

# To vaccinate or not to vaccinate? A coevolutionary dilemma

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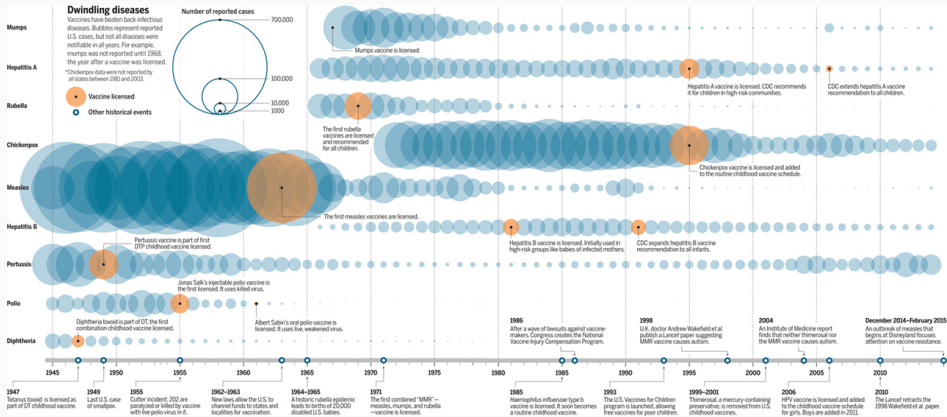
Complenet 2018

Network Science Institute – Northeastern University, Boston (USA)

Monday 5 March 2018



# Bad news . . .



Wadman, M., & You, J. (2017). The vaccine wars. *Science*, **356**(6336), 364–365.

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 1,475

DOI: [http://dx.doi.org/10.1016/S0140-6736\(97\)11996-0](http://dx.doi.org/10.1016/S0140-6736(97)11996-0) 

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colitis, and pe

Dr AJ Wakefield, FRCS, FRCPsych, AP Dhillon, MRC  
Smith, FRCP

Altmetric 1,475

DOI: <http://dx.doi.org/10.101>

Article Info

Summary

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July 4, 2016

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## Anti Vaccine Movement

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Summ

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Bad news . . .

