The impact of external market conditions on real options valuation

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Scope of the paper

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

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

... over time?

Scope of the paper

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

Scope of the paper

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)

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)

Theoretical framework

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...

$$\begin{aligned} \text{Probability of success} &= e^{-\lambda} \\ \text{Probability of technical failure} &= \sum_{k=1}^{\infty} \frac{\lambda^k e^{-\lambda}}{k!} = 1 - e^{-\lambda} \end{aligned}$$

Theoretical framework

The expected project value *conditional to technical risk* is given as

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

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

$$\begin{aligned} dY_t &= \mu dt + \sigma dW_t \Rightarrow \text{Arithmetic Brownian motion} \\ f(t) &= \text{Fourier series} \end{aligned}$$

- 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

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

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...

$$\Phi^{(j)} \quad \text{with} \quad j \in \mathbb{N}$$

Each state...

State vector

Let's define the economic state vector...

$$\Phi^{(j)} \quad \text{with} \quad j \in \mathbb{N}$$

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...

$$E\left[V\left|\Phi^{(j)}\right.\right] = V\left(t, C_t, I_t; \Phi^{(j)}\right) \cdot Pr\left(\Phi = \Phi^{(j)}\right)$$

Simulation exercise

Pharmaceutical project's stages

Two major phases...

1. Research and development phase
2. Market phase

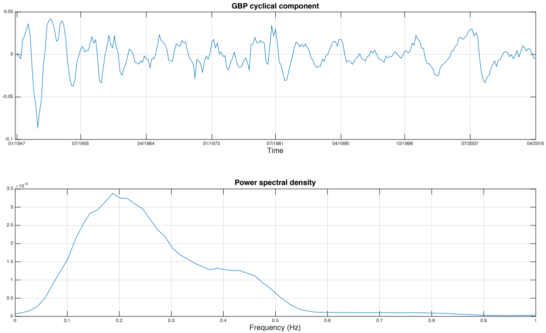
The failure of one stage leads to overall project termination. We assume that once the project successfully passes every test and stage of the R&D process and finally achieves regulatory approval, technical risk virtually vanishes.

Economic forces

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

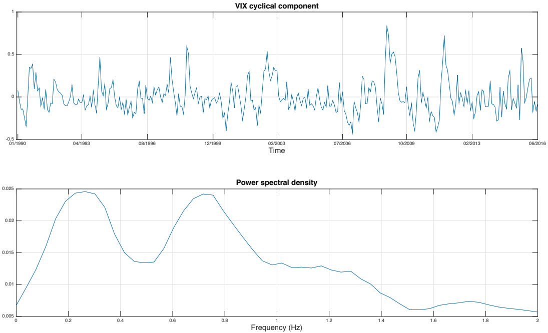
1. US Gross domestic product (GDP)
   - The business cycle is defined as the cyclical movement of the GDP around its long-term trend
   - Hodrick-Prescott (1997) filter to disentangle the cyclical behaviour from the long-term trend
   - 278 quarterly GDP observations ranging from January 1947 to April 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)

GDP cyclical component



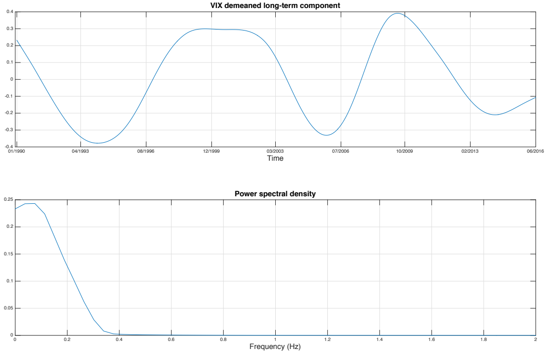
- Peak at a frequency of 0.1871Hz
- Representing a cyclical period of 5.35 years

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

	S5PHAR Index	DRG Index
GDP cyclical component	0.4907 (<0.001)	0.5011 (<0.001)
VIX cyclical component	0.0932 (0.195)	0.0913 (0.192)
VIX long-term component	0.3440 (<0.001)	0.3151 (<0.001)
R^2	0.1275	0.1350

