Valuing Pharmaceutical Drug Innovations

Aryal, Ciliberto, Farmer, Khmelnitskaya (2023)

Iván Rendo Barreiro - TSE's Health Reading Group

Objective:

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Why?

Policy: prerequisite to incentivise drug innovations in practice (e.g. prizes, patents, licensing…)

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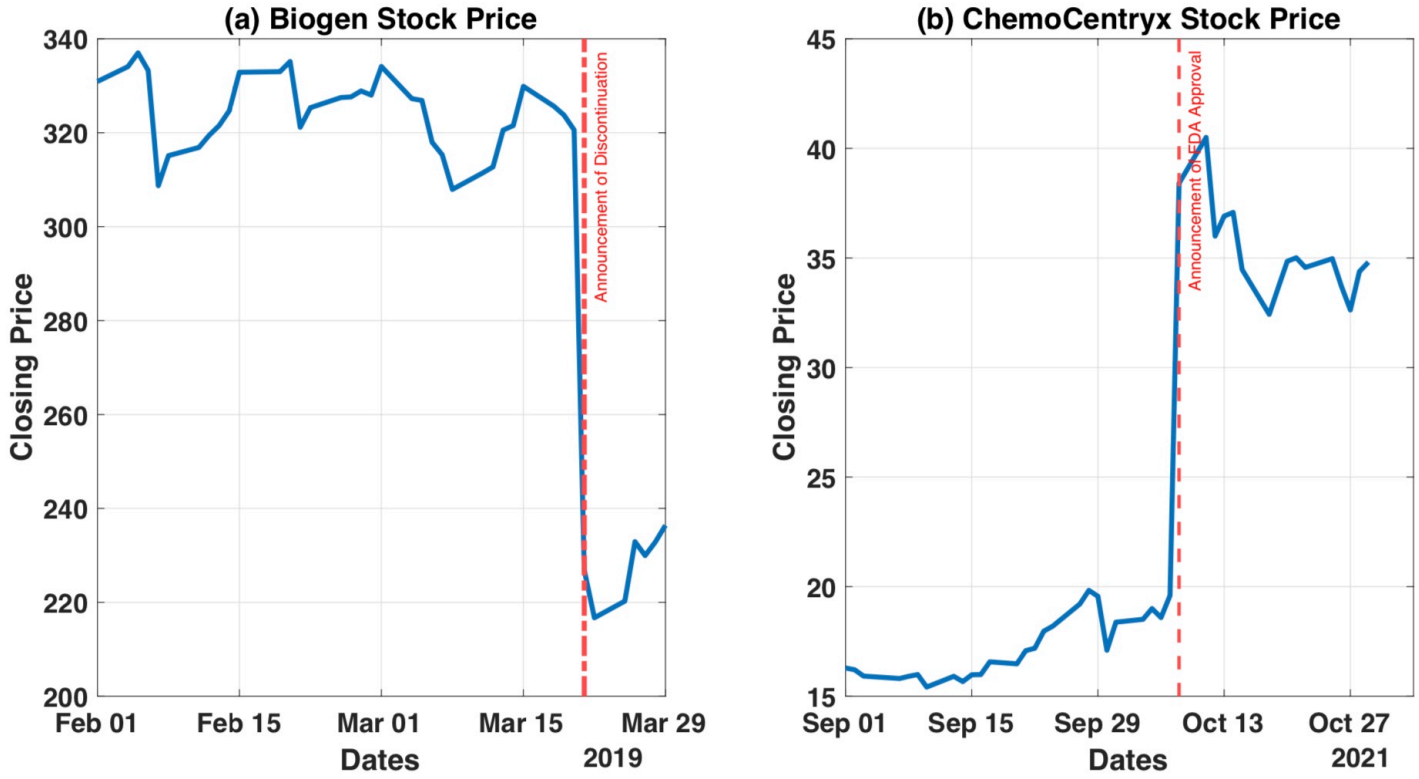
How?

Using abnormal returns when announcements concerning drugs’ development are made

First Glance at the 'How':

Figure 1: **Examples of Drug Announcements**



Note: Panels (a) and (b) display the time series of stock prices for Biogen and Merck around the announcement dates, respectively. On March 21, 2019, Biogen discontinued the Phase III clinical trial for a drug to treat Alzheimer's disease. On October 8, 2021, ChemoCentryx announced its FDA approval for a vasculitis drug.

First Glance at the Results:

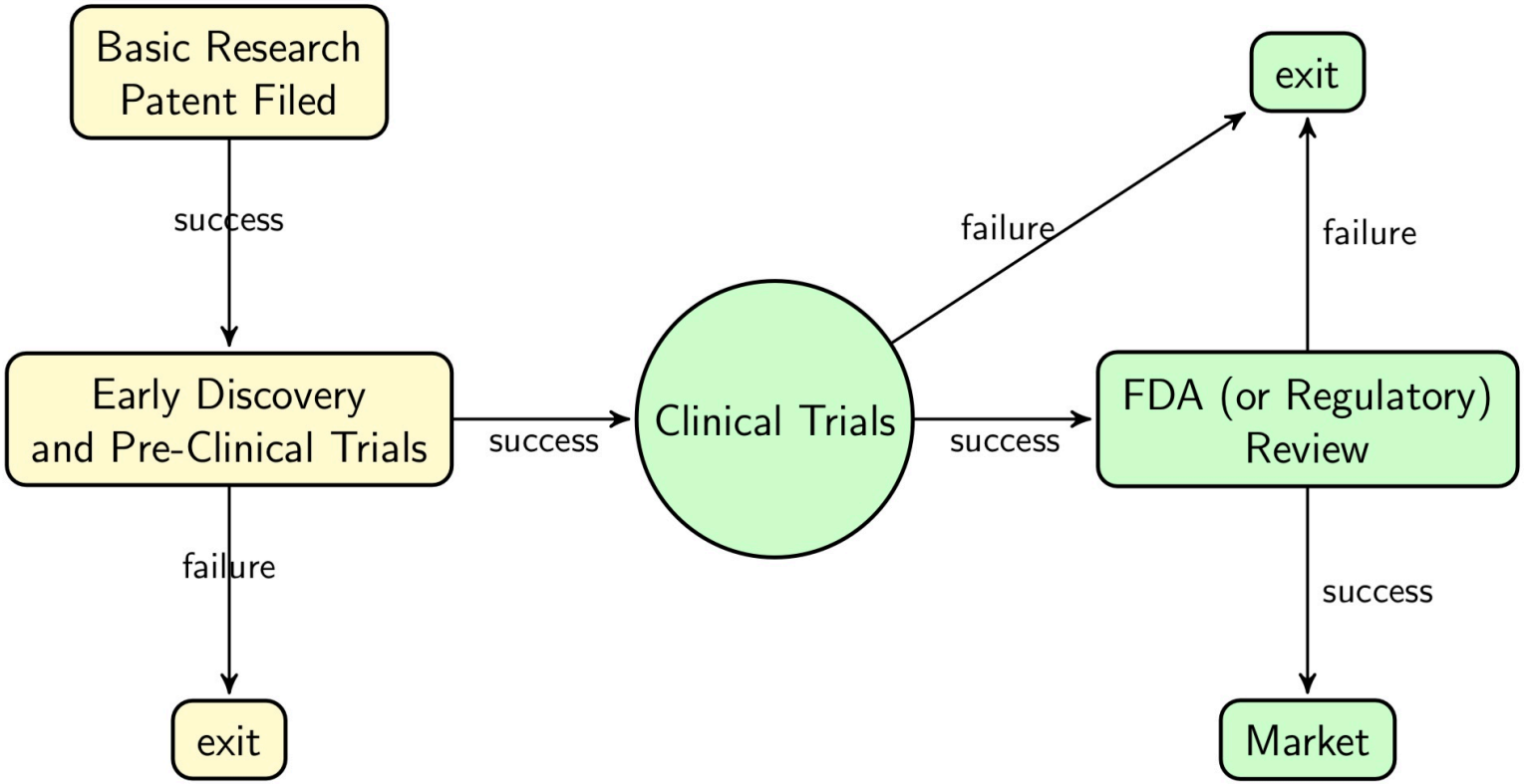
- Average market **value** of a successful drug: **$1.62 billion**
- At the discovery, average **value**: **$64.3 million**
- “ “ “ , average **cost**: **$58.5 million**

Roadmap

1. Institutional Background + Data (§ 3)
2. Model (§ 4)
3. Results (§ 5, 6)
4. Policy Implications (§ 7)

Institutional Background + Data

Figure 2: **Drug Development Process.**



Data: collect **dates of each success/failure announcement** to compare with stock market

… assuming homogeneous probabilities across drugs:

Table 2: **Transition Probabilities**

Stages	**Probability of Reaching a Stage** Marginal	Conditional
Phase I Clinical Trials	51.2%	51.2%
Phase II Clinical Trials	31.9%	62.4%
Phase III Clinical Trials	16.7%	52.4%
FDA Application	12.1%	72.3%
FDA Approval	10.8%	89%

Note: The unit of observation is a development project, i.e., a specific firm-drug-disease combination, associated with at least one announcement. The column labeled *Marginal* denotes the shares of all the initiated development projects, and the column labeled *Conditional* denotes the shares of the development projects that made it to the next stage. For example, 16.7% of all projects reached Phase III, and conditional in reaching Phase II, 52.4% made it to Phase III.

(They are used later in the model)

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- Daily returns from US pharma public firms
  - Including dividends
- Drop large firms (>95pc):
  - Increased chance of success
  - Different selection of drugs to develop

Model

I. From abnormal returns to values and costs

II. Identifying abnormal returns

III. Estimating discount rates

Big Remark

Everything is Homogeneous

Big Remark

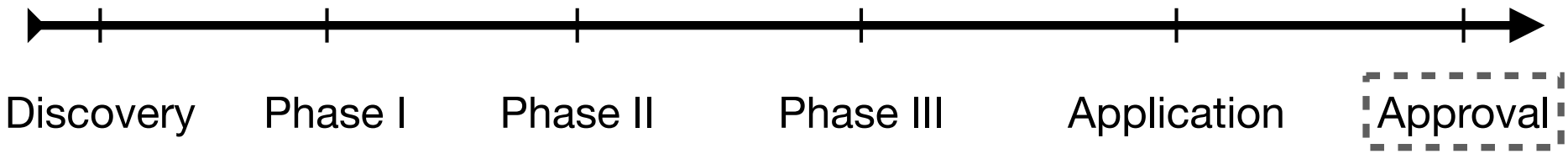
Everything is Homogeneous

E.g.: The expected value of a discovery, cost of development, probability of success, effects on the stock markets…

are homogenous across drugs and firms

I. From abnormal returns to values and costs

A. *Value at FDA approval stage*



V : value

S_k : stage k?