# Vaccination dilemma



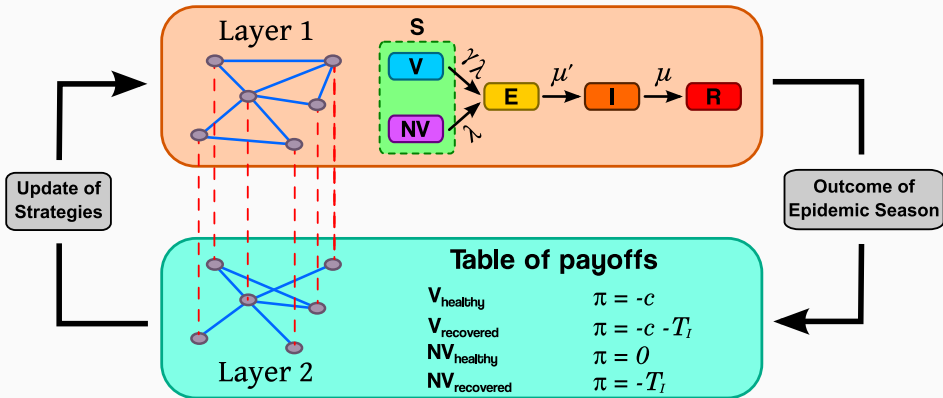
# Vaccination dilemma





**Cooperation VS Spreading**  
**who will prevail?**

# The coevolutionary model

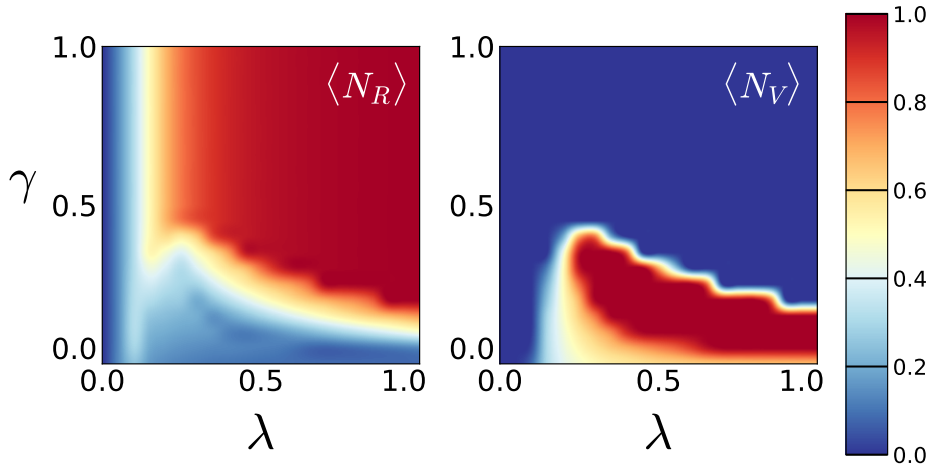


A. Cardillo, et al. "Evolutionary vaccination dilemma in complex networks."

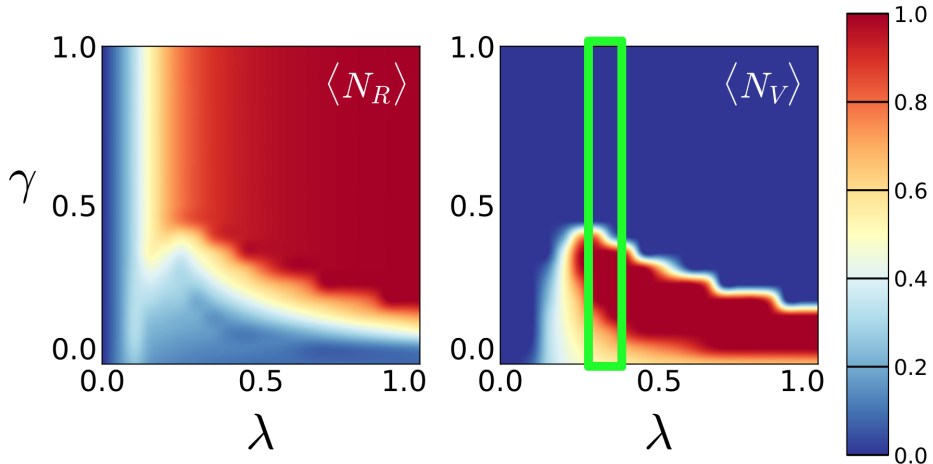
Phys. Rev. E, **88**, 032803. (2013).

# Results

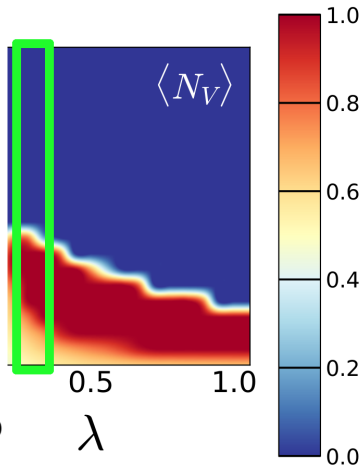
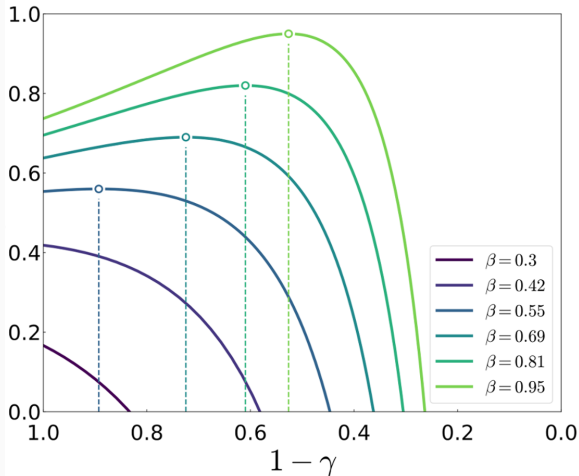
# Global behaviour (RGG – SF)



# Global behaviour (RGG – SF)



# Global behaviour (RGG – SF)







*Between 2005 and 2010, the proportion of French people in favour or very in favour of vaccination dropped from 90% to 60% (2013 INPES Peretti-Watel health barometer). The percentage of French people between the ages of 18 and 75 who are anti-vaccination increased from 8.5% in 2005 to 38.2% in 2010. In 2005, 58% of doctors questioned the usefulness of vaccines administered to children while 31% of doctors were expressing doubts about vaccine safety. These figures must surely have increased since then. (Michèle Rivasi)*





“

*Between 2005 and 2011, the percentage of French parents who refused to vaccinate their children*



