

# An Event Study Approach to Valuing Pharmaceutical Drugs

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(preliminary and incomplete)

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# Introduction

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# Question and Contributions of this Paper

- **Question.** How to incentivize firms to develop *new knowledge* when the (R&D) processes necessary to generate such knowledge are costly and prone to failures?
- **Institutional Answer.**
  - Give innovators exclusive rights, e.g., patents, to sell/license innovation for X yrs.
  - Promise of monopoly profits for those years is reward for taking the risk.
- **Our Proposal for Pharmaceutical Drugs.**
  1. Leverage efficient market hypothesis to learn value of drug from changes in value of a stock in response to surprise announcements regarding development of drug.
  2. Use these estimates to:
    - 2.1 buy the manufacturing rights of drugs and put those rights in the public domain.
    - 2.2 and design dynamic R&D contests that incentivizes firms to develop new drugs.

[in progress, not presented today]

# Pharmaceutical Industry

- Drug development quintessential high-risk endeavor where:
  - Finding a safe and efficacious drug is difficult, time-consuming, and costly.
  - Failure rates are higher for drugs candidates with new mechanisms of action.
  - Among the successful drugs, the development process takes an average of 12 years.
- Social value of a drug can differ significantly from its private value to a firm.
- Resulting in the under-provision of R&D in a *laissez faire* market.
- Determining the incentives for firms to develop new drugs is important.

The international journal of science / 1 April 2021

## nature

### It's time to consider a patent reprieve for COVID vaccines

**The pandemic is not a competition between companies and it won't end without more-equal vaccine distribution.**

**T**he world needs around 11 billion doses of coronavirus vaccine to immunize 70% of the world's population, assuming two doses per person. As of last month, orders had been confirmed for 8.6 billion doses, a remarkable achievement. But some 6 billion of these will go to high- and upper-middle-income countries. Poorer nations – which account for 80% of the world's population – so far have access to less than one-third of the available vaccines.

One reason for this imbalance is that wealthier countries have been able to place substantial advance orders with the relatively small group of companies that are making vaccines, most of which are based in richer countries. Unless manufacturing and supply can be distrib-

An alternative to the lifting of IP, they say, is for companies to increase the licensing of their product designs in exchange for payment. This would allow vaccines to be made by many more companies. In addition, the World Health Organization is setting up a facility for companies to share their vaccine technology, skills and other know-how.

Companies and richer countries also note that they are already backing a vaccine scheme called COVAX, which has secured more than 1 billion doses towards a 2 billion target for 2021 to vaccinate 20% of the most vulnerable groups in countries in need of help. However, it's not clear whether COVAX will be able to reach its full potential before some of the richer countries that are donating supplies have fully vaccinated their own people.

Richer nations were united in their opposition to the IP waiver until last week, when it emerged that the administration of US President Joe Biden is discussing its merits. One factor that could influence a change in policy is that the US government is named on a patent application for a technology used in vaccines being made by several companies, including Moderna in Cambridge, Massachusetts.

In 2016, researchers at the US National Institute of Allergy and Infectious Diseases in Bethesda, Maryland, working with colleagues at Dartmouth College in Hanover, New Hampshire, and the Scripps Research Institute in La Jolla, California, filed a patent for a technology that manipulates the spike protein found in coronaviruses, and which is known to develop vaccine antigens. The United States

**“  
Patents  
were never  
designed for  
use during  
global**

# Questioning the Use of Patents: Covid 19



Office of the United States Trade Representative

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**FOR IMMEDIATE RELEASE:**

May 5, 2021

**CONTACT:** [media@ustr.eop.gov](mailto:media@ustr.eop.gov)

**STATEMENT FROM AMBASSADOR KATHERINE TAI ON THE COVID-19 TRIPS  
WAIVER**

WASHINGTON – United States Trade Representative Katherine Tai today released a statement announcing the Biden-Harris Administration's support for waiving intellectual property protections for COVID-19 vaccines.

"This is a global health crisis, and the extraordinary circumstances of the COVID-19 pandemic call for extraordinary measures. The Administration believes strongly in intellectual property protections, but in service of ending this pandemic, supports the waiver of those protections for COVID-19 vaccines. We will actively participate in text-based negotiations at the World Trade Organization (WTO) needed to make that happen. Those negotiations will take time given the consensus-based nature of the institution and the complexity of the issues involved.

"The Administration's aim is to get as many safe and effective vaccines to as many people as fast as possible. As our vaccine supply for the American people is secured, the Administration will continue to ramp up its efforts – working with the private sector and all possible partners – to expand vaccine manufacturing and distribution. It will also work to increase the raw materials needed to produce those vaccines."

