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Estimating crop production resilience for the EU

From ecological theory to agricultural policy

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Joint Research Centre

Context

- EU adaptation strategy (2021)
- New Common Agricultural Policy
- Resilience communication (2020)
- 3 resilience aspects –robustness (resisting change, shock) absorption), adaptability (adjusting existing practices) and transformation (structural change of practices).
- The EU green deal: emphasis on transformation
- Many aspects need quantitative metrics along different dimensions (financial, social/innovation, governance and climate/environmental) but data are not always available or of sufficient quality.

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COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT AND THE COUNCIL

2020 Strategic Foresight Report
STRATEGIC FORESIGHT – CHARTING THE COURSE TOWARDS A MORE RESILIENT EUROPE

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Definitions and Outline

- **Definition**: ecological resilience is amplitude of the largest disturbance that the system can absorb without losing its structure and functions (Holling)

- **Assumptions: 1)** larger disturbances are rarer **2)** larger disturbances have larger impacts **1 + 2) Production resilience can be measured by the return period of the total (or large) production losses.**

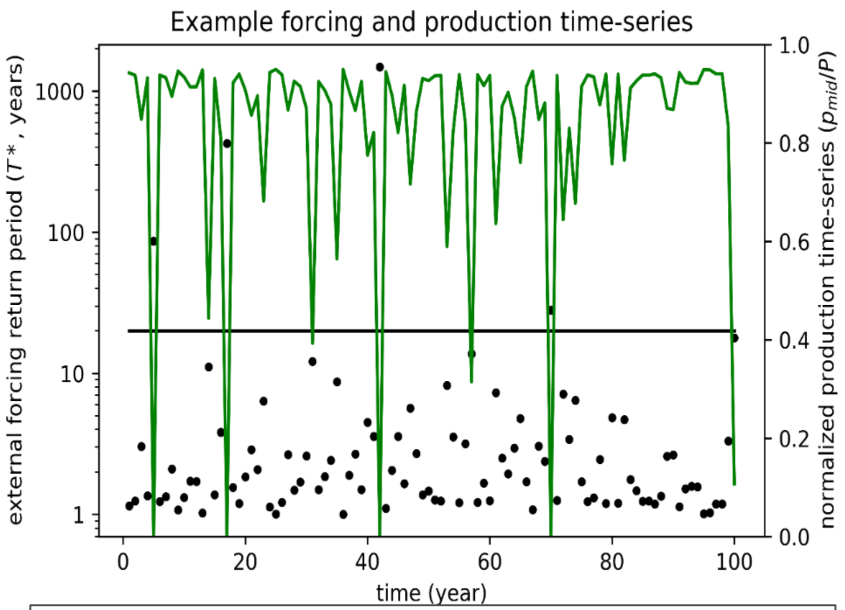
- **Annual Production Resilience Indicator ($R_p = \mu^2 \sigma^{-2}$)**

- **Effect of diversity**: large spatial aggregations, multi-crop systems, open-source software (ReciPy or PyResPro)

- **Summary and Outlook**: relevance for farms, climate scenarios, adaptation, how to measure climate related shocks

The Annual Production Resilience Indicator: computation from model and real data

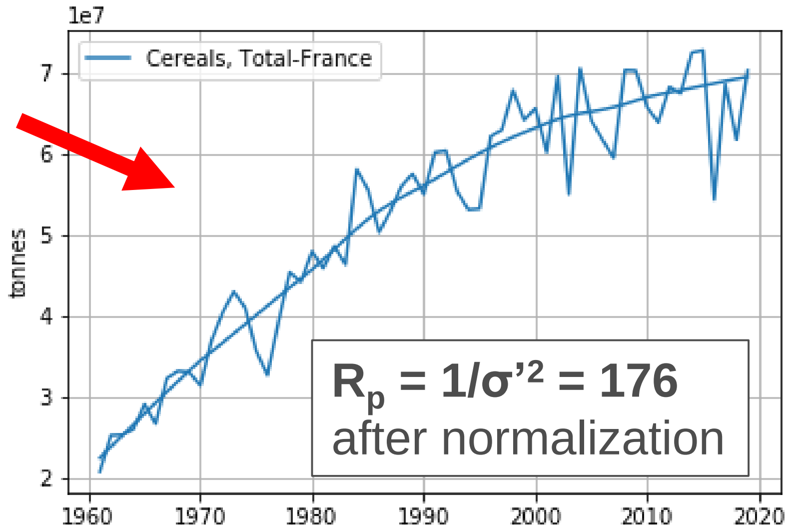
MODEL DATA: Single Field or Homogeneous Cropping Area



$R_p \sim T^*_{MAX} \cdot f$ (**Management , Memory)**

REAL DATA (Country)
are not stationary

Total production loss is never observed for **diversified and large spatial aggregations**. How to interpret this?



