Quantifying the evolution of individual scientific impact

Zirui Yan

Electrical, Computer, and Systems Engineering
Rensselaer Polytechnic Institute

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- R. Sinatra, et al. Quantifying the evolution of individual scientific impact. Science, 2016.
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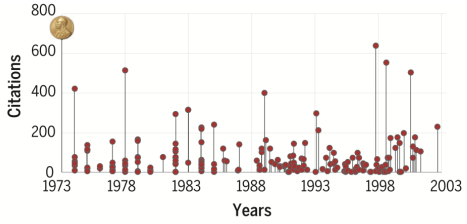
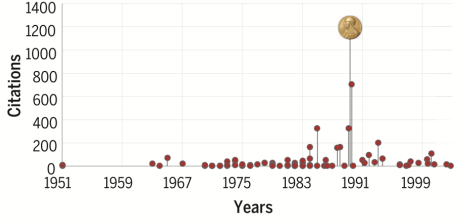
  2. Impact of publication field.
  3. Improving the accuracy.

Publication history of two Nobel laureates



Frank A. Wilczek
Physics Nobel,
2004



John B. Fenn
Chemistry Nobel,
2002

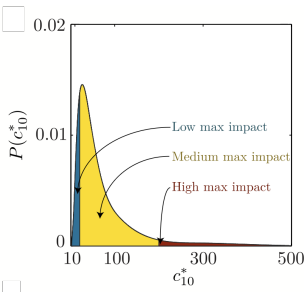
Problem

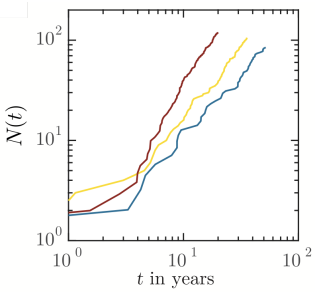
- How do impact and productivity change over a scientific career?
- Does impact follow predictable patterns?
- Can we predict the timing of a scientist's outstanding achievement?
- Can we model scientific careers in quantitative and predictive terms?

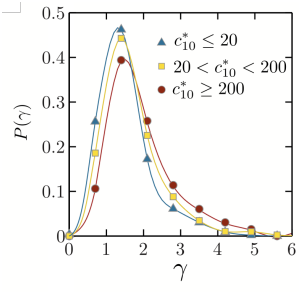
Dataset

- American Physical Society (APS) dataset
  - journal family *Physical Review*
  - 20 years of career + 10 papers + at least one paper every 5 years.
  - $500,000$ papers over 110 years
  - 3000 careers
- Impact of paper: Cumulative citations over 10 years c_{10}.

Distribution of max impact and productivity

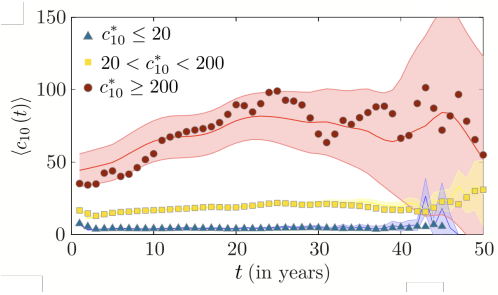


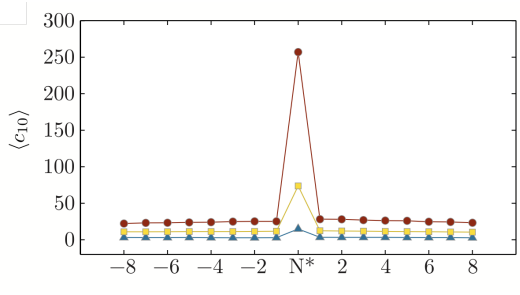




- Split into 3 groups: Low/Medium/High max impact.
- More products are expected from a high max impact group.
- Number of publication $N(t) = t^{\gamma}$.