###

## The Key Idea of this Paper

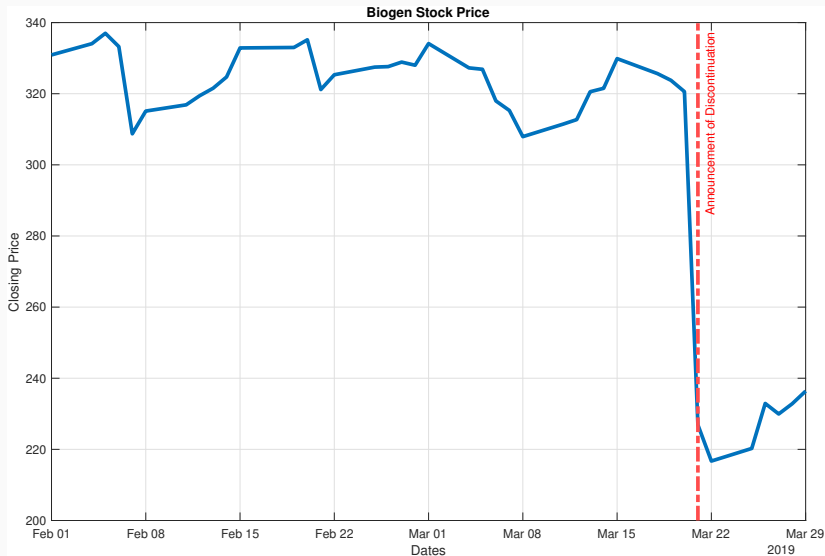
- Develop an empirical framework based on the **event study** method and the weak form of the **efficient markets hypothesis** to estimate the value of drugs and the average cost of developing a drug.
- Apply the method to two datasets: (i) firms' announcements about their drugs as they progress through different stages of development; and (ii) the daily U.S. stock prices of all publicly traded pharmaceutical firms.
- Intuition:
  - Say a firm announces discovery of a new drug compound to treat asthma.
  - Suppose this announcement was unexpected.
  - Change in its market value immediately after the announcement is the drug's NPV.
  - The higher the chance of getting FDA approval to sell the drug and the larger the asthma market, the larger the change in firm's value, and vice versa.

## Example 1: Biogen

- Date: March 21st, 2019.
- Firm: Biogen.
- Disease: Alzheimer's disease.
- Drug candidate: aducanumab.
- Announcement: discontinue Phase III clinical trial for aducanumab.
- Stock price:  $\approx$  30% drop.
- Magnitude of the drop informs the expected value of aducanumab.



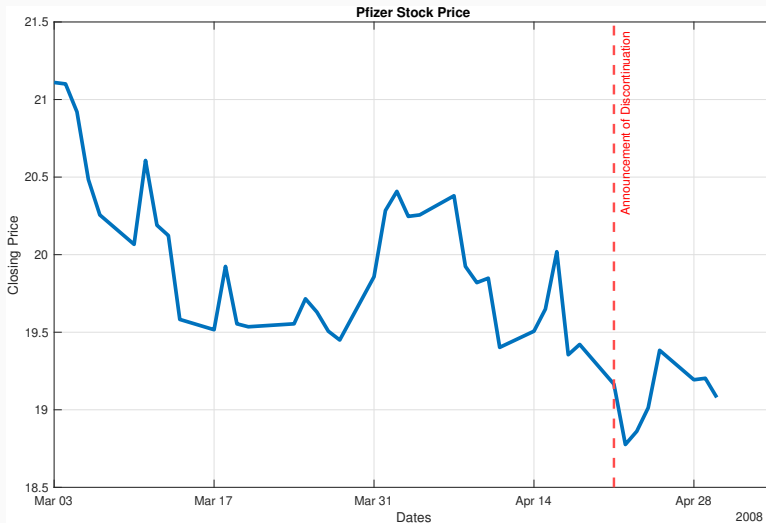
## Example 1: Biogen



## Example 1: Pfizer

- Date: April 21st, 2008.
- Firm: Pfizer.
- Disease: Advanced melanoma.
- Drug candidate: tremelimumab.
- Announcement: discontinue Phase 3 clinical trial for tremelimumab.
- Stock price: little drop.
- Suggesting: it was hard to develop, market of tremelimumab is small, etc.

## Example 1: Pfizer



## Our Contribution in More Detail

- We propose a simple (event study based) approach of valuing a drug candidate.
  1. Estimate the cumulative abnormal return, **CAR**, for every announcement.
  2. Estimate transition probabilities and stochastic discount rates between each stage.
  3. Infer value of a drug + expected development costs at each stage of development.
- The costs and value estimates are of interest by and in themselves. The current best estimate of costs by DiMassi et. al. relies on survey of 10 firms.
- In progress: propose a (draft!) of a system of prizes and cost-advance payment to encourage the development of drugs. [not presented today]

- Main data source is *Cortellis* with detailed information  $\geq 70,000$  drug candidates.
- *Every* drug candidate that has ever been in development since the early 1990s.
- We use two modules within *Cortellis*:
  1. Tracks progress for each drug candidate through the stages of clinical development.
  2. Collects information on clinical trials from `clinicaltrials.gov`.
- So for each drug we observe:
  1. Disease/indicator.
  2. Associated name of the pharmaceutical company.
  3. Date associated with each and every milestone.
- We supplement the announcement-dates from `ClinicalTrials.gov`.
- Stock Price Data from CRSP.
- Cortellis sales data.