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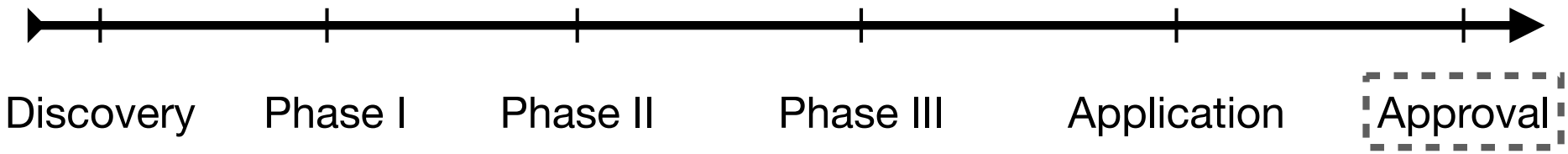

$$\mathbb{E}(CAR_{appr}) \times \text{mktcap} = \underbrace{\mathbb{E}(V \mid S_{appr} = 1)}_{\text{after announcement}} - \underbrace{\mathbb{E}(V \mid S_{appr} = 1) \times p_{appr|appl}}_{\text{just before announcement}}$$

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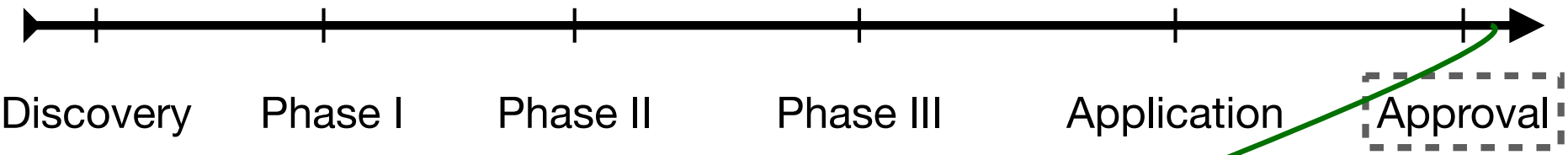

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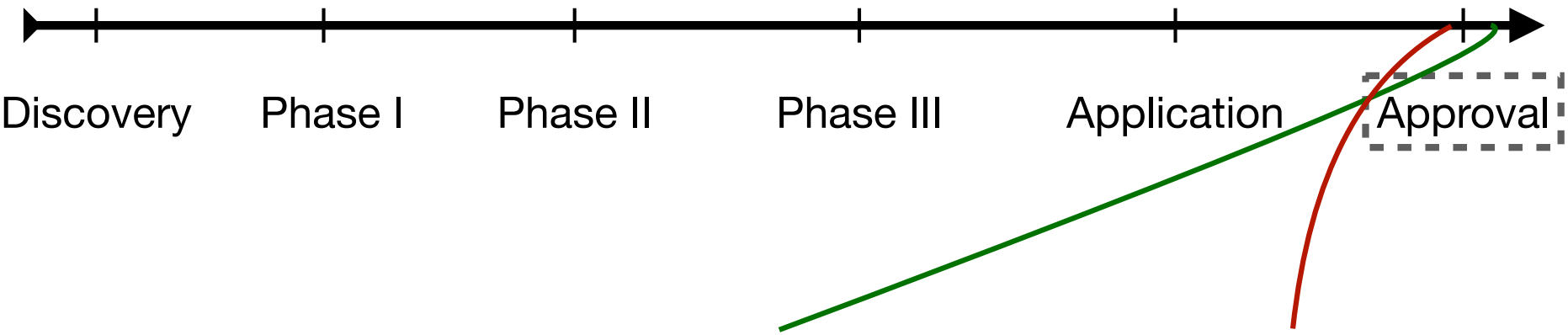

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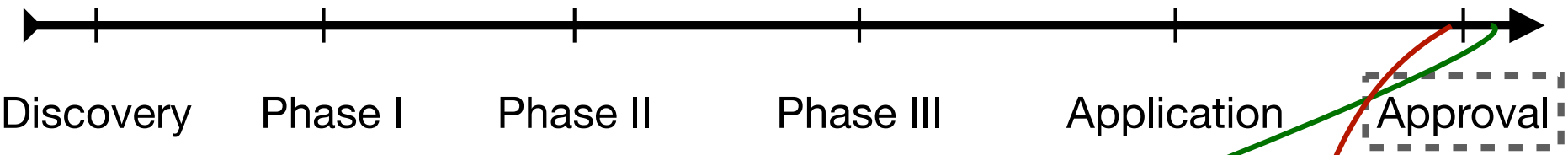

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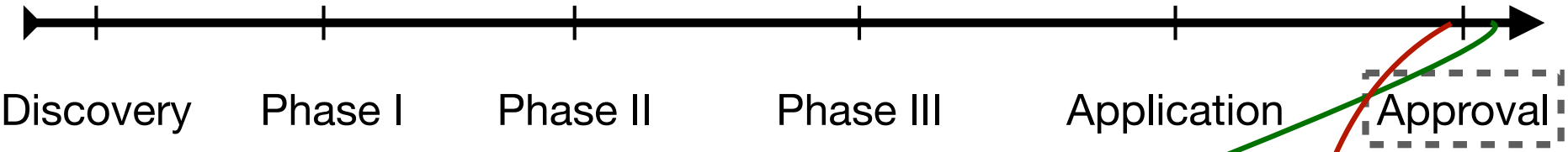

