

# Endogenous Heterogeneous Innovation

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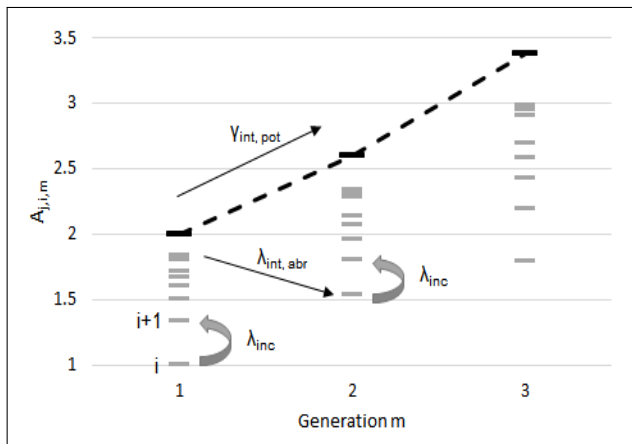
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# Theory Outline

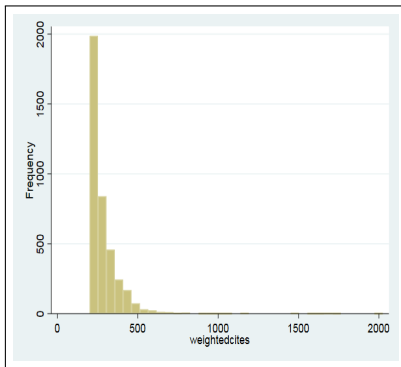
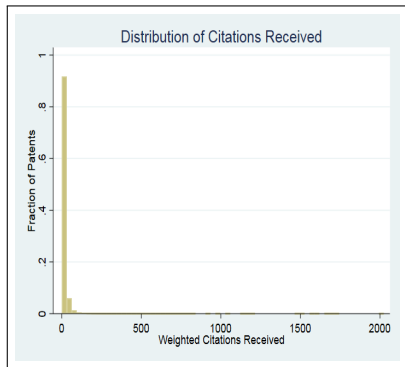
- Akcigit and Kerr (2016) included two different types of innovation (incremental and abrupt). Firms had no control over what type of innovation their R&D efforts would result in.
- We want to endogenize this distinction. Firms choose how much to invest in abrupt or internal innovations.
- We attempt to fit this model to patent citation distributions. The fit gives an impression of how well the model reflects reality. Also, the resulting parameter values have important theoretical interpretations.

# Framework - Innovation

**Focus:** Innovation: internal (incremental or abrupt), external, and entrants (the last two only abrupt).



# Data - Patent Citation Distributions



Summary: # obs = 3,278,174; Mean = 11.76; Std. Dev. = 20.00

# Theoretical Assumptions Regarding Patent Citations

- An abrupt patent is cited by every subsequent innovation within its technology cluster.
- Technology clusters are all contained within a patent classification.
- Abrupt patents will have a large number of citations overall (within and outside of their patent classifications)
- We need to choose a cutoff for distinguishing abrupt patents. The default is 10%. Later we test the robustness of our estimates to changes in this cutoff.

# Parameters

- Three parameters to estimate  $\{\alpha, \lambda_{inc,0}, \lambda_{abr} + \tau\}$
- $\alpha$  relates to the diminishing returns of incremental innovations. A low  $\alpha$  means that the step-size decreases very quickly.  $\alpha = 1$  means that step sizes are constant.
- $\lambda_{inc,0}$  is the rate of incremental innovations for new technology clusters. It is actually a function of the exogenous parameters  $\{D, \sigma, \varphi, \xi\}$ , which cannot be separated using citation distributions.
- $\lambda_{abr} + \tau$  is the total arrival rate of abrupt innovations. It is also a function of exogenous parameters.

# Estimation Strategy

- First the parameters  $\{\alpha, \frac{\lambda_{inc,0}}{(\lambda_{abr} + \tau)}\}$  are estimated using MLE on the abrupt, same-class citation distribution.
- Next the absolute values of  $\lambda_{inc,0}$  and  $\lambda_{abr} + \tau$  are determined using Compustat data on R&D intensity (= R&D expenditure/Sales).