$R_p = 1/\sigma'^2 = 176$
after normalization

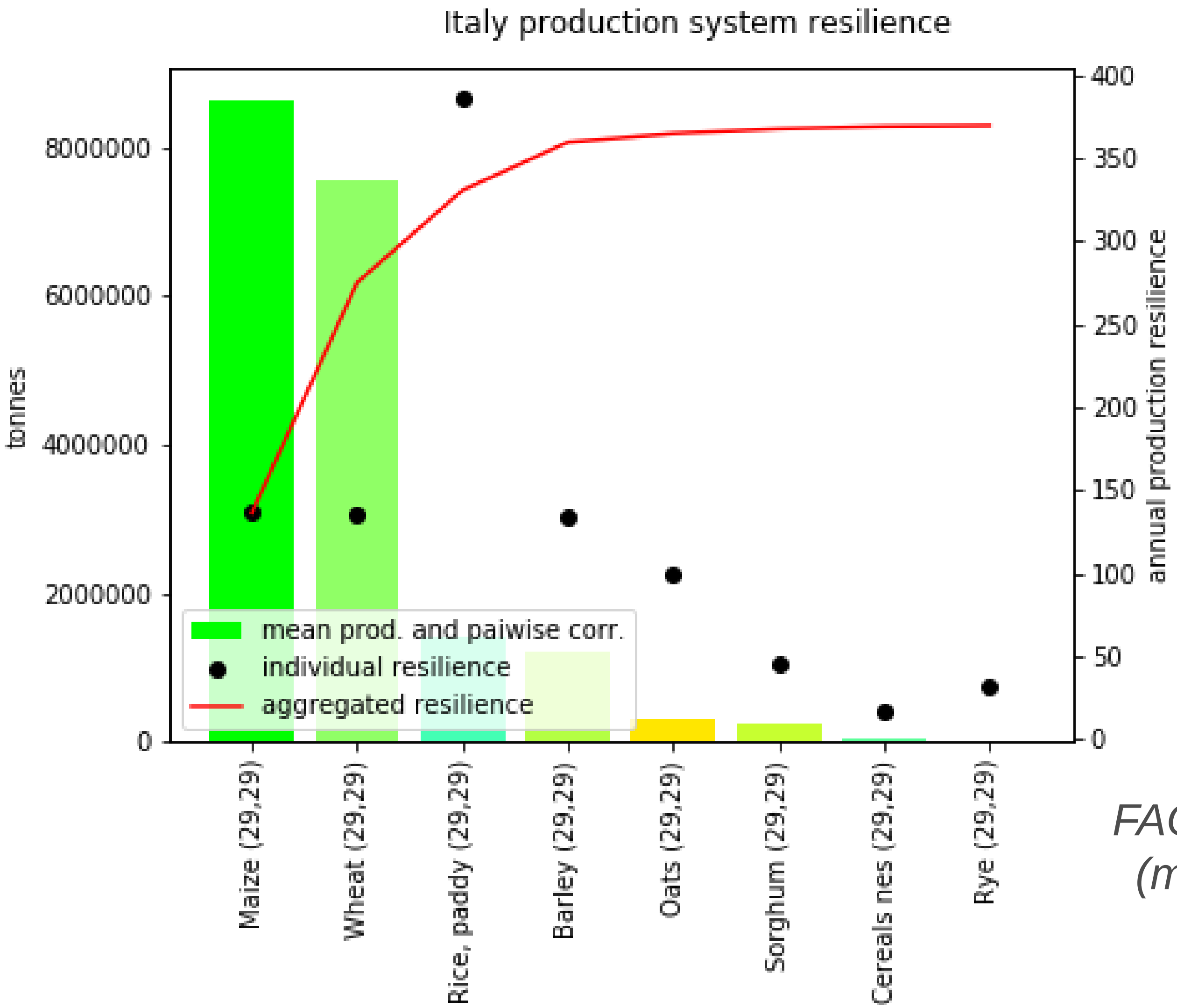
Effect of diversity

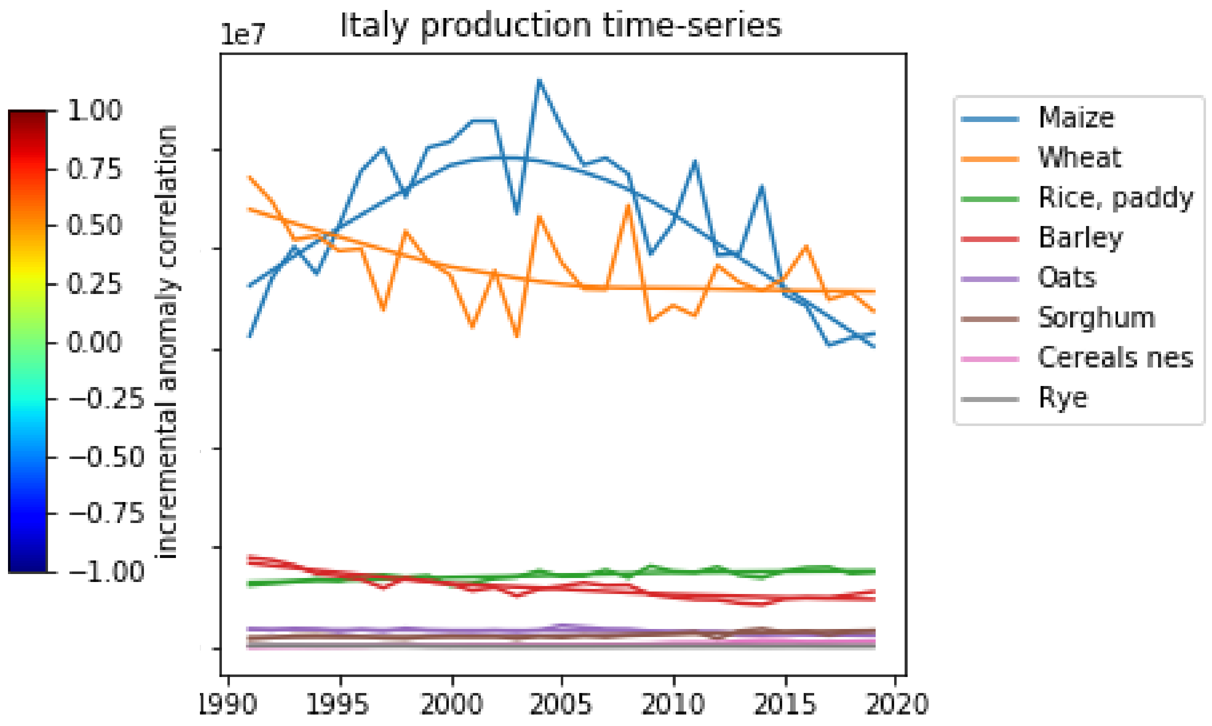
R_p of a diversified production system is proportional to the effective number of equivalent uncorrelated production units* (different crops and/or conditions related to management, environment, climate)

Spatial aggregations of large numbers of uncorrelated crop production reach very high R_p values and the <u>probability of total production losses is close to zero</u>, consistently with the diversity property of R_p

**hint for demonstration: think of the sum of two uncorrelated production time series with same μ and σ*

Diversity: multiple crops, cereals in Italy





Open-source software (PyResPro, ResiPy) to analyze FAOSTAT or EUROSTAT data, not yet applied at the farm level (masterclass at LANDSCAPE 2021 Berlin 20-22 September)