Citation varying with time



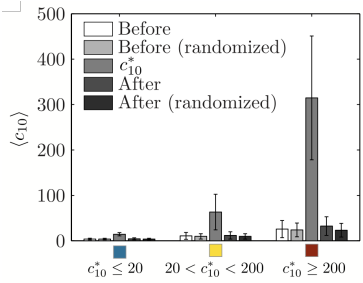


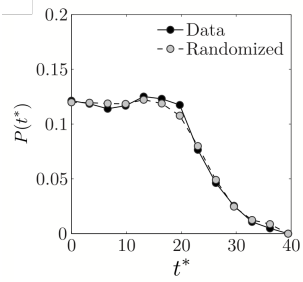
- High max impact group will constantly have a higher impact.
- High max impact happens randomly during the career.

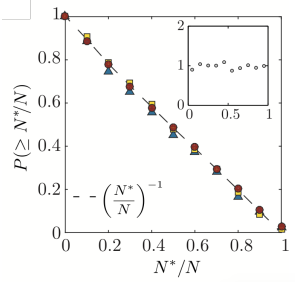
Random-impact rule

- Keep the publication time and citation number.

- Reshuffle the publication index.







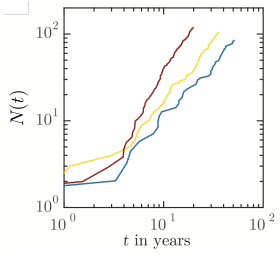
Random-impact rule

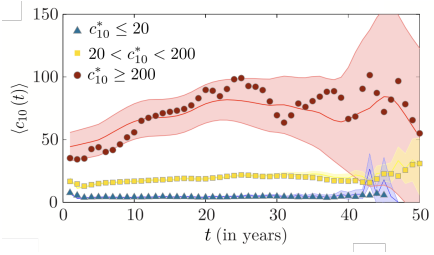
- Impact is random in a career.

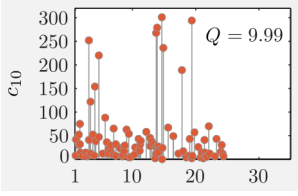
- There is always hope! If you keep publishing!

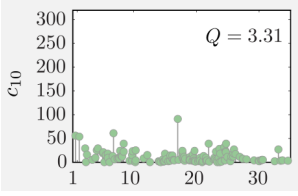
The role of scientist

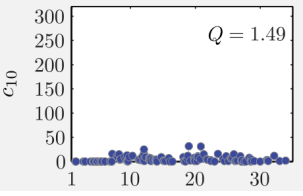
- There is systematic differences in impact between careers.











Models

- **Q-model:** Impact of a paper j by scientist i is

$$c_{10,ij} = p_j \, Q_i \ . \tag{1}$$

$$\text{Impact of j-th paper} = \text{lucky} * Q$$

- **Baseline: R-model:**

$$c_{10,j} = p_j \ , \tag{2}$$

where $p_j \sim P(c_{10})$.

  - The only factor differentiating two scientists is their overall productivity N.

Estimation in Q model

- The joint probability $P(p, Q, N)$ is verified to be log-normal.

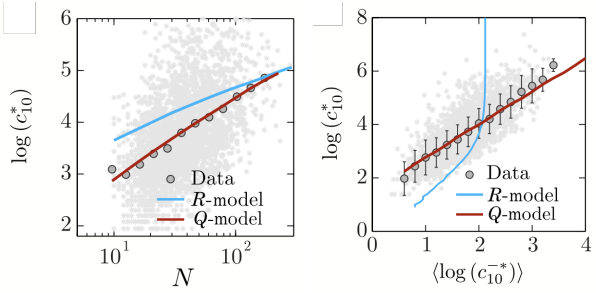
- Maximum-likelihood approach.

$$\mu = (\mu_p, \mu_Q, \mu_N) = (0.92, 0.93, 3.34) \tag{3}$$

$$\begin{aligned} \sum &= \begin{pmatrix} \sigma_p^2 & \sigma_{p,Q} & \sigma_{p,N} \\ \sigma_{p,Q} & \sigma_Q^2 & \sigma_{Q,N} \\ \sigma_{p,N} & \sigma_{Q,N} & \sigma_N^2 \end{pmatrix} \\ &= \begin{pmatrix} 0.93 & 0.00 & 0.00 \\ 0.00 & 0.21 & 0.09 \\ 0.00 & 0.09 & 0.33 \end{pmatrix} \end{aligned} \tag{4}$$

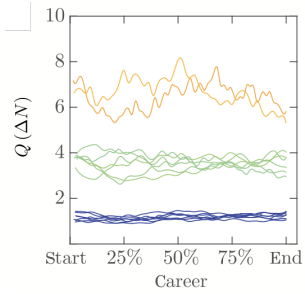
- $\sigma_{p,Q} = \sigma_{p,N} = 0$.