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

$$f(t) = 100\left\{0.4959\cos\left(1.1753 \cdot t + \phi_1\right)\right\}$$

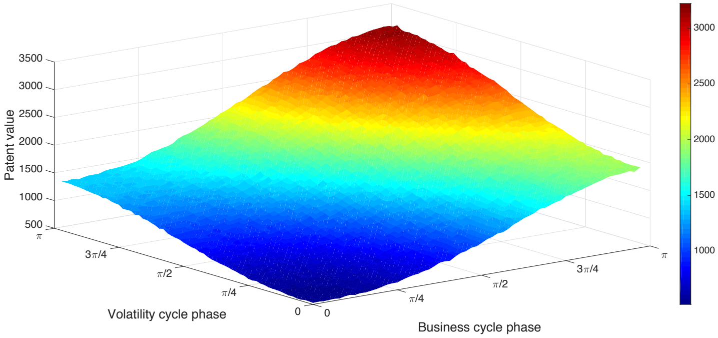
Simulation exercise - Business cycle

Conditional Expected Patent Value. Business cycle

Business Cycle Phase	Panel	
	A	B
$V(t, C_t, I_t; \phi_1 = 0)$	908.7 (3.2)	604.1 (4.3)
$V(t, C_t, I_t; \phi_1 = \pi)$	2553.7 (4.2)	2522.3 (4.4)
$V(t, C_t, I_t; \phi_1 = \pi/2)$	1584.4 (3.9)	1486.2 (4.4)

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)