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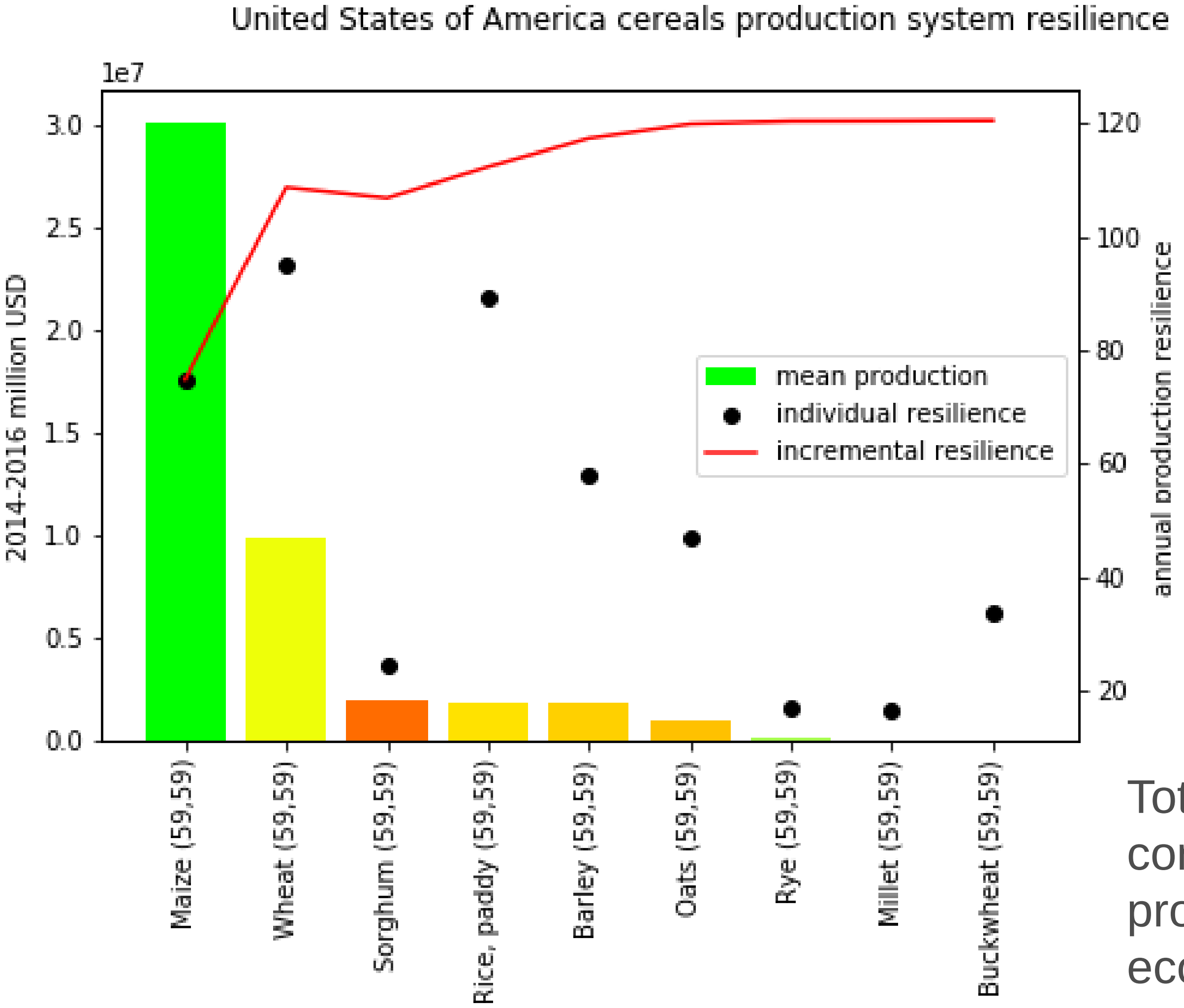