## Summary of Main Findings (preliminary)

1. Mean expected discounted stream of profits for an approved drug is \$2.93 billion.
2. Mean expected cost of developing a drug at discovery is approx. \$151.1 million.
3. Splitting our sample into two subsamples, small (large) firm if its market capitalization is less (greater) than the market-wide median of \$5.9 billion.
4. We find:
  - 4.1 Small firms: average value of an FDA-approved drug is \$504.8 million.
  - 4.2 Small firms: average expected cost to develop a drug, at discovery, is \$30.6 million.
  - 4.3 Large firms: average value of an FDA-approved drug is \$1.82 billion.
  - 4.4 Large firms: average expected cost to develop a drug at discovery is \$141.1 million.

# Organization of the Talk

- Related Work
- Institutional Background & Data
- Valuation and Cost of Development
- Estimating Cumulative Abnormal Returns
- Valuation: Empirical Exercise

## Related Work

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# Questioning patents

- Benefits: provides incentives for knowledge creation.
- Costs:
  - exclusive property rights are inefficient and generate deadweight losses.
  - generate even *negative innovation*, e.g., Feldman, Hyman, PriceRata [2021].
- Solutions
  - Nordhaus [1967, 1969] suggest determining the *optimal patent life*.
  - Kremer [19998] suggests government buy out patents and put them in public domain so other can use it.
- We adapt Kremer's solution to drugs.

## Kremer's [1998] Proposal

- But what price should the government pay for a patent?
- Kremer suggests using second-price auctions with common value.
- For this idea to work
  - **Q1** Several knowledgeable firms have to participate. But why should they?
  - **Ans.** With probability  $p$  one of these bidding firms may win the patent auction.
  - **Q2** What is the incentive for the patent owner to sell the patent?
  - **Ans.** Pay second-highest bid + markup ( $x\%$  of social value).
- **Q3** What about pharmaceutical drugs that have multiple patents?
- Our method is simpler and perhaps even more accurate than auctions.

## Advantages of our Method vs auctioning a patent

- Auction relies on other firms' voluntary participation and competitive bidding.
- The *efficient markets hypothesis* implies that the market price of a stock aggregates information dispersed among a large number of investors.
- We rely on the information held by a larger pool of investors.
- Our approach provides a more accurate valuation than auctions with few bidders.

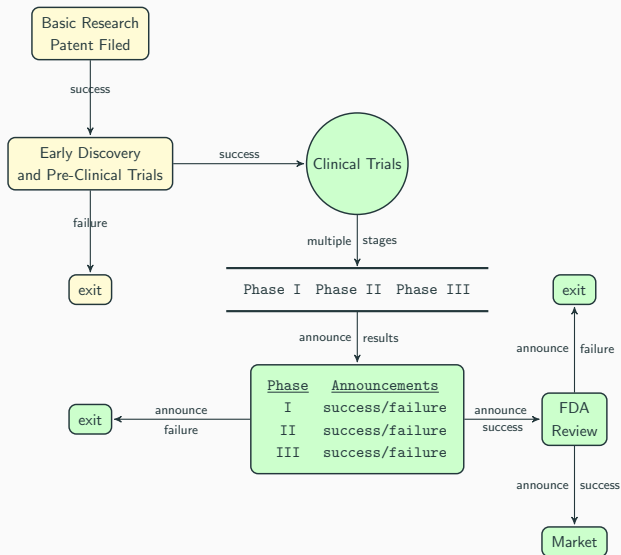
## **Institutional Background & Data**

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## The R&D process

- The R&D process consists of distinct stages defined by the FDA.
- Discovery: Creating a new molecule (or a system of molecules) and testing it (*in vitro* and *in vivo*) in the laboratory.
- Clinical Trials:
  - Phase I: test drug for possible toxicity among a small group of healthy subjects.
  - Phase II: tests for efficacy on a larger group of patients with the targeted disease.
  - Phase III: tests for its effectiveness on many patients.
- The firm can apply for FDA approval (after successful trials).
- If the FDA approves the drug, then the drug is launched in the market.

# Drug Development Process: A Figure



## Transition Probabilities

Stages	Probability of Reaching a Stage	
	Marginal	Conditional
Phase I Clinical Trials	0.43	0.43
Phase II Clinical Trials	0.31	0.72
Phase III Clinical Trials	0.16	0.52
FDA Application	0.12	0.73
FDA Approval	0.10	0.89

- Not all drugs are successful. The majority of drugs fail.

## Public Announcements in the US

- The Security and Exchange Commission (SEC);
  - Requires all public companies to disclose information to investors via the annual Form 10-K, a quarterly Form 10-Q, and current Form 8-K.
  - The *Regulation Fair Disclosure*, instituted in 2000, requires publicly traded firms to disclose all material information timely.
  - Under the *Sarbanes-Oxley Act* of 2002, the SEC monitors pharmaceutical companies' announcements about the FDA review process.
- Food and Drug Administration:
  - *Food and Drug Administration Modernization Act* of 1997 established the centralized registry called the ClinicalTrials.gov and every firm is required to register clinical trials within 21 days of enrolling the first subject.
  - FDA also requires firms to disclose information about their clinical trials and their application processes, and these announcements cannot be *materially misleading*.