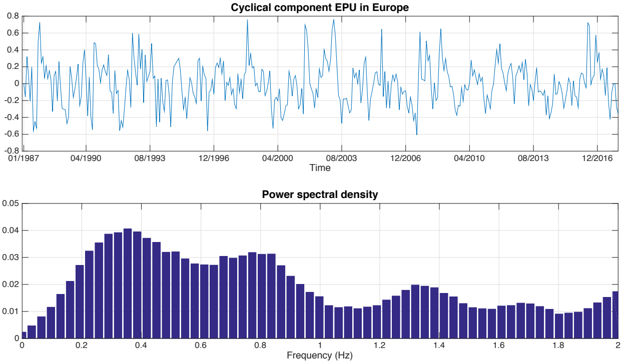
New simulation exercise

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

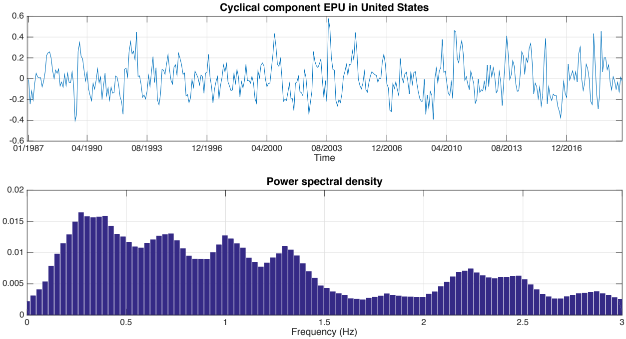
External forces

Figure: Spectral analysis EU EPU



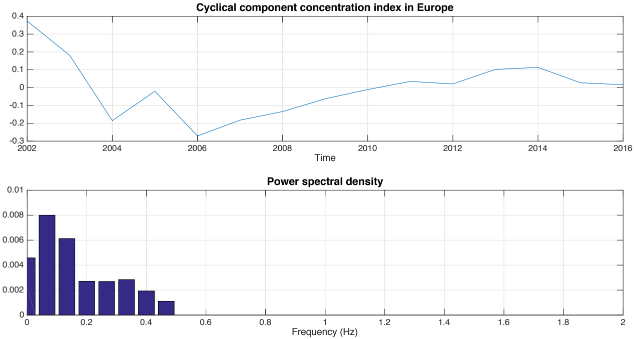
External forces

Figure: Spectral analysis US EPU



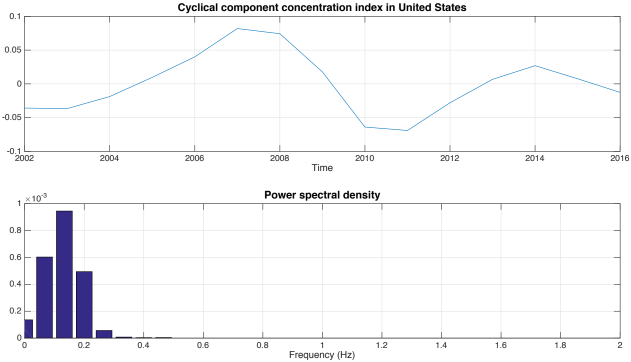
External forces

Figure: Spectral analysis EU Concentration



External forces

Figure: Spectral analysis US concentration



External forces

Table: Cyclical components of external factors

	Panel: United States		
	Angular Freq (ω)	Frequency (f)	Period
Economic Policy Uncertainty	1.7093	0.2720	3.68
Gross Domestic Product	1.1504	0.1831	5.46
Research and development expenditure (% of GDP)	0.6283	0.1000	10.00
Patent applications	1.0472	0.1667	6.00
Health expenditure per capita	0.3142	0.0500	20.00
Out of pocket health expenditure	0.9425	0.1500	6.67
Concentration	0.8378	0.1333	7.50

External forces

Table: Cyclical components of external factors

	Panel: Europe		
	Angular Freq (ω)	**Frequency (f)**	**Period**
Economic Policy Uncertainty	2.2235	0.3539	2.83
Gross Domestic Product	1.0927	0.1739	5.75
Research and development expenditure (% of GDP)	0.6283	0.1000	10.00
Patent applications	0.4654	0.0741	13.50
Health expenditure per capita	0.3142	0.0500	20.00
Out of pocket health expenditure	0.9425	0.1500	6.67
Concentration	0.4189	0.0667	15.00

Peer group analysis

Table: CF structure - Descriptive Statistics

	Anti-infective Pharmaceutical Market	
	EU: 13	**US:6**
Average quarterly Cash-Flow	817	120
Standard Deviation	472	180
Maximum	2755	547
Minimum	11	-615

	Anti-infective EU	
	Big-Cap: 3	**Small-Cap:3**
Average quarterly Cash-Flow	1748	13
Standard Deviation	950	28
Maximum	3667	105
Minimum	11	-44

Fitting forces to cash flow structure

Table: Factors and amplitudes

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

This table presents the standardized amplitude parameter (p-value) of each factor

Fitting forces to cash flow structure

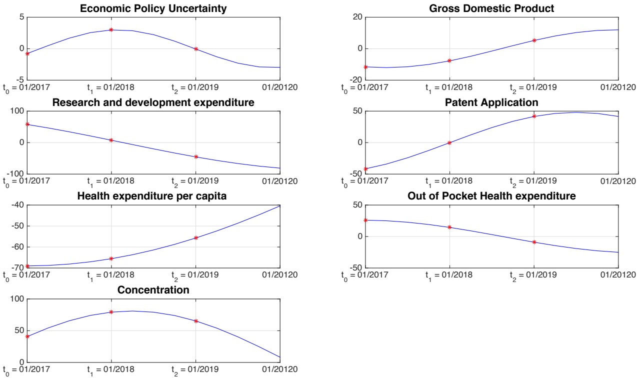
Table: Factors and amplitudes

	Panel: Europe			
	Big Cap		Small Cap	
	Amplitude	Phase	Amplitude	Phase
Economic Policy Uncertainty	7 (0.10)	5.9540	1 (0.37)	5.9540
Gross Domestic Product	10 (0.14)	0.6388	27 (0.11)	3.7804
Research and development expenditure (% of GDP)	18 (0.05)	3.1704	33 (0.19)	0.0288
Patent applications	15 (0.01)	1.0806	41 (0.22)	4.2222
Health expenditure per capita	107 (0.01)	2.1413	166 (0.01)	5.2829
Out of pocket health expenditure	16 (0.16)	0.4525	40 (0.16)	3.5941
Concentration	94 (0.01)	5.6940	100 (0.07)	2.5524