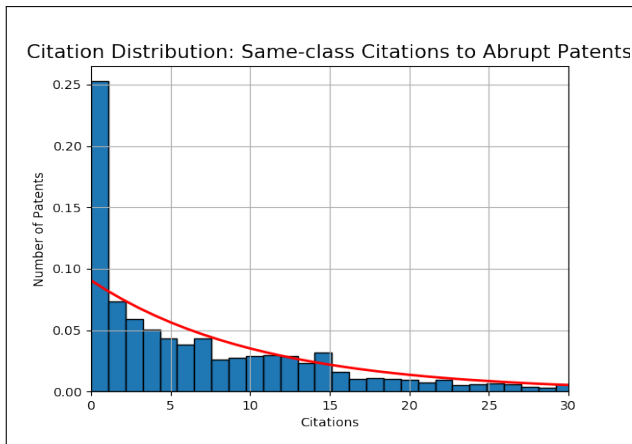
# Framework - Innovation

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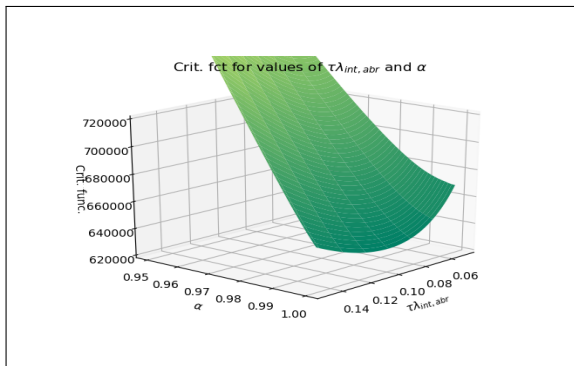
# Estimation Results

- $\alpha = 1$ ,  $\lambda_{int,0} = 0.357$ ,  $\lambda_{abr} + \tau = 0.0355$



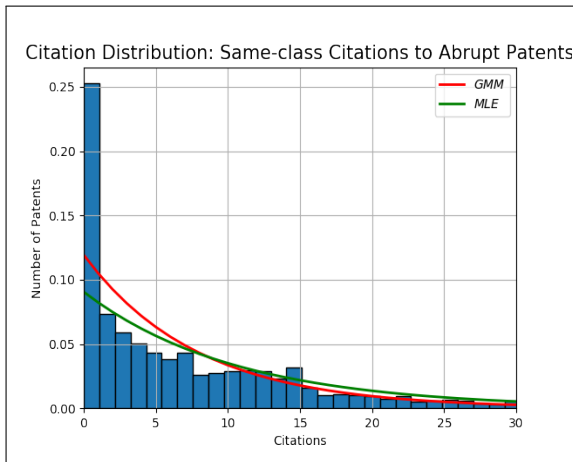
# Confidence in global optimum

- The result is robust to changes in initial conditions.
- "Basin Hopping" confirms the minimum.
- We tried fixing  $\alpha$  and running an unconstrained optimization. This gave the same results.



# Robustness

- We ran a GMM estimation:  $\alpha = 1$ ,  $\lambda_{int,0} = 0.351$ ,  $\lambda_{abr} + \tau = 0.047$



## Robustness - GMM

- Moments (GMM):

Moment	Data	Model
Mean of citations	10.06	7.39
Mean of first 5 seq. ratios	0.57	0.88
Sum of first 2 bins	0.26	0.22
R&D Intensity	0.068	0.068
Criterion	0.386	

- Untargeted moment: share of incremental R&D over total:

Moment	Data	Model
MLE		
Incremental/total	.90	.78
GMM		
Incremental/total	.90	.88

# Robustness Results

- When the cutoff for abrupt patents is adjusted, we get similar results.

Robustness Specification Results

Abrupt Cutoff	.1	.2	.05
$\lambda_{inc,0}$	.357	.362	.347
$(\lambda_{abr} + \tau)$	.0355	.0239	.0568
$\alpha$	1.0	1.0	1.0

# Robustness Results

- We tried relaxing the assumption that abrupt patents are cited by every incremental patent in their technology cluster. Results were identical.

Robustness Specification Results

	Baseline	Flexible
$\frac{\lambda_{inc,0}}{(\lambda_{abr} + \tau)}$	.104	.104
$\alpha$	1.0	1.0
$p$	-	1.0
log-likelihood	-627597	-627598

# Conclusion

- The model fits most of the citation distribution, but badly underestimates the number of patents with zero citations.
- No evidence was found for an important feature of the model: the diminishing return from incremental innovations.
- We are confident, given our theoretical specification, that we have found the parameters that maximize the log-likelihood.
- Our results pass a number of robustness checks.
- However, many key theoretical assumptions are still unchecked.