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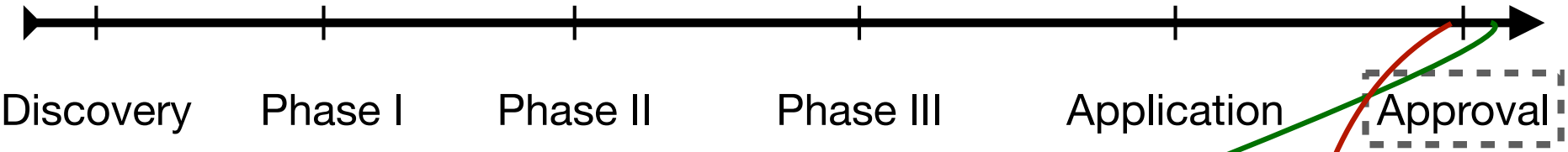

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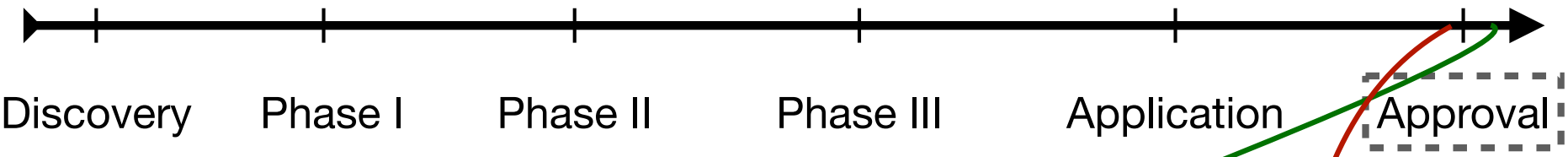

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Remark: No development costs at this stage!

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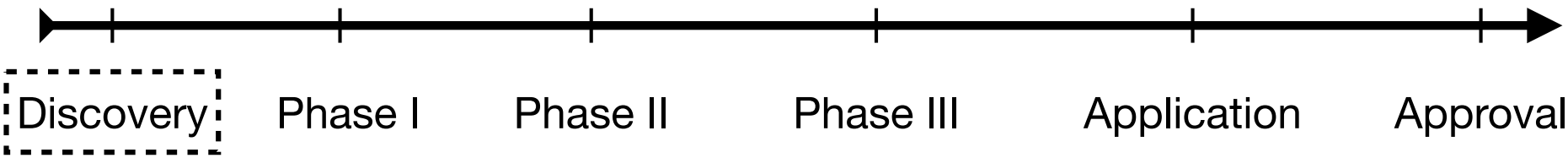
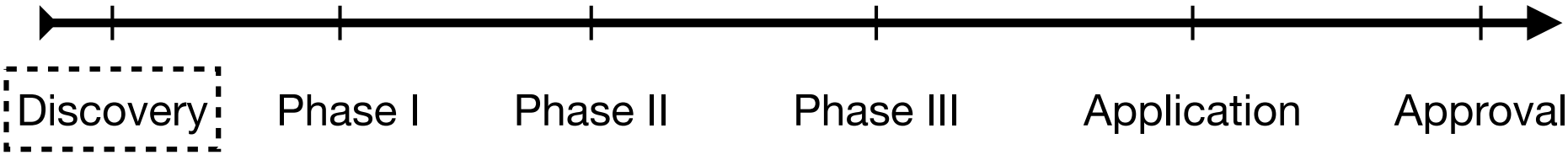


π - yearly profits (average)

I. From abnormal returns to values and costs

B. *Value at Discovery Stage*



$$\mathbb{E}(V \mid S_{disc} = 1) = \left(\sum_{\tau \geq 0} \sum_{t=\tau}^{\infty} \delta^t \pi \times \mathbb{P}(\tau \mid S_{disc} = 1) \right) \times p_{appr|appl} \times p_{appl|disc}$$

Probability that a drug will get FDA approval within the next τ years

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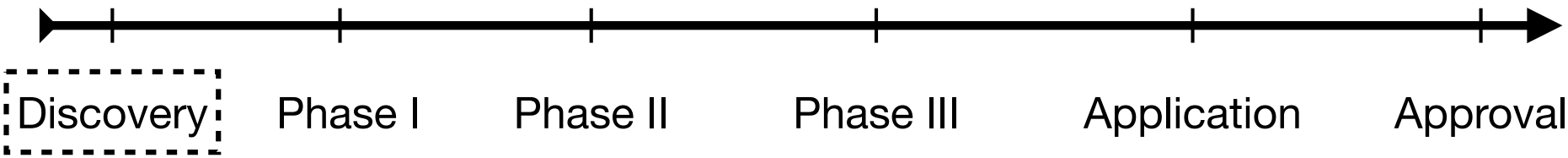