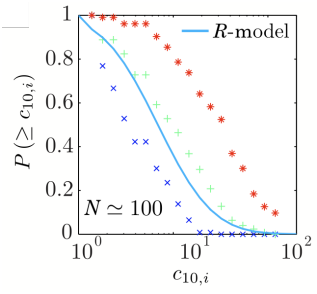
Goodness of model

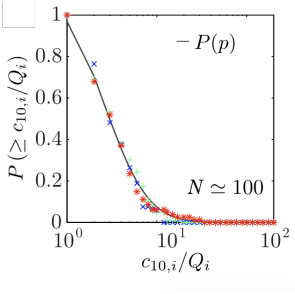


- R-model can not capture the correlation between c_{10}^* and N.
- R-model can not capture the correlation between c_{10}^* and c_{10}^{-*}, average citation exclude the most cited paper.
- Q-model is a good fit.

Number of highest citation



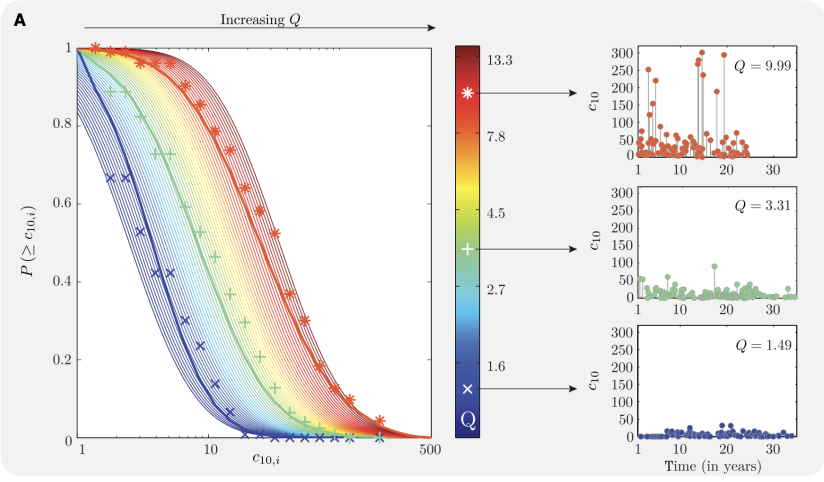




- Sliding widow: Q factor is a "constant" within career.
- Q-model capture the difference between different group.
- p is pure lucky!

Predicting individual Q factor

- calculate Q by maximizing the individual likelihood



Results

- Who is going to have an outstanding achievement?

  Lucky scientists with high Q value.

- And when?

  Randomly within their career.

Further experiment

National Institutes of Health Open Citation Collection (NIH-OCC) dataset[1]

- MedLine, PubMed Central (PMC), and CrossRef.
- 20 years of career + 10 papers
- 551274 careers with Publication since 1800
- Impact of paper: Average citations.

Longer history, larger dataset!

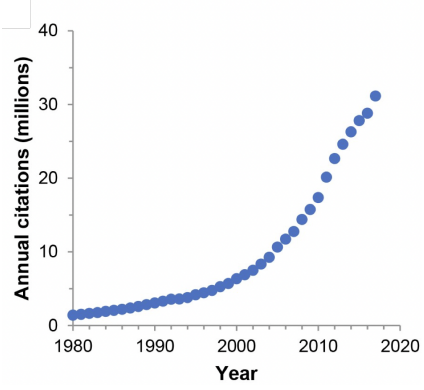
[1] Hutchins, B. Ian, et al. "The NIH Open Citation Collection: A public access, broad coverage resource." PLoS Biology, 2019.