## Public Announcements: A Selection

- These regulations incentivize firms to correctly and promptly inform the market.
- Yet, often, it is up to the firms to decide what is *material* and what is misleading.
- This ambiguity is more pronounced for large firms developing multiple drugs.
- Firms may either delay announcements and or bundle bad news with good.
- We consider only *major* announcements about drug candidates:
  1. drug discovery,
  2. whether a firm applies for FDA authorization to market the drug,
  3. the FDA's decision,
  4. if and when (before or after FDA application) the research was discontinued.
- For these announcements chances of strategic announcements are low.

## Public Announcements: International Announcements

- Firms also market drugs elsewhere e.g., EU and Canada.
- They too have similar rules governing timely announcements.
- We expect U.S. subsidiaries to behave similar to their parent companies in the US.

- Main data source is *Cortellis* with detailed information  $\geq 70,000$  drug candidates.
- *Every* drug candidate that has ever been in development since the early 1990s.
- We use two modules within *Cortellis*:
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## Announcements, by Development Stage

	Announcements		Dates	
	Frequency	%	N	%
Discovery	10,059	63.9	6,606	69.4
Dropped Before FDA Application	3,634	23.1	1,696	17.8
FDA Application	1,010	6.4	803	8.4
FDA Approval	963	6.1	686	7.2
Dropped After FDA Application	80	0.5	66	0.7
Total	15,746	100.0	9,523	100.0

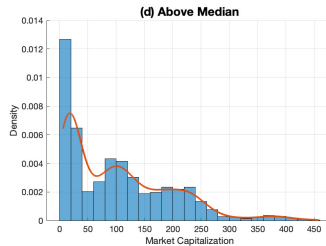
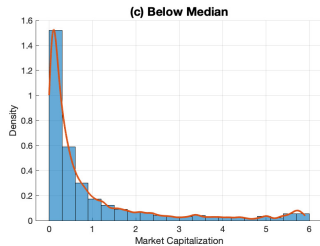
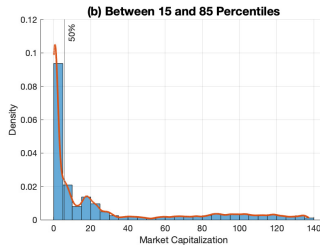
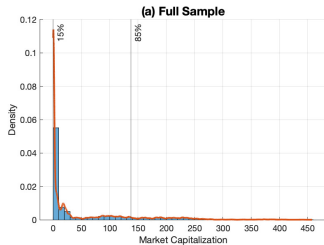
## Summary Statistics for the Number of Announcements

Announcements	Mean	Median	90th Prctl.	Std. Dev.	Min	Max
All	1.653	1	3	2.202	1	88
Discovery	1.056	1	2	1.824	0	86
FDA Application	0.106	0	0	0.438	0	17
FDA Approval	0.101	0	0	0.481	0	17
Dropped Before FDA Application	0.382	0	1	1.384	0	39
Dropped After FDA Application	0.008	0	0	0.118	0	6

## Stock Price Data

- The stock return data for *firms* comes from CRSP.
- We observe daily returns (including dividends) for all biomedical and pharmaceutical companies publicly listed in the U.S.
- To track firms across name changes, mergers, and acquisitions, we use CRSP generated permanent I.D. number associated with each firm.
- Market return is the return on the CRSP value-weighted portfolio.
- We merge the stock data with the Cortellis data by matching firms' names.
- We match if any name the firm has had in its history (i.e., any name associated with the same permanent I.D.) matches the name from the Cortellis data.
- After the merge, we end up with an unbalanced panel of firm-time observations.

# Market Capitalization



# Valuation and Cost of Development

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## The Key Idea of the Paper

- Consider a firm with one drug at the moment when it announces the *discovery* of a new drug candidate to treat some disease.
- The product of the cumulative abnormal return (CAR) and market capitalization on that announcement day is the change in the firm's market value.
- Because the only change that pertains to the firm was the discovery announcement, the former is the expected NPV of the drug candidate.
- The expected NPV of the drug is the difference between the expected present discounted value and the expected cost.
- We can reiterate the same idea when the firm announces that it will apply for the FDA approval, and when the firm announces FDA's decision about the drug.

## The Model: Values and Costs - Basic Notation

- $V$  is market value;
- $C$  is cost of development.
- $C_{\text{disc} \rightarrow}$  is the expected (remaining) cost from discovery to approval.
- $C_{\text{appl} \rightarrow}$  is the expected (remaining) cost from application to approval.
- $S_k \in \{0, 1\}$  denote stage  $k \in \{\text{disc}, \text{appl}, \text{appr}, \text{clinic}\}$  announcement.
- So,  $S_k = 1$  denotes success in stage  $k$  and  $S_k = 0$  denotes failure.
- For any two consecutive stages  $k$  and  $k'$ , let  $p_{k'|k}$  denote the conditional probability that the firm is successful in stage  $k'$ .
- E.g.,  $p_{\text{appl}|\text{clinic}}$  probability that a drug reaches the FDA application stage and the firm submits the application, conditional on successfully completing the third-stage clinical trial

## The Model: How We Develop it - Backward Induction

- Unit of observation: drug candidate-firm-indication.
- We start with the later stages announcements and move backwards.
- We will start from the last announcement, whether or not the drug was approved.
- Then consider firm's announcement whether it applied for the FDA approval.
- And end with the first announcement, i.e., discovery of a new compound.