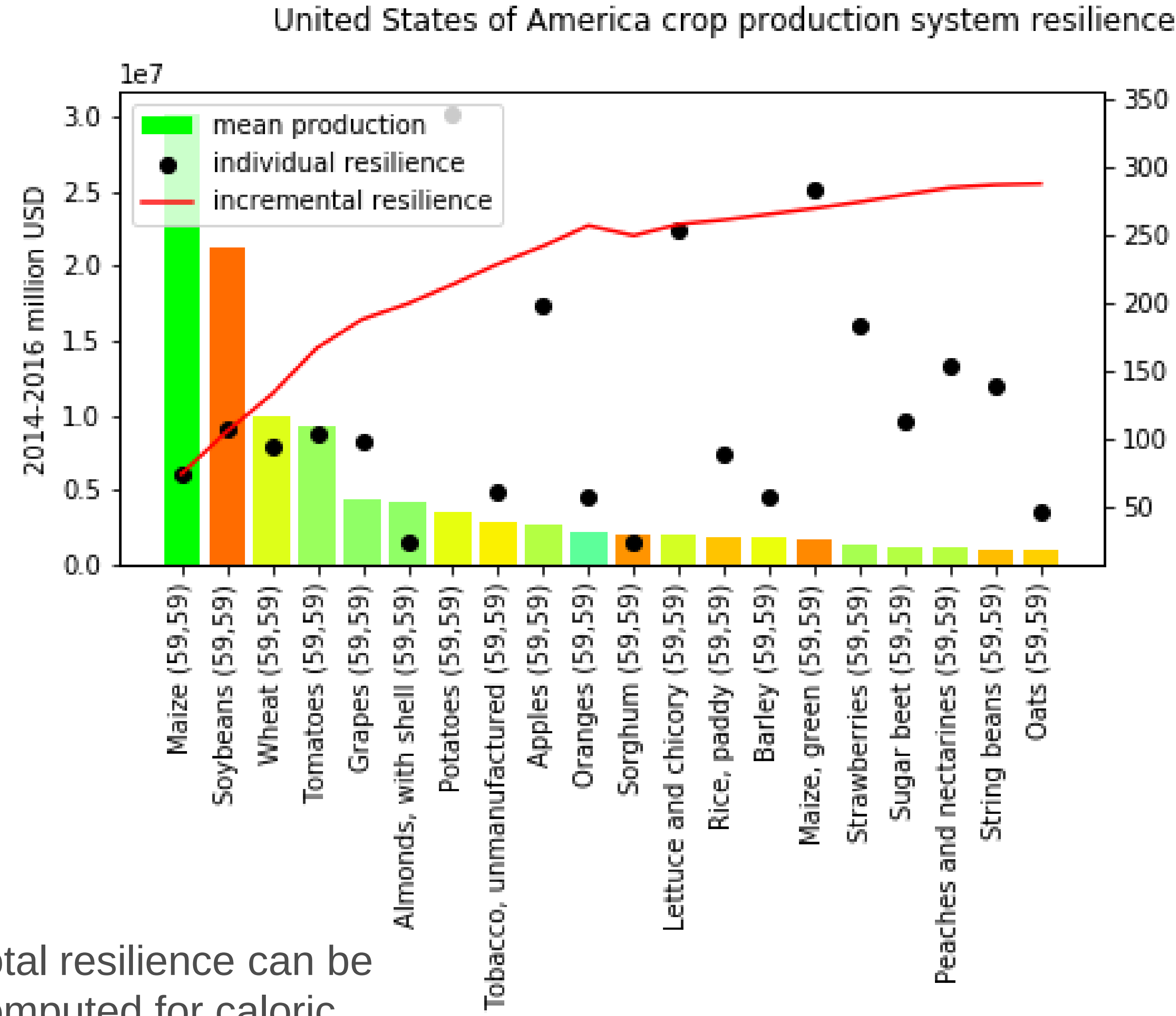
Diversity: other OECD countries