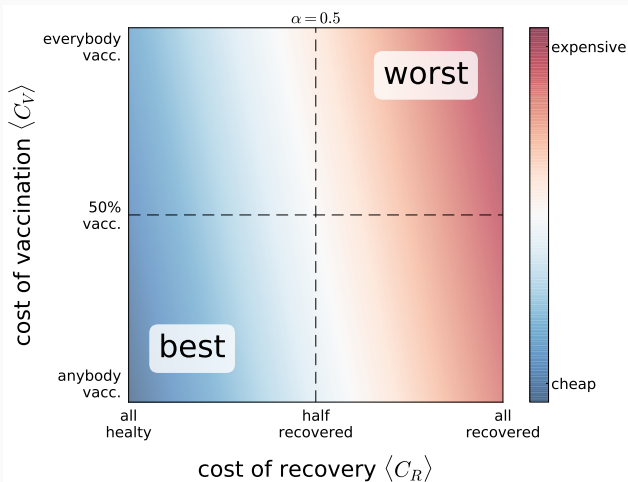
*dropped from 8.5% in 2005 to 38% in 2011.*

*of vaccination  
percentage of  
from 8.5% in  
administered  
these figures*

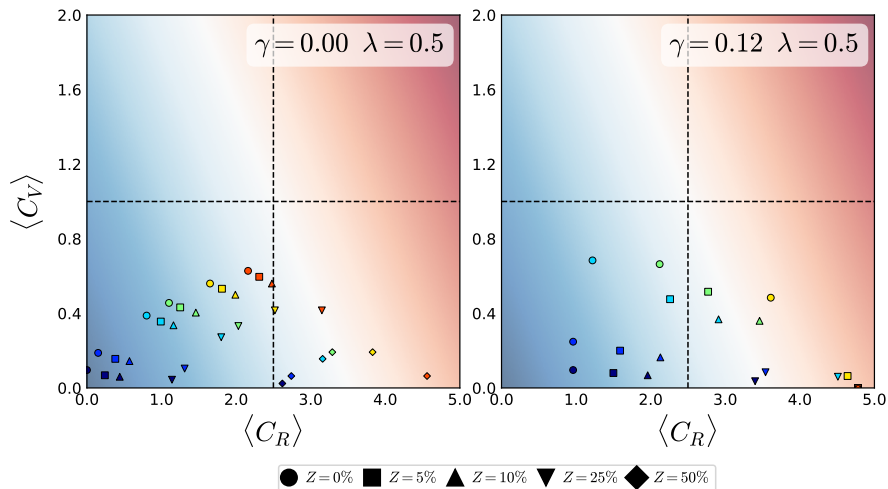
”

# Zealots & overall cost

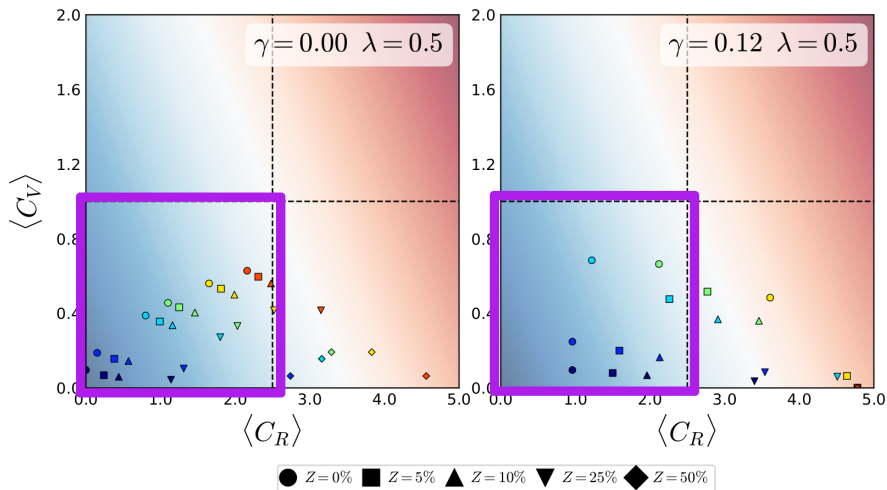
$$\rho = \alpha \langle C_V \rangle + (1 - \alpha) \langle C_R \rangle$$



