)
1 R&D valuation model
   ▪ Literature Review
   ▪ Our contribution: modeling external forces
   ▪ Project’s value

2 Simulation analysis
   ▪ Practical case
   ▪ Practical case v1
   ▪ Practical case v2 (new)

3 Concluding remarks
R&D valuation model
Theoretical framework

In the extant literature, real options have been used to model

- staged investments (e.g. Madj and Pindyck, 1987, JFE; Berk et al., 2004, RFS)
- the optimal timing of investments (e.g. McDonald and Siegel, 1986, QJE; Posner and Zuckerman, 1990, JAP)
- the impact of uncertainty in cash flows and cost on the project’s value and risk (e.g. Schwartz, 2004, EN; Berk et al., 2004, RFS)
Theoretical framework

Modeling choices

- Modeling project’s market value (e.g. Madj and Pindyck, 1987, JFE; Pennings and Sereno, 2011, EJOR; Alexander et al., 2012, EJOR)
- Modeling project’s cash flows (e.g. Berk et al., 2004, RFS; Schwartz, 2004, EN)
- Modeling cost of completion and expenditures (e.g. DiMasi et al., 2003, JHE; Pindyck, 1993, JFE; McDonald and Siegel, 1986, QJE)
- Modeling technical risk (e.g. Schwartz, 2004, EN; Pindyck, 1993, JFE; Pennings and Sereno, 2011, EJOR)
In the literature, it is common to model the evolution of the project or the evolution of the cash flow as a stochastic differential equation...

\[ dC_t = \mu(C, t)dt + \sigma(C, t)dW \]

- Geometric Brownian motion
- Arithmetic Brownian motion
- Ornstein-Uhlenbeck process

These models account for market uncertainty and idiosyncratic risk of the project but not for external cyclical forces.
Theoretical framework

To account for technical risk, we generalize the Poisson distribution...

\[
\text{Probability of success} = e^{-\lambda}
\]

\[
\text{Probability of technical failure} = \sum_{k=1}^{\infty} \frac{\lambda^k e^{-\lambda}}{k!} = 1 - e^{-\lambda}
\]
The expected project value *conditional to technical risk* is given as

$$E [V | \text{Technical Risk}] = V(k = 0) \cdot e^{-\lambda} + V(k = 1, 2, ..., \infty) \cdot (1 - e^{-\lambda})$$

Assuming $V(k = 1, 2, ..., \infty) = 0$

- During the development process the discount factor is given by

$$e^{-r_d t} = e^{-(r+\hat{\lambda})t}$$
Theoretical framework

All these models share the same source of uncertainty...

- A random walk weighted by $\sigma(C, t)$ for capturing market and idiosyncratic risk
- A Poisson distribution to account for technical risk

No model accounts for...

- Seasonal effects
- Business cycle
- Other relevant external forces
Economic and market external forces

Consider the net cash flow stream of a successful project

\[ C_t = f(t) + Y_t \]

Where

\[ dY_t = \mu dt + \sigma dW_t \Rightarrow \text{Arithmetic Brownian motion} \]
\[ f(t) = \text{Fourier series} \]

- The net cash flow of a successful project is given by an arithmetic Brownian motion process plus a time-dependent component depicted by a Fourier series.
- The Fourier series is a function defined as the sum of a set of simple sines and cosines, representing all the forces that impact the generation of cash flows.
Cash flow generation

Under the risk neutral probability $\mathbb{P}^Q$, the solution at any given time $t$ is

$$Y_t = Y_0 e^{rt} + \sigma \int_0^t e^{r(t-s)} dW_s^Q$$

$$C_t = Y_0 e^{rt} + f(t) + \sigma \int_0^t e^{r(t-s)} dW_s^Q$$

where $W_t^Q$ is a standard Wiener process under the risk-neutral measure $\mathbb{P}^Q$. 
State vector

Let’s define the economic state vector...