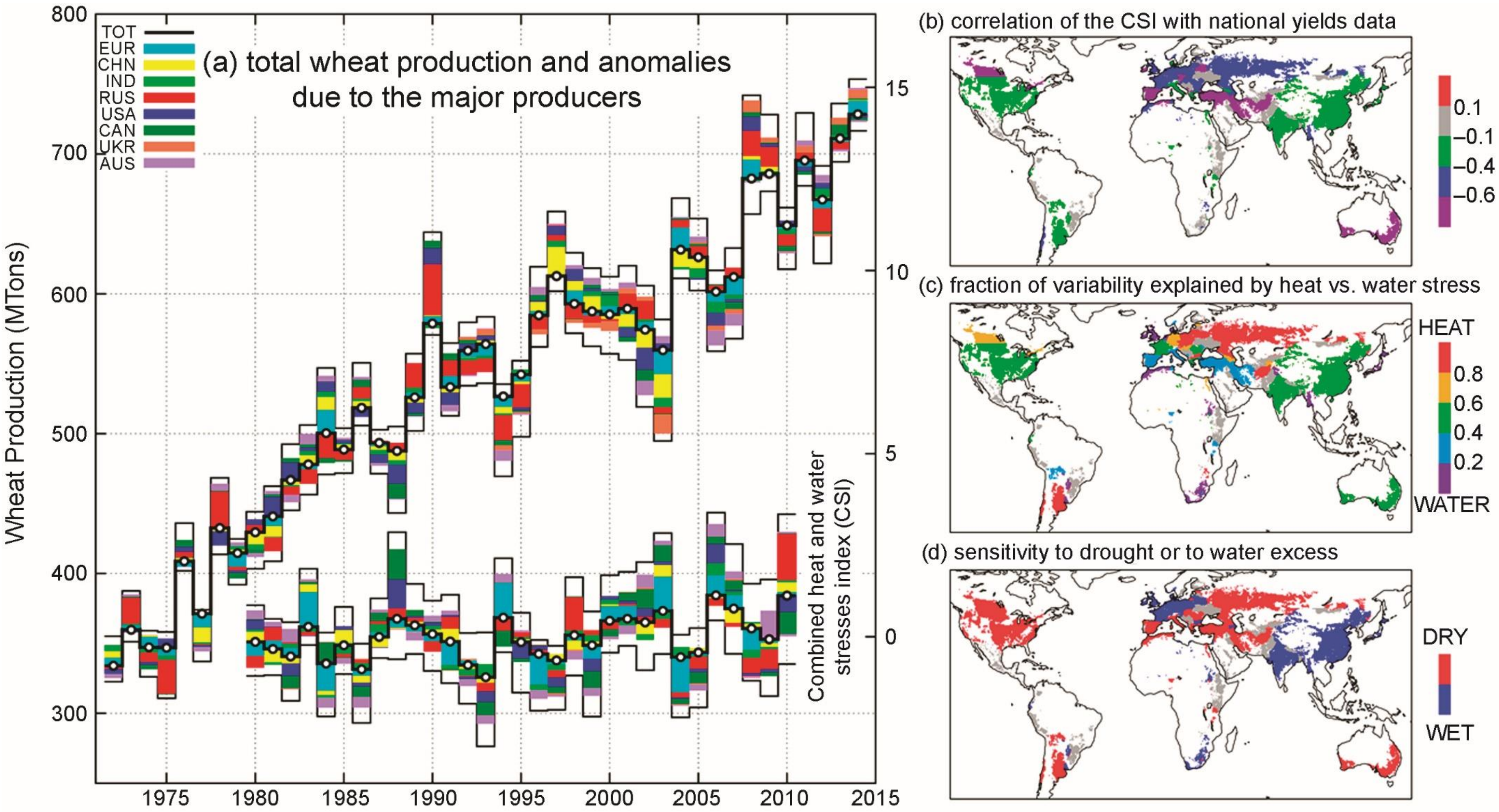




Total resilience can be computed for caloric production, protein, or economic value as here.

Could this figures provide useful informations for farm choices such as which crop to go for?