Goal

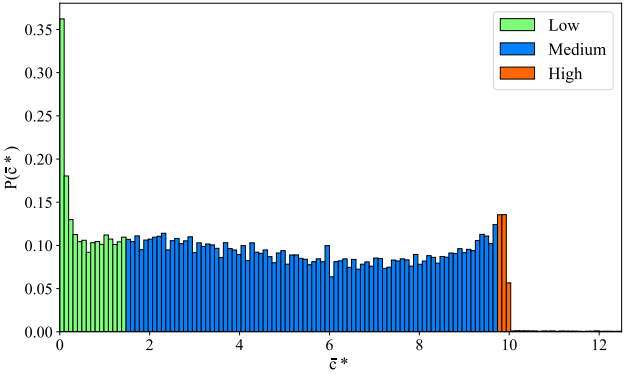
- Impact of career time.
- Impact of publication field.
- Improving the accuracy.

Influence of career time

- The citation number is exploding.

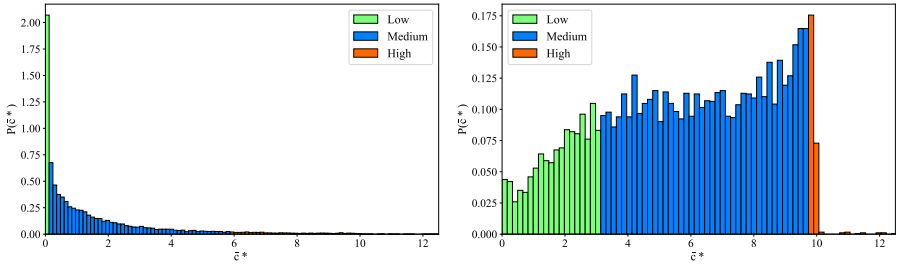


Influence of career time



Influence of career time

- Early: Last publication < 1990 v.s. Late: First publication > 1990.

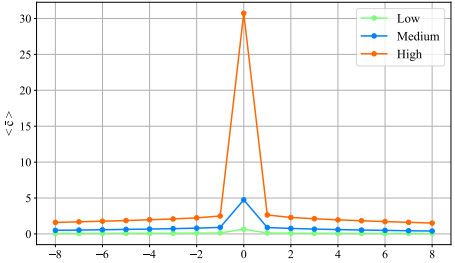


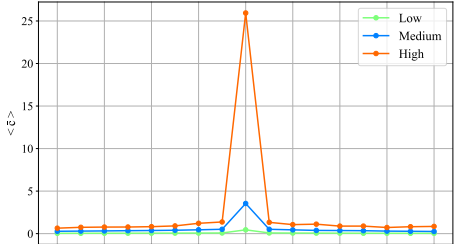
Percentage	20%	95%
all	1.57	9.74
early	0.07	5.98
late	3.15	9.82

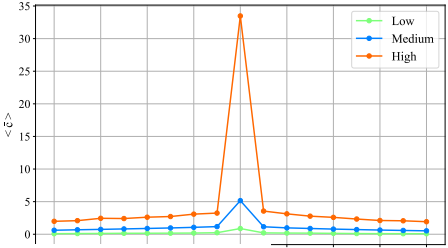
- Career time does impact the average citation.

Influence of career time

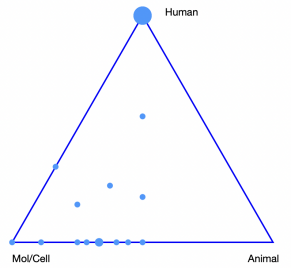
- Random rule still holds.