\[ \Phi^{(j)} \text{ with } j \in \mathbb{N} \]

Each state...
State vector

Let’s define the economic state vector...

\[ \Phi^{(j)} \text{ with } j \in \mathbb{N} \]

Each state...
- corresponds to a specific scenario
- described by the cyclicality and the phase of the economic forces
Patent value

The expected patent value conditional to certain economic state is given as...

\[ E \left[ V \mid \Phi^{(j)} \right] = V \left( t, C_t, I_t; \Phi^{(j)} \right) \cdot Pr \left( \Phi = \Phi^{(j)} \right) \]
Simulation exercise
Pharmaceutical project’s stages

Two major phases...

1. Research and development phase
2. Market phase

The failure of one stage leads to overall project termination. We assume that once the project successfully passes every test and stage of the R&D process and finally achieves regulatory approval, technical risk virtually vanishes.
Economic forces

For the sake of simplicity let’s assume two economic forces...

1. **US Gross domestic product (GDP)**
   - The business cycle is defined as the cyclical movement of the GDP around its long-term trend
   - Hodrick-Prescott (1997) filter to disentangle the cyclical behaviour from the long-term trend
   - 278 quarterly GDP observations ranging from January 1947 to April 2016, obtained from the Federal Reserve Bank of St. Louis web page

2. **VIX index**
   - Barometer of investor sentiment and market volatility
   - Hodrick-Prescott (1997) filter
   - 1990-2016, monthly observations provided by the Chicago Board Options Exchange (CBOE)
Peak at a frequency of 0.1871 Hz

Representing a cyclical period of 5.35 years
**Volatility cycle**

- **VIX short- to medium-term cyclical component**
- **Two dominating peaks with period of 1.4 and 3.8 years**
Volatility cycle

- Volatility long-term component
- Representing a long term period of 13.25 years (0.0755 Hz)
Amplitude parameter

We use two well known Pharmaceutical Indexes:

- S&P 500 Pharmaceutical Index
- NYSE ARCA Pharmaceutical Index
- Ranging from July 1992 to April 2016

<table>
<thead>
<tr>
<th></th>
<th>S5PHAR Index</th>
<th>DRG Index</th>
</tr>
</thead>
<tbody>
<tr>
<td>GDP cyclical component</td>
<td>0.4907 (&lt;0.001)</td>
<td>0.5011 (&lt;0.001)</td>
</tr>
<tr>
<td>VIX cyclical component</td>
<td>0.0932 (0.195)</td>
<td>0.0913 (0.192)</td>
</tr>
<tr>
<td>VIX long-term component</td>
<td>0.3440 (&lt;0.001)</td>
<td>0.3151 (&lt;0.001)</td>
</tr>
<tr>
<td>$R^2$</td>
<td>0.1275</td>
<td>0.1350</td>
</tr>
</tbody>
</table>
Simulation exercise

Project’s net cash flow when launching

- at the peak of the cycle and entering into recession, that is $\phi = 0$
- at the trough of the cycle and entering into the recovery phase, that is $\phi = \pi$
- at an intermediate phase, $\phi = \pi/2$
Simulation exercise - Business cycle

Business cycle impact on the project’s net cash flow is modeled as

\[ f(t) = 100 \{ 0.4959 \cos (1.1753 \cdot t + \phi_1) \} \]
## Simulation exercise - Business cycle

### Conditional Expected Patent Value. Business cycle

<table>
<thead>
<tr>
<th>Business Cycle Phase</th>
<th>Panel</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A</td>
</tr>
<tr>
<td>$V(t, C_t, I_t; \phi_1 = 0)$</td>
<td>908.7 (3.2)</td>
</tr>
<tr>
<td>$V(t, C_t, I_t; \phi_1 = \pi)$</td>
<td>2553.7 (4.2)</td>
</tr>
<tr>
<td>$V(t, C_t, I_t; \phi_1 = \pi/2)$</td>
<td>1584.4 (3.9)</td>
</tr>
</tbody>
</table>