Linking production resilience to climatic factors



The Combined Stress Index (**CSI**, Zampieri et al. 2017) is a calibrated superposition of two climate indexes compute for specific phenological stages, one for

WATER BALANCE

and one for

HEAT STRESS

The CSI explains 42% global wheat production variability.

The CSI is implemented in AgLINK-COSIMO

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Conclusions

- The Annual Production Resilience Indicator (R_p) is simple but powerful, straightforward interpretation, and rich of properties (diversity, factorization)

- R_p can be coupled to other indicators for a more comprehensive resilience assessment and computed for other variables (e.g. natural vegetation primary production, farm factor income)

- In comparative studies with similar climate conditions adaptation strategies that increase total production stability could be captured by R_p

- At the farm level, the length of the time series might be an issue. Country/regional level analyses as well as model results could also be useful to drive decision at farm level. R_p computed on farm factor income could be a proxy of adaptive capacity

- Resilience of what to what? It depends on the data being used. R_p is sensitive to all sources of variability. The specific drivers have to be identified with other indicators (water, heat, spring frost..)

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Thanks for the attention!

MAIN RESILIENCE REFERENCES

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Zampieri, M., Toreti, A., Ceglar, A., De Palma, P., Chatzopoulos T. 2020. Analysing the resilience of the European commodity production system with PyResPro, the Python Production Resilience package, arXiv preprint arXiv:2006.08976

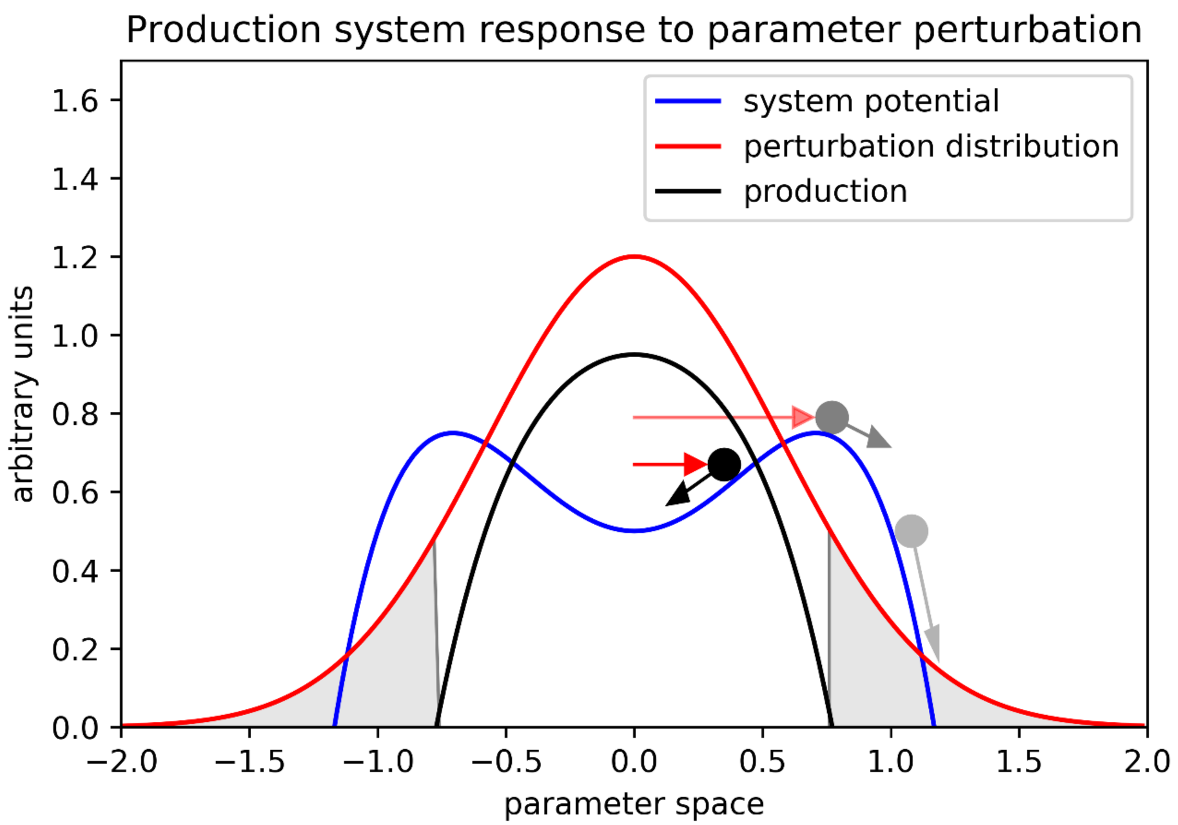
CROP-CLIMATE AND MARKET IMPACTS (AGLINK-COSIMO)

Zampieri M., Ceglar A., Dentener F., Toreti A., 2017. Wheat yield loss attributable to heat waves, drought and water excess at the global, national and subnational scales. Environmental Research Letters 12 (6), 064008

Zampieri M., Ceglar A., Dentener F., et al., 2018. When will current climate extremes affecting maize production become the norm? Earth's Future 7 (2), 113-122

Chatzopoulos T., Domínguez I.P., Zampieri M., Toreti A. 2019. Climate extremes and agricultural commodity markets: a global economic analysis of regionally simulated events. Weather and Climate Extremes 27, 100193

Assumptions and definitions



ecological resilience is amplitude of the largest disturbance that the system can absorb without losing its structure and functions, but how to measure it?