## The Model: Expected Value at the time of Approval

- Efficient markets hypothesis: change in value of the firm, immediately following the announcement of FDA approval is equal to the increase in the discounted profit from selling the drug, now that all uncertainties have been resolved:

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$$\mathbb{E}(\text{CAR}_{i,\text{appr}}) \times \text{MKTCAP}_{i,t_{\text{appr}}} = \underbrace{\mathbb{E}(V|S_{\text{appr}} = 1)}_{\text{value at announcement}} - \underbrace{\mathbb{E}(V|S_{\text{appr}} = 1) \times p_{\text{appr}|\text{appl}}}_{\text{value just before announcement}}$$

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- Identifies the value of a drug,  $\mathbb{E}(V|S_{\text{appr}} = 1)$  at the time of approval.
- No cost because, at approval, all those sunk costs have been paid.

## Notations

- Let  $\tau \in \mathbb{N}$  number of years it takes for the drug to get FDA approval.
- $\tau \sim \mathbb{P}_k(\tau|S_k = s)$ : the probability depends on the stage  $k$  and announcement  $S_k$ .
- Let  $\delta \in (0, 1)$  annual discount factor.
- Let  $\mathbb{E}(\delta^{\tau_{k \rightarrow}})$  expected stochastic discounting from the stage  $k$  to the market.
- We estimate  $\hat{\mathbb{P}}_k(\tau|S_k = s)$  nonparametrically then plug-in to estimate  $\widehat{\mathbb{E}(\delta^{\tau_{k \rightarrow}})}$ .
- Let  $\pi$  be the (average) yearly profit from selling the drug after FDA approval.



## The Model: Expected Value at the time of Discovery

$$\begin{aligned}\mathbb{E}(V|S_{\text{disc}} = 1) &= \left( \sum_{\tau \geq 0} \left( \sum_{t=\tau}^{\infty} \delta^t \pi \right) \times \mathbb{P}_{\text{disc}}(\tau|S_{\text{disc}} = 1) \right) \times p_{\text{appr}|\text{appl}} \times p_{\text{appl}|\text{disc}} \\&= \left( \sum_{\tau \geq 0} \pi \times \left( \sum_{t=\tau}^{\infty} \delta^t \right) \times \mathbb{P}_{\text{disc}}(\tau|S_{\text{disc}} = 1) \right) \times p_{\text{appr}|\text{appl}} \times p_{\text{appl}|\text{disc}} \\&= \underbrace{\frac{\pi}{1-\delta}}_{:=\mathbb{E}(V|S_{\text{appr}}=1)} \underbrace{\left( \sum_{\tau \geq 0} \delta^{\tau} \times \mathbb{P}_{\text{disc}}(\tau|S_{\text{disc}} = 1) \right)}_{:=\mathbb{E}(\delta^{\tau_{\text{disc}} \rightarrow})} \times p_{\text{appr}|\text{appl}} \times p_{\text{appl}|\text{disc}} \\&= \mathbb{E}(V|S_{\text{appr}} = 1) \times \mathbb{E}(\delta^{\tau_{\text{disc}} \rightarrow}) \times p_{\text{appr}|\text{appl}} \times p_{\text{appl}|\text{disc}}.\end{aligned}\tag{1}$$

## The Model: Expected Cost at the time of Discovery

- Use the efficient markets hypothesis to get

$$\mathbb{E}(\text{CAR}_{i,\text{disc}}) \times \text{MKTCAP}_{i,t_{\text{disc}}} = \mathbb{E}(V|S_{\text{disc}} = 1) - \mathbb{E}(C_{\text{disc} \rightarrow} | S_{\text{disc}} = 1), \quad (2)$$

where  $\mathbb{E}(C_{\text{disc} \rightarrow} | S_{\text{disc}} = 1)$  is the expected cost *from discovery to the market*.

## The Model: Expected Cost at the time of Application

- Use the efficient markets hypothesis to get

$$\begin{aligned}\mathbb{E}(\hat{C}AR_{i, \text{appl}}) \times MKTCAP_{i, t_{\text{appl}}} &= \mathbb{E}(V|S_{\text{appr}} = 1) \times \mathbb{E}(\delta^{\tau_{\text{appl}} \rightarrow}) \times p_{\text{appr}|\text{appl}} \\ &\quad - \mathbb{E}(V|S_{\text{appr}} = 1) \times \mathbb{E}(\delta^{\tau_{\text{appl}} \rightarrow}) \times p_{\text{appr}|\text{appl}} \times p_{\text{appl}|\text{clinic}} \\ &\quad - (\mathbb{E}(C_{\text{appl} \rightarrow} | S_{\text{appl}} = 1) - \mathbb{E}(C_{\text{appl} \rightarrow} | S_{\text{appl}} = 1) \times p_{\text{appl}|\text{clinic}}) \\ &= \mathbb{E}(V|S_{\text{appr}} = 1) \times \mathbb{E}(\delta^{\tau_{\text{appl}} \rightarrow}) \times p_{\text{appr}|\text{appl}} \times (1 - p_{\text{appl}|\text{clinic}}) \\ &\quad - \mathbb{E}(C_{\text{appl} \rightarrow} | S_{\text{appl}} = 1) (1 - p_{\text{appl}|\text{clinic}}). \tag{3}\end{aligned}$$

We can then use equation (3) to estimate  $\mathbb{E}(C_{\text{appl} \rightarrow} | S_{\text{appl}} = 1)$ .