**Table:** This table presents the patent value conditional to the phase parameter in the business cycle.

Panel A: With abandon option
Panel B: Without abandon option
Simulation exercise - Business and volatility cycles
We perform a new exercise fitting the parameters of the fourier series to cash flow data of pharmaceutical firms active in anti-infective drug

- New external forces are assumed to better impact a specific pharmaceutical project
  - Economic and political (business cycle and economic policy uncertainty index)
  - Innovation (R&D expenditure as % of GDP, patent applications)
  - Health expenditures (per capita, out of pocket)
  - Competition (H concentration index based on sales)
New simulation exercise

We consider the impact of these forces on a hypothetical project’s success, abandon rate and value

- The project has an initial cash-flow of 100 M$ (50 M$ standard deviation) per quarter with an initial cost to completion equal to 1000 M$ ($\sigma = 0.5$)
- US versus Europe (EU)
- Big versus small caps
External forces

Figure: Spectral analysis EU EPU
External forces

**Figure:** Spectral analysis US EPU

Cyclical component EPU in United States

Power spectral density
External forces

Figure: Spectral analysis EU Concentration

Cyclical component concentration index in Europe

Power spectral density
External forces

Figure: Spectral analysis US concentration

Cyclical component concentration index in United States

Power spectral density

Frequency (Hz)

0 0.2 0.4 0.6 0.8 1 1.2 1.4 1.6 1.8 2

0 0.2 0.4 0.6 0.8 1 ×10⁻³

Time

### External forces

**Table:** Cyclical components of external factors

<table>
<thead>
<tr>
<th></th>
<th>Angular Freq (ω)</th>
<th>Frequency (f)</th>
<th>Period</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Economic Policy Uncertainty</strong></td>
<td>1.7093</td>
<td>0.2720</td>
<td>3.68</td>
</tr>
<tr>
<td><strong>Gross Domestic Product</strong></td>
<td>1.1504</td>
<td>0.1831</td>
<td>5.46</td>
</tr>
<tr>
<td><strong>Research and development expenditure (% of GDP)</strong></td>
<td>0.6283</td>
<td>0.1000</td>
<td>10.00</td>
</tr>
<tr>
<td><strong>Patent applications</strong></td>
<td>1.0472</td>
<td>0.1667</td>
<td>6.00</td>
</tr>
<tr>
<td><strong>Health expenditure per capita</strong></td>
<td>0.3142</td>
<td>0.0500</td>
<td>20.00</td>
</tr>
<tr>
<td><strong>Out of pocket health expenditure</strong></td>
<td>0.9425</td>
<td>0.1500</td>
<td>6.67</td>
</tr>
<tr>
<td><strong>Concentration</strong></td>
<td>0.8378</td>
<td>0.1333</td>
<td>7.50</td>
</tr>
</tbody>
</table>
**External forces**

Table: Cyclical components of external factors

<table>
<thead>
<tr>
<th>Economic Policy Uncertainty</th>
<th>2.2235</th>
<th>0.3539</th>
<th>2.83</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gross Domestic Product</td>
<td>1.0927</td>
<td>0.1739</td>
<td>5.75</td>
</tr>
<tr>
<td>Research and development expenditure (% of GDP)</td>
<td>0.6283</td>
<td>0.1000</td>
<td>10.00</td>
</tr>
<tr>
<td>Patent applications</td>
<td>0.4654</td>
<td>0.0741</td>
<td>13.50</td>
</tr>
<tr>
<td>Health expenditure per capita</td>
<td>0.3142</td>
<td>0.0500</td>
<td>20.00</td>
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<td>Out of pocket health expenditure</td>
<td>0.9425</td>
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<td>6.67</td>
</tr>
<tr>
<td>Concentration</td>
<td>0.4189</td>
<td>0.0667</td>
<td>15.00</td>
</tr>
</tbody>
</table>
# Peer group analysis