# Zealots & overall cost

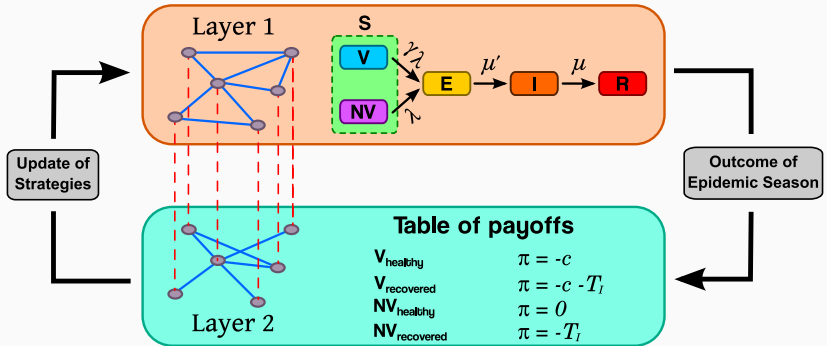


# Zealots & overall cost



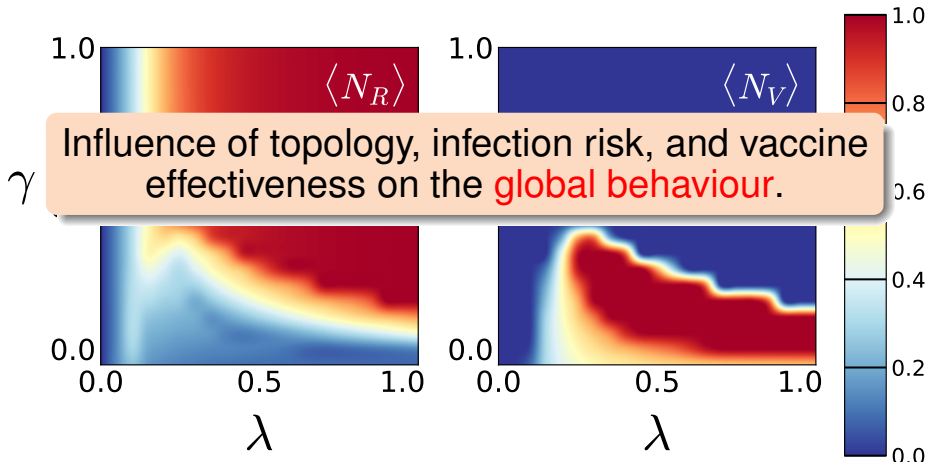
# Conclusions

# Summing up ...



Coevolutionary model based on **epidemic spreading** and **evolutionary game theory** on multiplex networks.

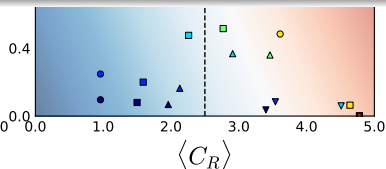
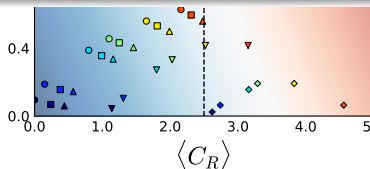
# Summing up ...



# Summing up ...



Effects of **zealotry** on the overall performances



●  $Z = 0\%$  ■  $Z = 5\%$  ▲  $Z = 10\%$  ▼  $Z = 25\%$  ◆  $Z = 50\%$

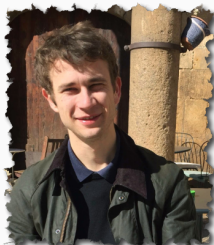


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Mopari**



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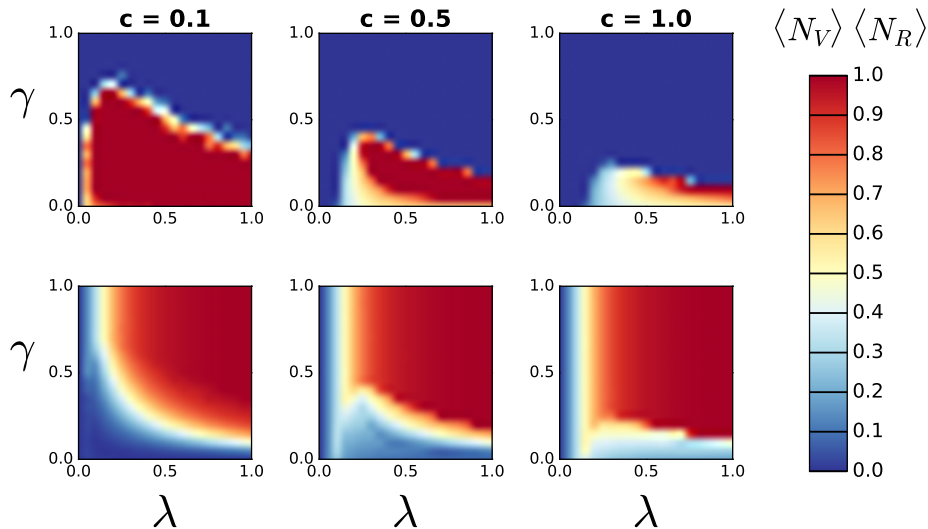