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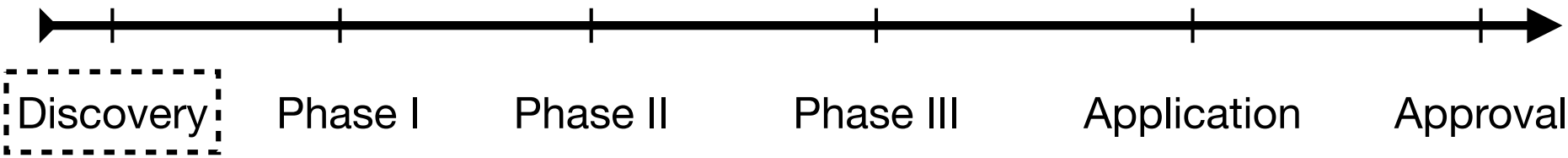

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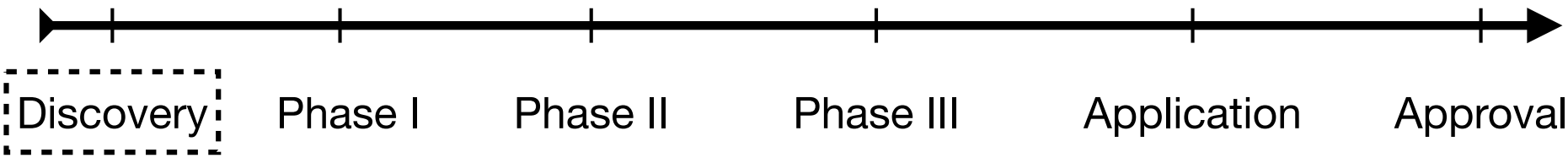

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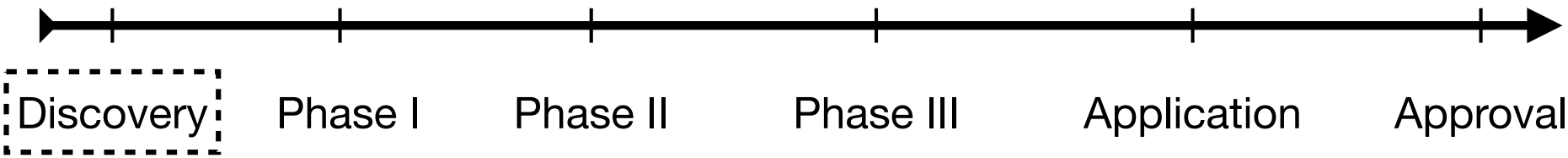

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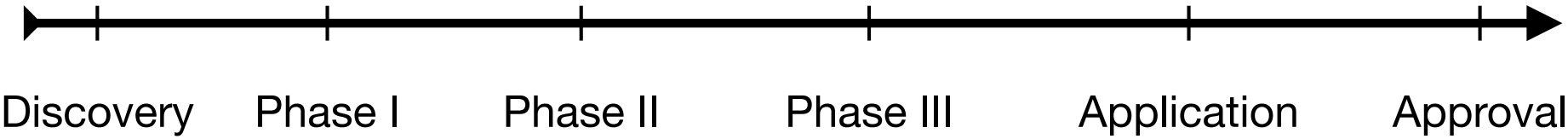
(Expected discount rate at discovery)
(Assume we know this)

π - yearly profits (average)

I. From abnormal returns to values and costs

C. *Cost at discovery stage*



I. From abnormal returns to values and costs

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$$\mathbb{E}(CAR_{disc}) \times \text{mktcap} = \mathbb{E}(V \,|\, S_{disc} = 1) - \mathbb{E}(C_{disc\rightarrow} \,|\, S_{appr} = 1)$$

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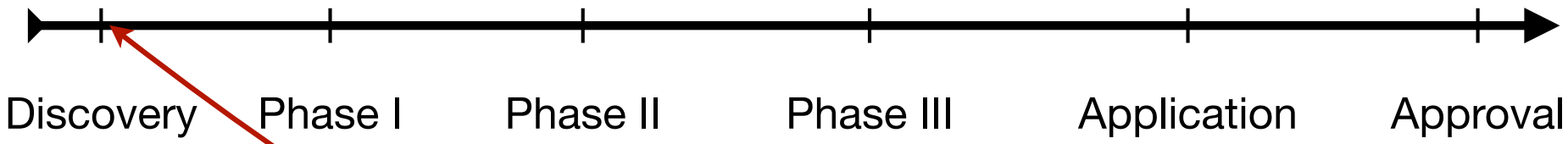

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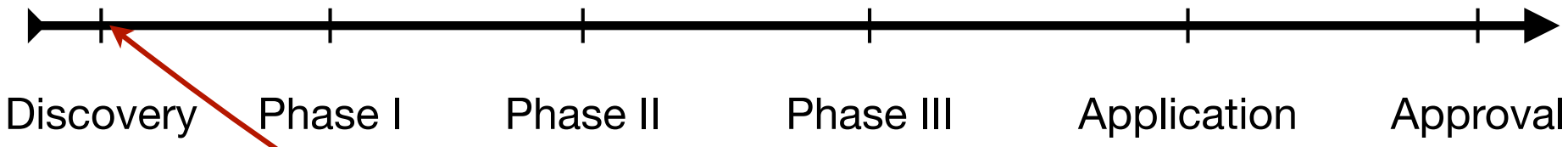