**Table: CF structure - Descriptive Statistics**

<table>
<thead>
<tr>
<th></th>
<th>Anti-infective Pharmaceutical Market</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>EU: 13</td>
<td>US: 6</td>
</tr>
<tr>
<td>Average quarterly Cash-Flow</td>
<td>817</td>
<td>120</td>
</tr>
<tr>
<td>Standard Deviation</td>
<td>472</td>
<td>180</td>
</tr>
<tr>
<td>Maximum</td>
<td>2755</td>
<td>547</td>
</tr>
<tr>
<td>Minimum</td>
<td>11</td>
<td>-615</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Anti-infective EU</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Big-Cap: 3</td>
<td>Small-Cap:3</td>
</tr>
<tr>
<td>Average quarterly Cash-Flow</td>
<td>1748</td>
<td>13</td>
</tr>
<tr>
<td>Standard Deviation</td>
<td>950</td>
<td>28</td>
</tr>
<tr>
<td>Maximum</td>
<td>3667</td>
<td>105</td>
</tr>
<tr>
<td>Minimum</td>
<td>11</td>
<td>-44</td>
</tr>
</tbody>
</table>
Fitting forces to cash flow structure

Table: Factors and amplitudes

<table>
<thead>
<tr>
<th>Panel: Anti-infective</th>
<th>EU Market</th>
<th></th>
<th>US Market</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Amplitude</td>
<td>Phase</td>
<td>Amplitude</td>
<td>Phase</td>
</tr>
<tr>
<td>Economic Policy Uncertainty</td>
<td>1 (0.11)</td>
<td>5.9540</td>
<td>3 (0.01)</td>
<td>4.1818</td>
</tr>
<tr>
<td>Gross Domestic Product</td>
<td>14 (0.08)</td>
<td>0.6388</td>
<td>12 (0.01)</td>
<td>4.0168</td>
</tr>
<tr>
<td>Research and development expenditure (% of GDP)</td>
<td>18 (0.09)</td>
<td>3.1704</td>
<td>88 (0.01)</td>
<td>0.8577</td>
</tr>
<tr>
<td>Patent applications</td>
<td>9 (0.01)</td>
<td>4.2222</td>
<td>48 (0.04)</td>
<td>5.7576</td>
</tr>
<tr>
<td>Health expenditure per capita</td>
<td>47 (0.01)</td>
<td>2.1413</td>
<td>69 (0.01)</td>
<td>0.0000</td>
</tr>
<tr>
<td>Out of pocket health expenditure</td>
<td>17 (0.03)</td>
<td>0.4525</td>
<td>26 (0.05)</td>
<td>3.1786</td>
</tr>
<tr>
<td>Concentration</td>
<td>47 (0.01)</td>
<td>5.6940</td>
<td>81 (0.02)</td>
<td>3.1416</td>
</tr>
</tbody>
</table>

This table presents the standardized amplitude parameter (p-value) of each factor.
### Fitting forces to cash flow structure

**Table:** Factors and amplitudes

<table>
<thead>
<tr>
<th>Economic Policy Uncertainty</th>
<th>Big Cap Amplitude</th>
<th>Big Cap Phase</th>
<th>Small Cap Amplitude</th>
<th>Small Cap Phase</th>
</tr>
</thead>
<tbody>
<tr>
<td>7 (0.10)</td>
<td>5.9540</td>
<td>1 (0.37)</td>
<td>5.9540</td>
<td></td>
</tr>
<tr>
<td>10 (0.14)</td>
<td>0.6388</td>
<td>27 (0.11)</td>
<td>3.7804</td>
<td></td>
</tr>
</tbody>
</table>

| Gross Domestic Product      | 18 (0.05)         | 3.1704        | 33 (0.19)           | 0.0288          |
| 15 (0.01)                   | 1.0806            | 41 (0.22)     | 4.2222              |                 |

| Research and development expenditure (% of GDP) | 107 (0.01) | 2.1413 | 166 (0.01) | 5.2829 |
| Patent applications          | 16 (0.16)  | 0.4525 | 40 (0.16)  | 3.5941  |
| Health expenditure per capita| 94 (0.01)  | 5.6940 | 100 (0.07) | 2.5524  |
| Out of pocket health expenditure |                 |       |            |        |
| Concentration                |                 |       |            |        |