ASSUMPTIONS:

1) larger disturbances are rarer

2) larger disturbances have larger impacts

DEFINITION:

Production resilience can be measured by the return period (inverse frequency) of the larger impacts (production losses)

NOTES:

- Focus on production. Other functions are not considered.

- Changes of structure are allowed as well as shifts in the basi equilibrium state (ADAPTATION).

- Return periods of extreme impacts are expected to get shorted under climate change.

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Proof 1

Binomial distributed production ***p = P or 0***

Let ***f*** be the frequency or probability of production failure ($f = 1/T^*_{MAX}$)

We have $\mu = P\,(1 - f)$ and $\sigma^2 = P^2\,(1 - f)\,f$

$R_P = (1 - f) / f \approx 1 / f = R_e$ q.e.d.

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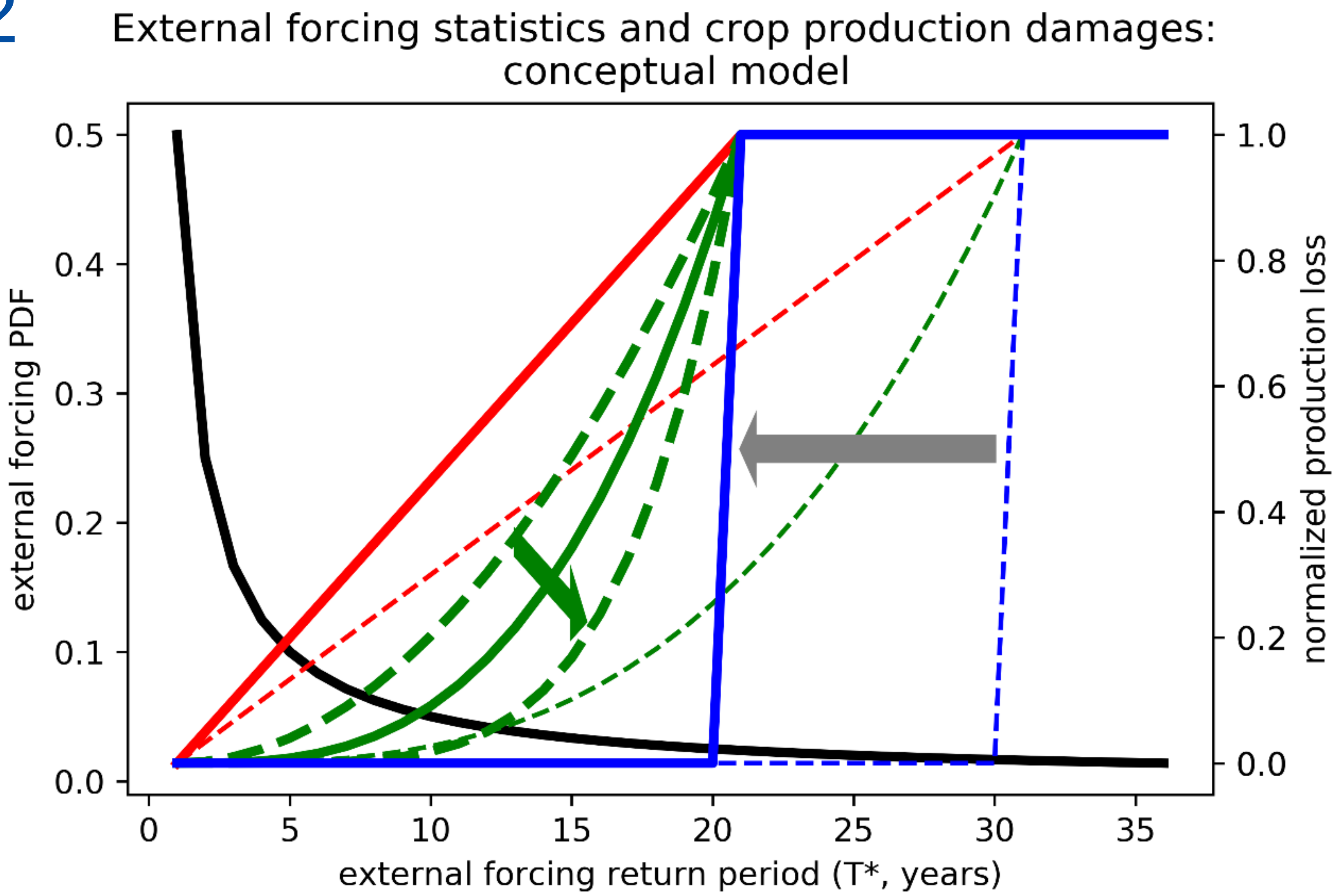
Proof 2