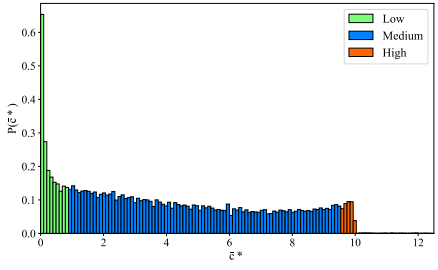


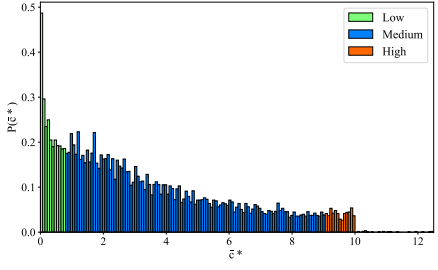


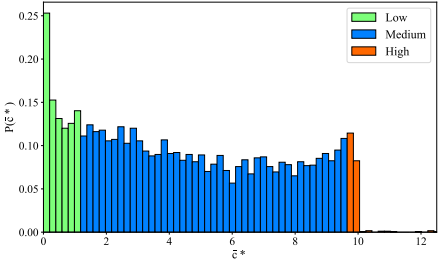


Influence of field









Influence of field

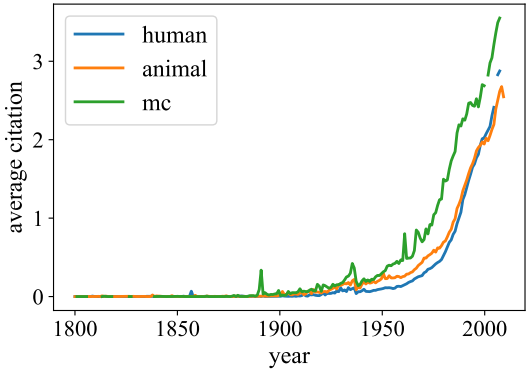
Percentage	20%	95%
all	1.57	9.74
human	0.92	9.62
animal	0.85	9.07
molecular cellular	1.34	9.72

Table: Percentage of average citation

- Field do impact the average citation.

- Better to publish cross-field papers.

Correlation between career time and filed



- Career time and filed are correlated.

Failure of Q-model

- We now have 4 factors: lucky (p), career year (y), filed (f) and scientist power Q.
- The dataset is too large which is computational inefficient
- Correlation between career time (y) and filed (f) such that

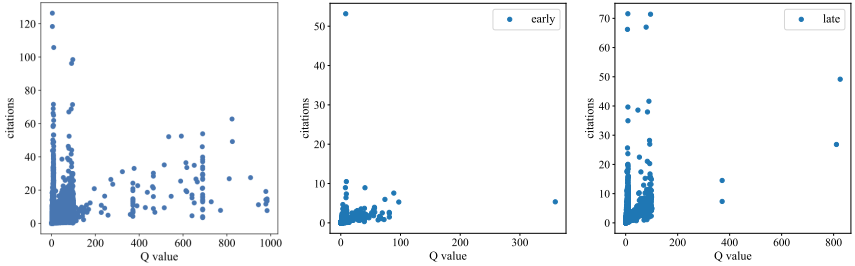
$$\bar{c} \neq p\mu_y fQ \tag{5}$$

- Use neural network to predict the mean of average citation

$$\mu_{\bar{c}} = \mathrm{NN}(y, f) \ . \tag{6}$$

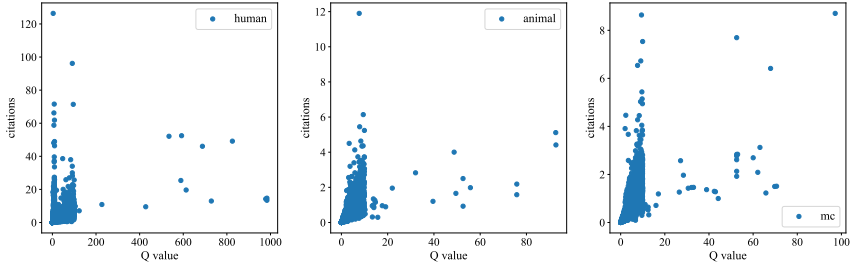
Neural network (preliminary)

- Trained three layer neural network with ReLU activation
- Q_i is average of $\bar{c}_j/\mathrm{NN}(y_j, f_j)$
- the influence of career time



Neural network (preliminary)

- influence of field



Conclusion of additional experiment

- Career time and publication field do impact the average citation.
- Q-model is not capable for this setting.
- Neural network can help enhance the prediction.

Future work

- Improve the prediction results of neural network.
- Rescale number of citations.
- Author name disambiguation.