This table presents the standardized amplitude parameter (p-value) of each factor.
Launching time in US

Figure: All firms

- **Economic Policy Uncertainty**
- **Gross Domestic Product**
- **Research and development expenditure**
- **Patent Application**
- **Health expenditure per capita**
- **Out of Pocket Health expenditure**
- **Concentration**
Launching time in EU

Figure: All firms
Launching time in EU

Figure: Big Caps EU
Launching time in EU

Figure: Small Caps EU

- Economic Policy Uncertainty
- Gross Domestic Product
- Research and development expenditure
- Patent Application
- Health expenditure per capita
- Out of Pocket Health expenditure
- Concentration
Simulation analysis

Hypothetical project (for every group): initial cash-flow of 100 M$ (50 M$ std dev) per quarter and initial cost to completion of 1000 M$ (std dev = 0.5)

Table: Project’s value - Panel A: With abandon option Panel B: Without abandon option

<table>
<thead>
<tr>
<th></th>
<th>United States Panel</th>
<th>Europe Panel</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A</td>
<td>B</td>
</tr>
<tr>
<td>Launching at t = 0y</td>
<td>797.6 (4.5)</td>
<td>390.2 (5.8)</td>
</tr>
<tr>
<td>Abandon rate</td>
<td>50.77%</td>
<td>-</td>
</tr>
<tr>
<td>Launching at t = 1y</td>
<td>621.9 (3.9)</td>
<td>73.2 (5.7)</td>
</tr>
<tr>
<td>Abandon rate</td>
<td>58.16%</td>
<td>-</td>
</tr>
<tr>
<td>Launching at t = 2y</td>
<td>722.6 (4.3)</td>
<td>264.3 (5.7)</td>
</tr>
<tr>
<td>Abandon rate</td>
<td>53.13%</td>
<td>-</td>
</tr>
</tbody>
</table>
Simulation analysis

Hypothetical project (for every group): initial cash-flow of 100 M$ (50 M$ std dev) per quarter and initial cost to completion of 1000 M$ (std dev = 0.5)

Table: Project’s value - Panel A: With abandon option Panel B: Without abandon option

<table>
<thead>
<tr>
<th>Launching at t = 0y</th>
<th>EU BigCap</th>
<th>EU SmallCap</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abandon rate</td>
<td>A</td>
<td>B</td>
</tr>
<tr>
<td></td>
<td>1094.5 (5.3)</td>
<td>839.7 (6.10)</td>
</tr>
<tr>
<td>Abandon rate</td>
<td>37.09%</td>
<td>-</td>
</tr>
<tr>
<td>Launching at t = 1y</td>
<td>829.6 (4.5)</td>
<td>458.1 (5.8)</td>
</tr>
<tr>
<td>Abandon rate</td>
<td>45.09%</td>
<td>-</td>
</tr>
<tr>
<td>Launching at t = 2y</td>
<td>571.7 (3.6)</td>
<td>-10.2 (5.6)</td>
</tr>
<tr>
<td>Abandon rate</td>
<td>55.49%</td>
<td>-</td>
</tr>
</tbody>
</table>
We have...

- developed a novel valuation model and methodology to value a (pharmaceutical) R&D project based on real options approach
- performed simulation analyses considering the interaction of different external economic and market forces
- shown that the same project launched in different countries or by different firms (small or large) might have different success and abandon rates due to the impact of the economic and industry contexts

Our research provides managers with an important tool for timing the introduction of an R&D product to the market.
Thank you for your attention!