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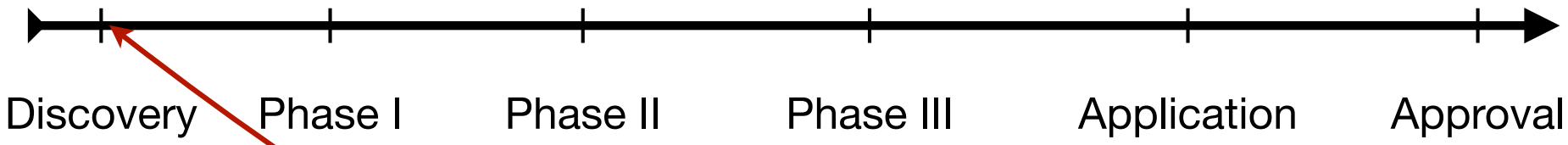

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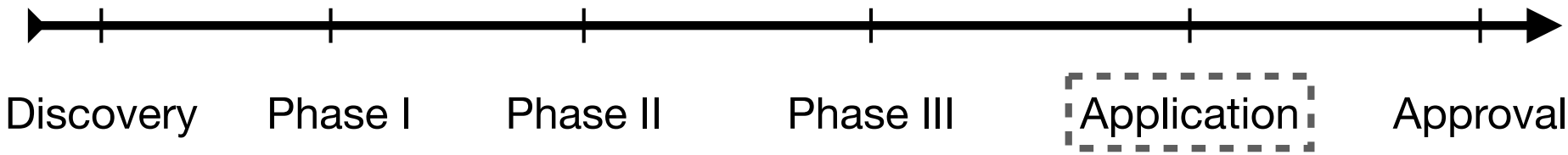
Expected cost of drug development at discovery

I. From abnormal returns to values and costs

D. *Cost of FDA Application*



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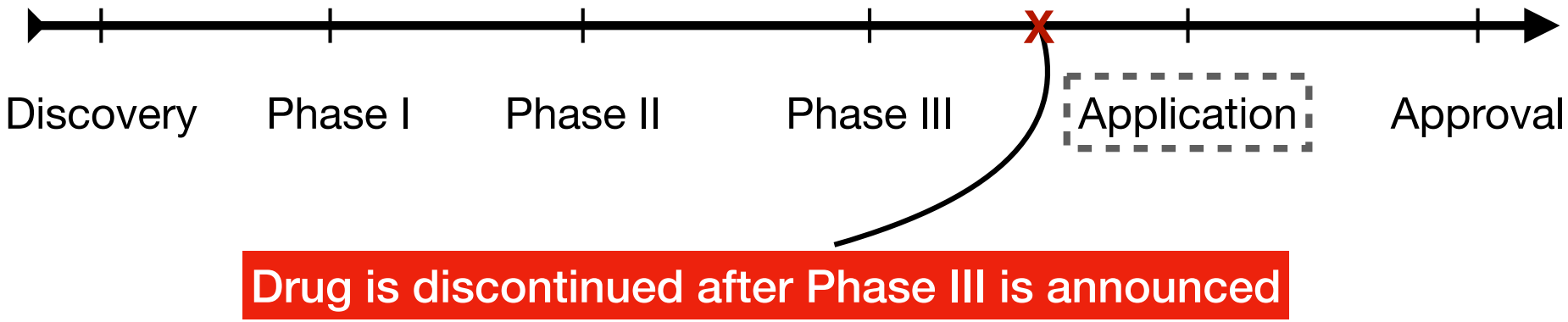

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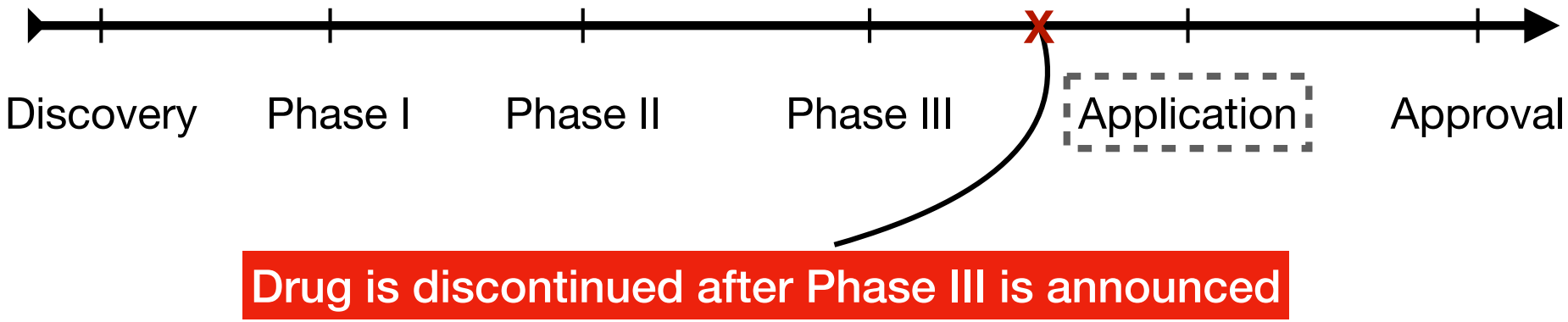

$$\mathbb{E}(CAR_{drop\ after\ phase\ III}) \times \text{mktcap} = -\underbrace{\mathbb{E}(V \mid S_{phaseIII} = 1)}_{\text{value lost after discontinuation}} + \underbrace{\mathbb{E}(C_{appl\rightarrow} \mid S_{appl} = 1) \times p_{appl|phaseIII}}_{\text{cost savings}}$$