## The Model: Expected Clinical Cost at the time of Discovery

- Finally, we can take one more step and estimate  $\mathbb{E}(C_{\text{disc} \rightarrow \text{appl}} | S_{\text{disc}} = 1)$ , which is the development cost faced from discovery to the application for the FDA approval by using the following equation:

$$\mathbb{E}(C_{\text{disc} \rightarrow \text{appl}} | S_{\text{disc}} = 1) = \mathbb{E}(C_{\text{disc} \rightarrow} | S_{\text{disc}} = 1) - \mathbb{E}(C_{\text{appl} \rightarrow} | S_{\text{disc}} = 1), \quad (4)$$

where  $\mathbb{E}(C_{\text{appl} \rightarrow} | S_{\text{disc}} = 1) = \mathbb{E}(C_{\text{appl} \rightarrow} | S_{\text{appl}} = 1) \times \mathbb{E}(\delta^{\tau_{\text{disc} \rightarrow \text{appl}}}) \times p_{\text{appl} | \text{disc}}$ .

## **Estimating CAR and Stochastic Discount Rates**

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- The unrestricted market model posits that firm  $i$ 's return is given by

$$\underbrace{r_{i,t_{i,j}}}_{\text{stock return}} = \alpha_i + \beta_i \underbrace{r_{t_{i,j}}}_{\text{market return}} + \underbrace{\varepsilon_{i,t_{i,j}}}_{\text{abnormal return}}. \quad (5)$$

- where  $t_{i,j}$ : date when firm  $i$  makes its  $j^{\text{th}}$  out of  $J_i$  announcements.
- For each  $(i, t_{(i,j)})$  pair we determine  $\{r_{i,t}, r_t\}$  for a 200 day window that ends 10 days before the announcement date  $t_{(i,j)}$ , and we fit (5) using OLS.
- (5) is flexible to capture competition and firm effects.

- For each firm  $i$ , we estimate Equation (5)  $J_i$ -many times.
- We obtain estimates  $\{\hat{\alpha}_{i,j}, \hat{\beta}_{i,j}\}$ ,  $j = 1, \dots, J_i$  of  $\{\alpha_i, \beta_i\}$ .
- Abnormal returns associated with announcement  $j \in J_i$ :  $\hat{\varepsilon}_{i,j,t} \equiv r_{i,t} - \hat{r}_{i,j,t}$ .
- **CAR** associated with announcement  $j \in J_i$ :

$$\widehat{\text{CAR}}_{i,j,t_{(i,j)}} = \sum_{t=t_{(i,j)}-1}^{t_{(i,j)}+2} \hat{\varepsilon}_{i,j,t}, \quad (6)$$

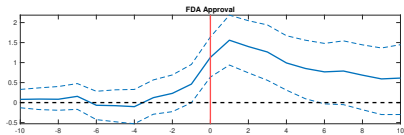
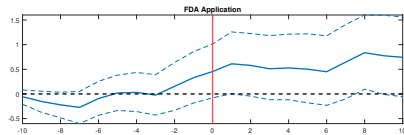
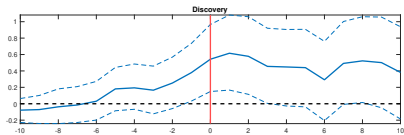
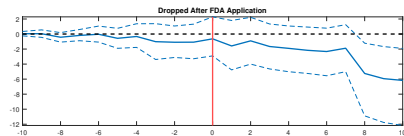
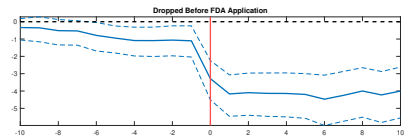
- One day before, two days after window of cumulation captures potential information leakage and time it may take for market to adjust to news.

## Summary Statistics of CAR

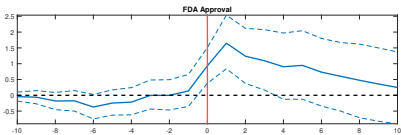
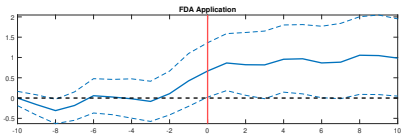
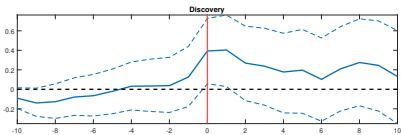
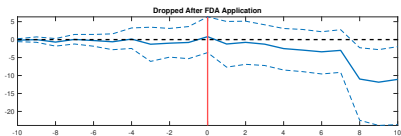
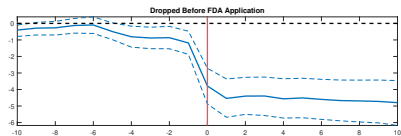
	Mean	Median	Std. Dev.	Min	Max	N
Overall	-0.265	-0.013	11.608	-180.528	207.120	9,523
Discovery	0.239	0.033	9.477	-137.464	165.573	6,606
FDA Application	0.473	0.191	7.259	-44.239	116.284	803
FDA Approval	1.295	0.281	11.270	-68.960	207.120	686
Dropped Before FDA Appl.	-3.357	-0.375	18.575	-180.528	66.176	1,696
Dropped After FDA Appl.	-0.017	0.047	7.162	-43.724	16.100	66