# References

- [1] ACEMOGLU, D., AKCIGIT, U., AND CELIK, M. A. Young, restless and creative: Openness to disruption and creative innovations. Working Paper 19894, National Bureau of Economic Research, 2014.
- [2] AKCIGIT, U., AND KERR, W. R. Growth through heterogeneous innovations. forthcoming, 2016.
- [3] KLETTE, T. J., AND KORTUM, S. Innovating firms and aggregate innovation. *Journal of Political Economy* 112, 5 (2004), 986–1018.
- [4] PHILIPPE AGHION, C. H. P. H., AND VICKERS, J. Competition, imitation and growth with step-by-step innovation. *Review of Economic Studies* 68, 3 (2001), 467–492.



## Appendix: Framework - Innovation

- Law of motion ( $A_{m+1} = A_m \gamma_{int,pot}$ ):

$$A_{t+\Delta t} = \begin{cases} A_m(1 - \alpha^s), \lambda_{inc} \Delta t, \alpha \in (0, 1), s \in \{1, 2, \dots\} \\ A_t \gamma_{int,abr}, \lambda_{int,abr} \Delta t \\ A_t, [1 - \lambda_{inc} \Delta t; 1 - \lambda_{int,abr} \Delta t] \end{cases}$$

- Incremental R&D cost:  $\psi_{inc}(\lambda_{inc}, A_t) = \xi_j A_t \lambda_{inc}^\eta$
- Catching-up: laggards pay  $\psi_{inc}(\lambda_{inc}, A_t)$  and get an arrival  $\lambda_{inc} + h$ ;
- Abrupt R&D cost (for  $n_p > 0$ ):  $\psi_{abr}(\lambda_{ext,abr}, \bar{A}_t) = \xi_j \bar{A}_t \lambda_{ext,abr}^\eta$ ,  $\bar{A}_t$  sector average;
- Cournot competition: profits  $\pi_t$  scale with  $\frac{A_{j,i,m}}{\sum_j A_{j,i,m}}$  within an industry.

## Appendix: Framework - Innovation

Outside entrepreneur:

- Value function:

$$rV_0 - \dot{V}_0 = \max_{\lambda_{ext,abr}} [\lambda_{ext,abr} [E_j[V(A_{t,m+1})] - V_0] - v\bar{A}_t\lambda_{ext,abr}]$$

- Cost:  $C_E(\lambda_{ext,abr}, \bar{A}_t) = v\bar{A}_t\lambda_{ext,abr}$ ,  $v$  a constant;
- Free entry condition:  $E_j[V(A_{t,m+1})] = v\bar{A}_t$
- $\Rightarrow$  Each firm faces an aggregate endogenous creative destruction (CD) of rate  $\tau_{CE}$  and internal competition rate  $\tau_I$ .

# Appendix: Framework - Innovation

Incumbents:

- Value function:  $rV(A_t) - \dot{V}(A_t) =$

$$\max_{\substack{\lambda_{inc}, \lambda_{int,abr} \\ \lambda_{ext,abr}}} \left[ \sum_k^{n_{j,p}} \left[ \begin{aligned} &\pi_t n_{j,p} - \{ \xi_j \lambda_{inc}^\eta A_{t,m}; \xi_j \bar{A}_t \lambda_{int,abr}^\eta \} \\ &+ \{ \lambda_{inc} [V(A_{t,m}^k \cup A_{t+\Delta t,m}^k) - V(A_{t,m})]; \\ &\lambda_{int,abr} [E_j [V(A_{t,m}^k \cup A_{t+\Delta t,m+1}^k) - V(A_{t,m})]] \} \\ &- \tau_I [V(A_{t,m} \setminus \bar{A}_{t+\Delta t,m}^k) - V(A_{t,m})] \\ &- \tau_{CE} [V(A_{t,m} \setminus \bar{A}_{t+\Delta t,m+1}^k) - V(A_{t,m})] \\ &+ \lambda_{ext,abr} [E_j [V(A_{t,m}^k \cup A_{t+\Delta t,m+1}^{k'}) - V(A_{t,m})] \\ &- \xi_j \bar{A}_t \lambda_{int,abr}^\eta - \Phi \bar{A}_t \end{aligned} \right] \right]$$

- 1<sup>st</sup>: instant returns - costs;
- 2<sup>nd</sup>, 3<sup>rd</sup>: return from int. R&D;
- 4<sup>th</sup>: internal competition;
- 5<sup>th</sup>: external CE;
- 6<sup>th</sup>: return from abr. R&D;
- 7<sup>th</sup>: Abr. R&D and fixed costs;