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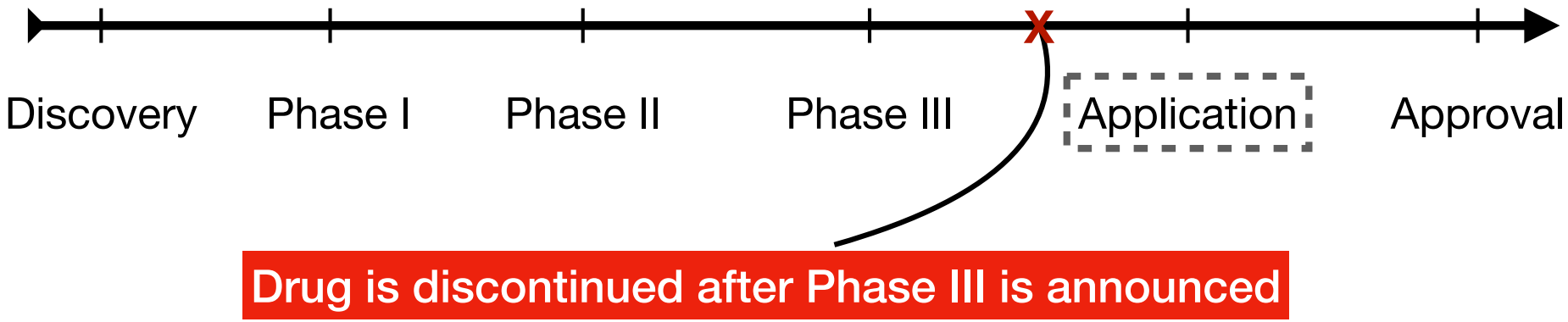

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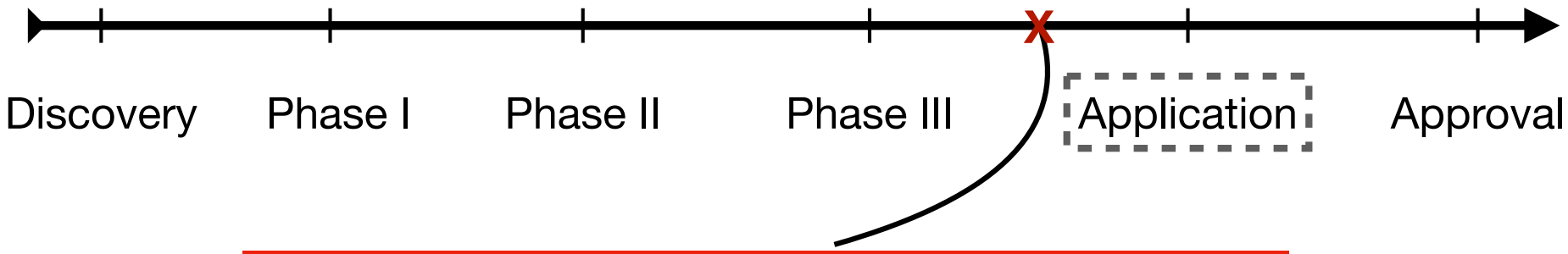

Drug is discontinued after Phase III is announced

Can solve for this

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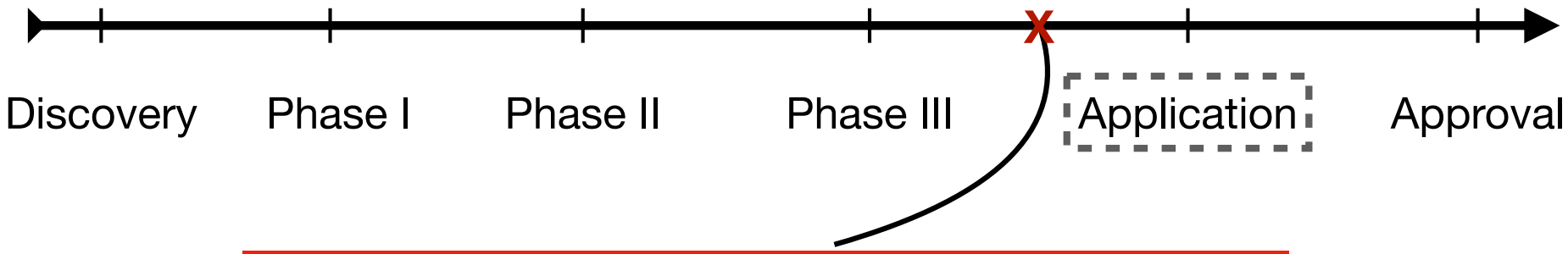

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$$= \mathbb{E}(V \mid S_{appr} = 1) \times \mathbb{E}(\delta^{\tau_{appl\rightarrow}}) \times p_{appr|appl} \times p_{appl|phaseIII}$$

+ similar derivations for **expected costs of**

Phase I, II, III, and clinical trials

II. Identifying (cumulative) abnormal returns

Strategy: abnormal r = actual r - expected r

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Procedure:

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Procedure:

$r_{i,t}$ = log(returns) firm i, period t; j announcements

For each announcement j:

(i) Fit $r_{i,t} = \alpha_i + \beta_i r_t + \varepsilon_{i,t}$ for $t = -110,\ldots,-10$ (before announcement)

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Strategy: abnormal r = actual r - expected r

Procedure:

$r_{i,t}$ = log(returns) firm i, period t; j announcements

(i) Fit $r_{i,t} = \alpha_i + \beta_i r_t + \varepsilon_{i,t}$ for $t = -110,..., -10$ (before announcement)