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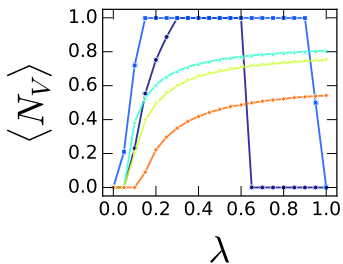
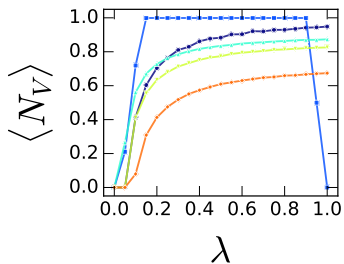
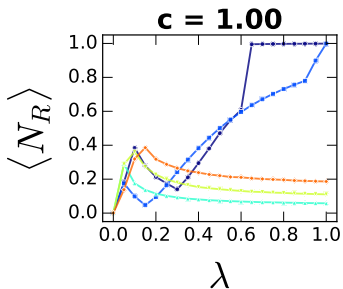
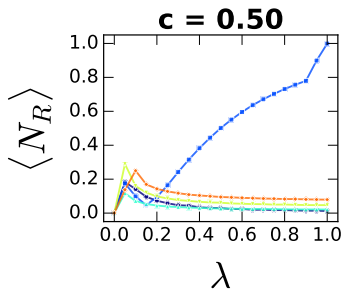
Part II