This table presents the standardized amplitude parameter (p-value) of each factor

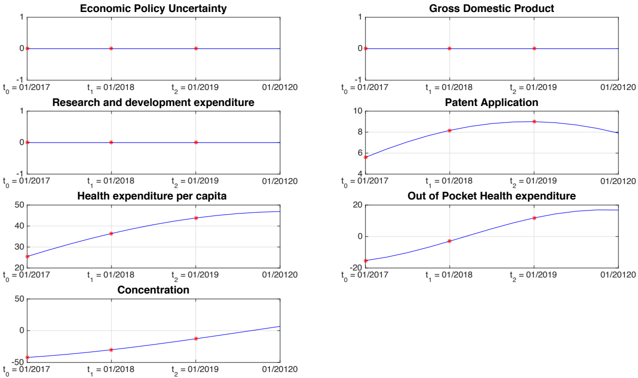
Launching time in US

Figure: All firms



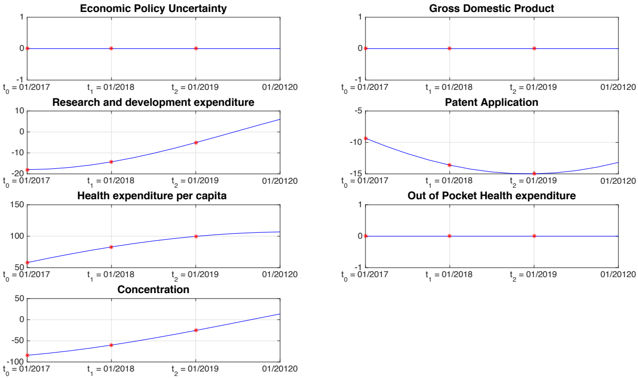
Launching time in EU

Figure: All firms



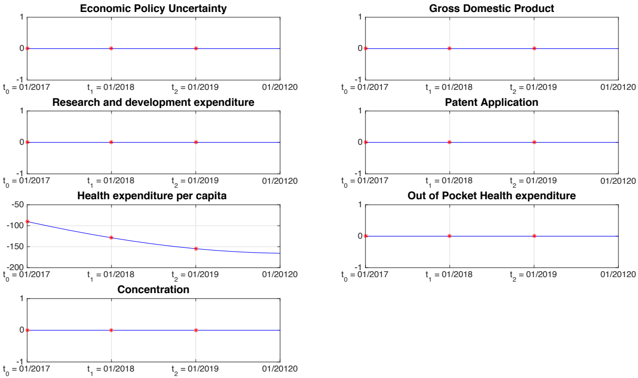
Launching time in EU

Figure: Big Caps EU



Launching time in EU

Figure: Small Caps EU



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

	United States Panel		Europe Panel	
	A	**B**	**A**	**B**
Launching at t = 0y	797.6 (4.5)	390.2 (5.8)	945.0 (4.8)	640.3 (5.9)
Abandon rate	50.77%	-	42.33%	-
Launching at t = 1y	621.9 (3.9)	73.2 (5.7)	750.3 (4.2)	333.3 (5.7)
Abandon rate	58.16%	-	49.70%	-
Launching at t = 2y	722.6 (4.3)	264.3 (5.7)	569.5 (3.6)	-21.3 (5.6)
Abandon rate	53.13%	-	57.34%	-

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

	EU BigCap Panel		EU SmallCap Panel	
	A	**B**	**A**	**B**
Launching at t = 0y	1094.5 (5.3)	839.7 (6.10)	1486.2 (6.1)	1331.3 (6.6)
Abandon rate	37.09%	-	29.22%	-
Launching at t = 1y	829.6 (4.5)	458.1 (5.8)	1708.0 (6.7)	1601.2 (7.1)
Abandon rate	45.09%	-	25.54%	-
Launching at t = 2y	571.7 (3.6)	-10.2 (5.6)	1832.2 (7.1)	1760.3 (7.5)
Abandon rate	55.49%	-	23.74%	-

Concluding remarks

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!