(ii) Define abnormal returns: $\hat{\varepsilon}_{i,j,t} \equiv r_{i,t} - \hat{r}_{i,j,t}$

II. Identifying (cumulative) abnormal returns

Strategy: abnormal r = actual r - expected r

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(iv) $\widehat{CAR}_{i,j,t} = \beta_{disc} \times \text{disc}_{i,j,t} + \beta_{appl} \times \text{appl}_{i,j,t} + \ldots + \omega_{i,j,t}$

Table 6: **Effects of Announcements on CAR**

	Full Sample	**Middle 90%**	**Bottom 95%**
Discovery	0.213	0.37	0.401
	[0.029, 0.420]	[0.029, 0.420]	[0.029, 0.420]
Discontinued during Discovery	-0.921	-2.429	-2.43
	[-2.239, 0.255]	[-2.238, 0.254]	[-2.238, 0.254]
Discontinued during Phase I	-1.150	-2.33	-2.319
	[-2.191, -0.157]	[-2.191, -0.157]	[-2.191, -0.157]
Discontinued during Phase II	-3.637	-7.63	-7.813
	[-5.199, -2.252]	[-5.198, -2.252]	[-5.198, .2.252]
Discontinued during Phase III	-7.310	-15.8	-15.809
	[-9.963, -4.626]	[-9.962, -4.625]	[-9.962, -4.625]
FDA Application	0.496	0.672	0.683
	[0.047, 0.953]	[0.047, 0.953]	[0.047, 0.953]
Discontinued after FDA Application	-1.384	-3.451	-3.451
	[-3.736, 0.850]	[-3.736, 0.849]	[-3.736, 0.849]
FDA Approval	1.158	4.017	4.017
	[0.547, 1.836]	[0.546, 1.836]	[1.836, 1.985]
Observations	8,281	3,968	4,032
$\overline{R}^2$	0.021	0.047	0.048

Note: The table presents estimated coefficients from Equation (7) using only single announcements. Each coefficient is followed by a 90% bootstrap confidence interval estimated using 1,000 bootstrap samples.

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Follows Aalen (1976), rather technical.

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  - For each interval, possible to estimate: $\frac{P(\text{success before } t)}{P(\text{no change before } t)}$ only with counting data
  - Use this to estimate $\mathbb{P}$ process-by-process

Results

Table 8: **Expected Value of Drugs**

	Full Sample	**Middle 90%**	**Bottom 95%**
At Approval			
All Drugs	\$6.83 bil	\$1.62 bil	\$1.6 bil
Drugs with Complete Path	\$7.43 bil	\$1.89 bil	\$1.99 bil
At Discovery			
All Drugs	\$331.12 mm	\$63.37 mm	\$65.97 mm
Drugs with Complete Path	\$360.16 mm	\$74.05 mm	\$82.21 mm

Note: The table presents the mean of the expected value of individual drugs at the time of approval, $\mathbb{E}(V|S_{\texttt{appr}} = 1)$, and at discovery, $\mathbb{E}(V|S_{\texttt{disc}} = 1)$. The 90% sample refers to the drugs developed by firms with real market capitalization between 5% and 95% of the entire sample. The row, "Drugs with Complete Path" refers to the sample of drugs for which we observe discovery, FDA application, and FDA approval announcements. Of the 84 such drugs, 29 belong to the Middle 90% and Bottom 95% samples. The row "Average" refers to drugs for which we observe only a few stages.

Table 11: **Total Development Costs, at Discovery**

	Middle 90%	Bottom 95%
All Drugs	\$58.51 mm	\$60.72 mm
Drugs with Complete Path	\$69.24 mm	\$77.01 mm

Note: The table presents the mean of the expected cost of clinical trials and the FDA application and review process (in millions of U.S. dollars) at the time of discovery. The 90% sample refers to the drugs developed by firms with real market capitalization between 5% and 95% of the entire sample. The row "Drugs with Complete Path" refers to the sample of drugs for which we observe discovery, FDA application, and FDA approval announcements. There are 84 such drugs, out of which 29 belong to the Middle 90% and Bottom 95% samples. The row "Average" refers to drugs for which we do not observe the complete path but only a subset.

Table 13: **Costs of Clinical Trials**

	Middle 90%	Bottom 95%
Phase I	\$0.62 mm	\$0.22 mm
Phase II	\$30.48 mm	\$34.46 mm
Phase III	\$41.09 mm	\$39.71 mm

Note: The table presents the mean of the expected cost of the three phases of clinical trials. Middle 90% sample refers to the drugs developed by firms with real market capitalization between 5% and 95% of the entire sample.

Table 12: **Cost of FDA Review and Application**

Middle 90%	Bottom 95%
\$638.75 mm	\$648.04 mm

Note: The table presents the mean of the expected cost of FDA review and FDA application at the time of discovery. Middle 90% sample refers to the drugs developed by firms with real market capitalization between 5% and 95% of the entire sample.

Policy Discussion

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1. Buyout drugs

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1. **Buyout drugs**
   - A. After FDA Approval
     Problem: Lucas Critique
   - B. At Discovery Stage
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1. **Buyout drugs**
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Problems:
- Crowd out private investment
- Promote socially wasteful R&D
- Difficult to target “right” drugs

Conclusion

This *simple* paper gives what it promises:

“Valuing Pharmaceutical Drug Innovations”