**Appendix**

# Global behaviour

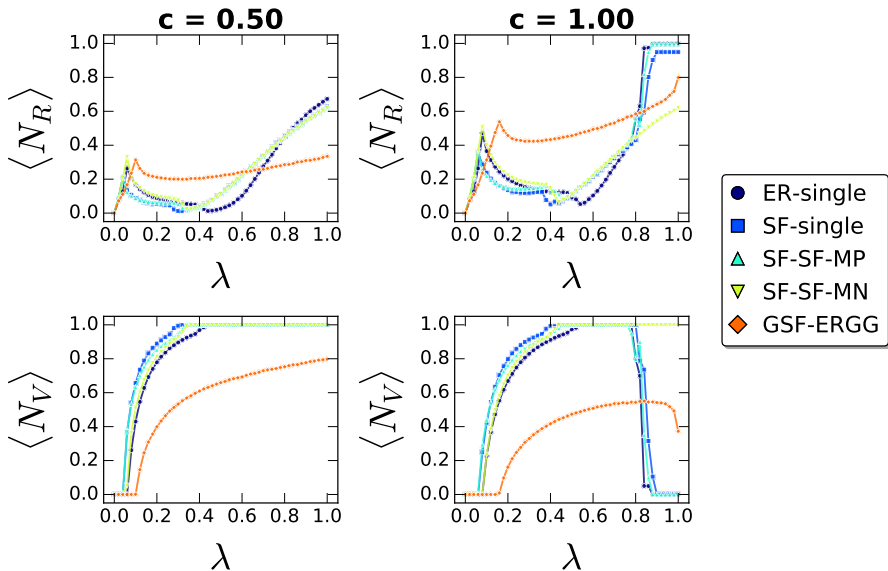


# Effect of multiplexity/topology

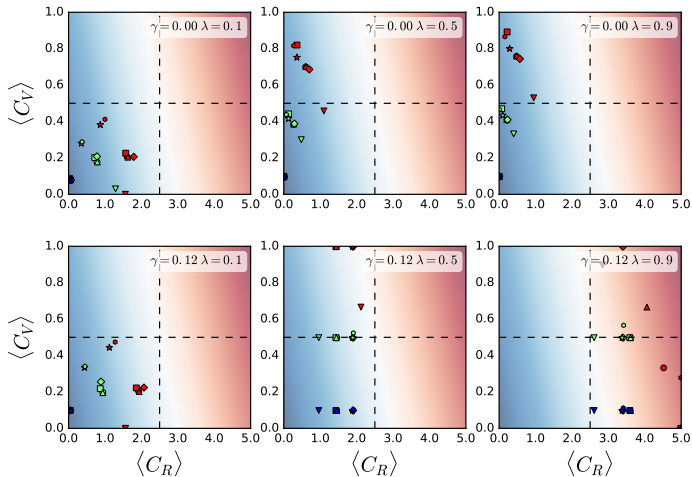


- ER-single
- SF-single
- ▲ SF-SF-MP
- ▼ SF-SF-MN
- ◆ GSF-ERGG

# Effect of multiplexity/topology

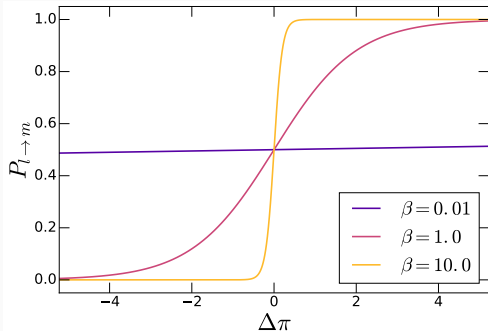


# Effect of multiplexity/topology



● ER-single ■ SF-single ▲ SF-SF-MP ▼ SF-SF-MN ◆ ER-ER ★ GSF-EER ● GSF-ERGG

# Update of strategy

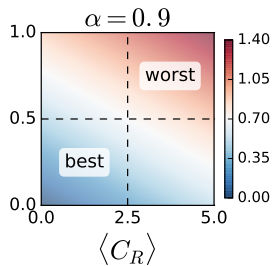
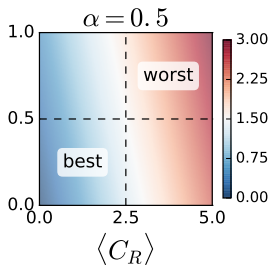
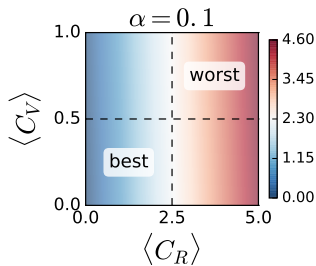


## Fermi's Rule

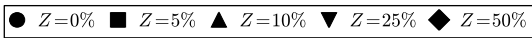
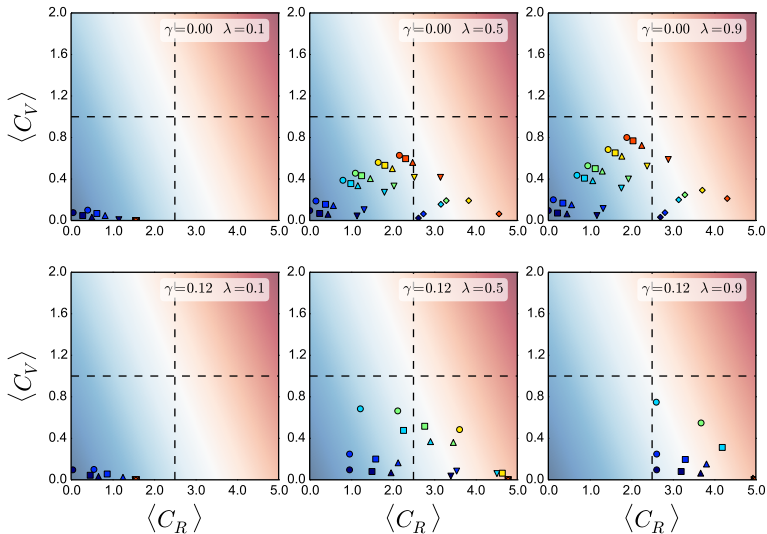
$$P_{l \rightarrow m} = \frac{1}{1 + e^{-\beta(\pi_m - \pi_l)}}.$$








# Relative cost



# Performances & Zealots



# Bibliography

-  A. Cardillo, *et al.* Phys. Rev. E, **88**, 032803. (2013).
-  B. Steinegger *et al.* arXiv preprint, arXiv:1802.00883 (2018).
-  Wang, Z., *et al.* Phys. Rep., **664**, 1–113 (2016).
-  N. Masuda, Sci. Rep., **2**, 646 (2012).
-  <http://www.thevaccinereaction.org/2015/08/the-french-national-debate-on-vaccine-safety/>