# No Information Leakage: Multiple Announcements



# No Information Leakage: One announcement



## Regressing CAR on Announcements

$$\begin{aligned}\widehat{\text{CAR}}_{i,j,t(i,j)} = & \beta_{\#disc} \times \ln \left( 1 + \#disc_{i,j,t(i,j)} \right) + \beta_{\#appl} \times \ln \left( 1 + \#appl_{i,j,t(i,j)} \right) \\ & + \beta_{\#appr} \times \ln \left( 1 + \#appr_{i,j,t(i,j)} \right) \\ & + \beta_{\#drop-before} \times \ln \left( 1 + \#Dropped-before-FDA_{i,j,t(i,j)} \right) \\ & + \beta_{\#drop-after} \times \ln \left( 1 + \#Dropped-after-FDA_{i,j,t(i,j)} \right) + \omega_{i,j,t(i,j)},\end{aligned}\quad (7)$$

- Consider all the announcements, including when firms make multiple announcements for different drugs, possibly of different types on the same day.
- Amenable to introducing heterogeneity across firms.

## Regressing CAR on Announcements: Results

Variables	All Announcements	One Announcement
Discovery	0.354 [0.107,0.633]	0.253 [-0.019,0.521]
FDA Application	0.601 [0.063,1.139]	0.686 [0.084,1.317]
FDA Approval	1.340 [0.548,2.199]	1.445 [0.468,2.585]
Dropped Before FDA Application	-2.816 [-3.767,-1.957]	-3.776 [-5.133,-2.703]
Dropped After FDA Application	1.302 [-1.003,3.438]	-0.297 [-4.188,2.527]
N	9,523	6,856
$\overline{R}^2$	0.014	0.017

Bootstrapped confidence intervals.

## Expected Stochastic Discount

- To estimate expected discounting, apply the procedure in Aalen [1976].
- Specifically:
  - A drug that starts clinical development can either fail, be terminated, or be successful and apply for FDA approval.
  - Drug's years in development can be modeled using a competing risks model.

Discount Rates \ $\delta$	0.98	0.96
$\mathbb{E}(\delta^{\tau_{\text{disc}} \rightarrow})$	0.64	0.41
$\mathbb{E}(\delta^{\tau_{\text{clinic}} \rightarrow})$	0.85	0.72
$\mathbb{E}(\delta^{\tau_{\text{appl}} \rightarrow})$	0.91	0.83

## **Valuation: Empirical Exercise**

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## Steps for the Empirical Analysis: Summary and What is Next

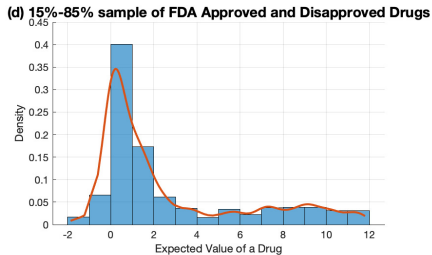
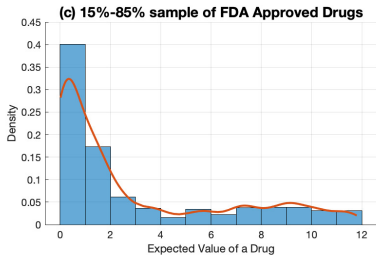
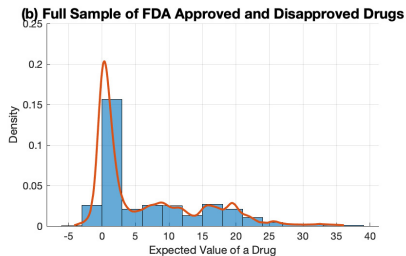
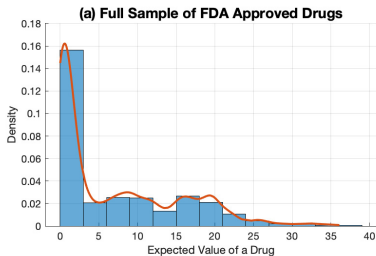
1. Estimate the CAR associated with each announcement.
2. Using OLS predict the CAR as a function of announcement type.
3. Estimate the transition probabilities and the expected discount rates.
4. Determine the change in the firm's value immediately following an announcement.

# Steps for the Empirical Analysis: Summary and What is Next

$$\begin{bmatrix} \mathbb{E}(\text{CAR}_{i,\text{appr}}) \text{MKT}CAP_{i,t_{\text{appr}}} \\ \mathbb{E}(\hat{\text{CAR}}_{i,\text{appl}}) \text{MKT}CAP_{i,t_{\text{appl}}} \\ \mathbb{E}(\text{CAR}_{i,\text{disc}}) \text{MKT}CAP_{i,t_{\text{disc}}} \end{bmatrix} = \begin{bmatrix} \mathbb{E}(V|S_{\text{appr}} = 1)(1 - p_{\text{appr}|\text{appl}}) \\ \mathbb{E}(V|S_{\text{appr}} = 1) \times \mathbb{E}(\delta^{\tau_{\text{appl}} \rightarrow}) \times p_{\text{appr}|\text{appl}} \times (1 - p_{\text{appl}|\text{clinic}}) \\ - \mathbb{E}(C_{\text{appl} \rightarrow} | S_{\text{appl}} = 1) (1 - p_{\text{appl}|\text{clinic}}) \\ \mathbb{E}(V|S_{\text{appr}} = 1) \times \mathbb{E}(\delta^{\tau_{\text{disc}} \rightarrow}) \times p_{\text{appr}|\text{appl}} \times p_{\text{appl}|\text{disc}} - \mathbb{E}(C_{\text{disc} \rightarrow} | S_{\text{disc}} = 1) \end{bmatrix}$$



# Expected Value of Individual Drugs, at the FDA Approval



## Subsamples

- **Sample 1.** Drugs that are developed by firms that have market capitalization that is between 15% and 85% of the entire sample. Thus, we drop the bottom and the top 15% of the firms from our analysis.
- **Sample 2.** Drugs that are developed by firms whose market capitalization is within one standard deviation from the mean, where the mean and the standard deviation is calculated for the entire sample. This approach ends up excluding firms at the top, such as Pfizer, but none at the low end of the market capitalization.
- **Samples 3 and 4.** Two subsamples that are complement to each other. One considers all drug-announcement observations for which the market capitalization was below its median; and the other for which it was above the median.

## Mean Expected Value of Drugs, at Approval

	Full Sample	Sample 1	Sample 2	Sample 3	Sample 4
Successful Drugs	7,086.4	2,933	3,865	504.82	1,826.5
All Drugs	6,491.6	2,656	3,486	467.5	1,656.3

## External Validity: Information on Actual Sales.

- Use sales data from the Cortellis Competitive Intelligence database. Data include information on yearly drug-level total (worldwide) sales for public firms.
- Sales data at drug level, but the announcements are at the drug-disease level.
  - We do not observe the breakdown of sales by disease, so, we have to allocate the sales data across all the diseases for which a given drug was launched for.
  - So we equally distribute sales across the disease.
  - If a drug was launched to target 3 disease, then each gets one-third of the total sales.
- In order to correct for the short panel duration in the sales data, we average sales across all the years available for a given drug-disease for a given firm.

## External Validity: Total Discounted Sales (in millions)

Sample	N	10 years	15 years	20 years
Full Sample	3,959	2,551.93	3,647.09	4,637.04
Sample 1	2,587	2,535.97	3,624.28	4,608.04
Sample 2	2,574	2,529.88	3,615.59	4,596.98
Sample 3	915	1,305.98	1,866.44	2,373.06
Sample 4	3,044	3,019.59	4,315.46	5,486.82

## Expected Value of Individual Drugs, at Discovery

Recall:  $\mathbb{E}(V|S_{\text{disc}} = 1) = \mathbb{E}(V|S_{\text{appr}} = 1) \times \mathbb{E}(\delta^{\tau_{\text{disc}} \rightarrow}) \times p_{\text{appr}|\text{appl}} \times p_{\text{appl}|\text{disc}}.$

	Full Sample	Sample 1	Sample 2	Sample 3	Sample 4
Only Successful Drugs	469.2	205.4	269.3	35.9	123
All Drugs	429.8	186.1	243.5	33.2	111.6

## Expected Drug Development Costs, at Discovery

Recall:

$$\mathbb{E}(\text{CAR}_{i,\text{disc}}) \times \text{MKTCAP}_{i,t_{\text{disc}}} = \mathbb{E}(V|S_{\text{disc}} = 1) - \mathbb{E}(C_{\text{disc} \rightarrow} | S_{\text{disc}} = 1), \quad (8)$$

	Full Sample	Sample 1	Sample 2	Sample 3	Sample 4
Version 1	231	150.5	132.8	30.6	141.1
Version 2	298.3	166	188.7	29.3	125.4

- Cost small relative to estimates from earlier work because we are here presenting the expected cost at discovery, not the actual accounting costs.

## Summary: Expected Costs

	Full Sample	Sample 1	Sample 2	Sample 3	Sample 4
At Discovery	231.8	150.5	132.8	30.6	141.1
At Application	4,334.8	2,041	2,490.6	384.9	584



## Concern with Having Too Few Observations

- Cortellis dataset does not contain discovery announcements for most drugs for which we observe FDA approval announcements.
- Of 957 drugs that the FDA successfully approved, we observe the discovery announcements for only 77.
- For these 77, expected cost at discovery equals \$231.8 million.
- Cross checking with other sources show that overall our estimates are reasonable.
- But we are working to collect more data by studying all of the SEC filings.

Still too early, but I welcome your questions and feedback! Thank you!