Idealized crop model



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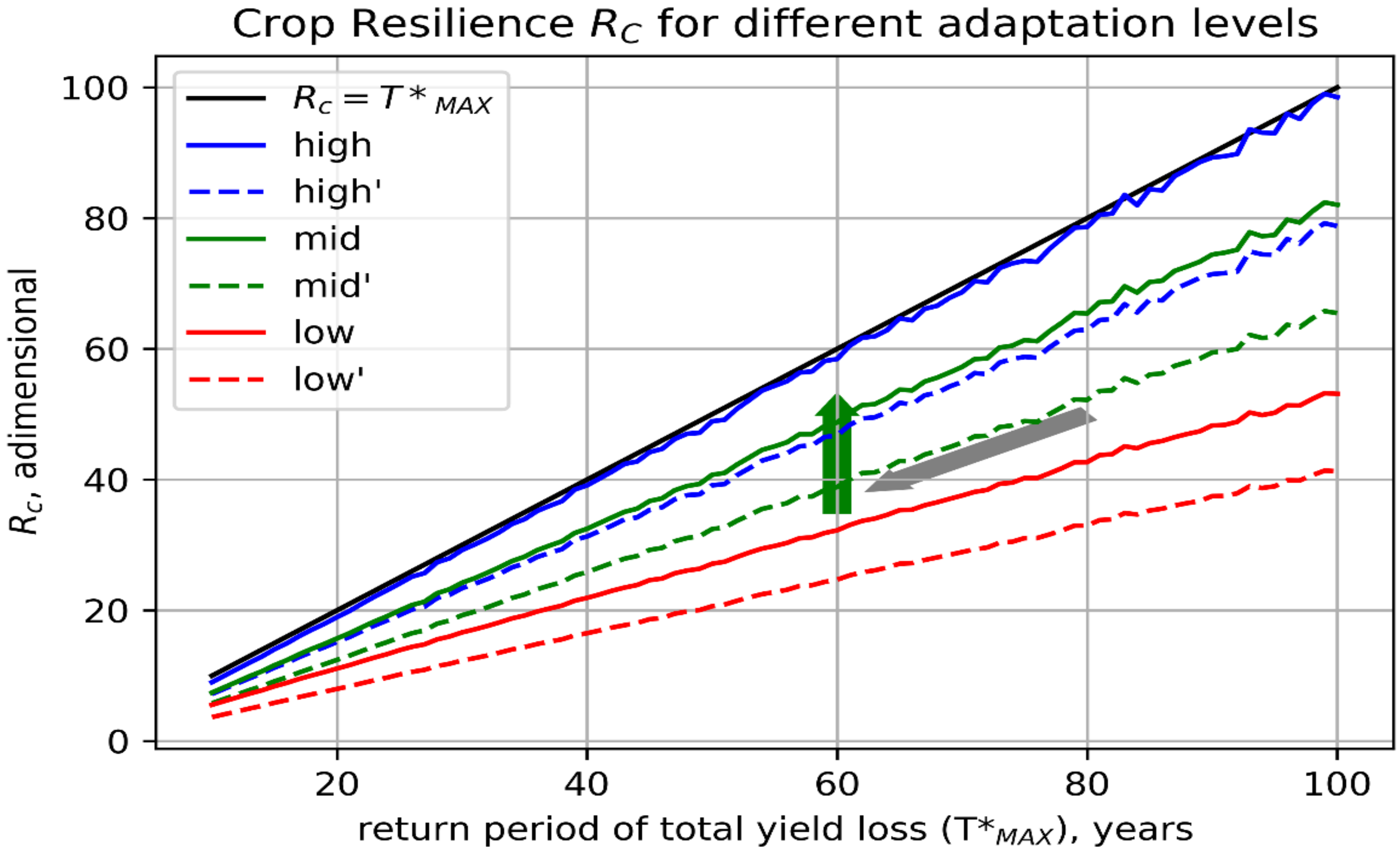
Proof 2

Results



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Effects of diversity: basic property

The APRI is proportional to the number of equivalent uncorrelated production time-series

If we have two production time series p_1 and p_2 with

$$\mu_1 = \mu_2\,,\ \sigma_1 = \sigma_2\,,\ \text{and}\ \ Cov_{1,2} = 0$$

we have

$$\mu_{1+2} = \mu_1 + \mu_2 = 2 \cdot \mu_1,$$

$$\boldsymbol{\mu^2_{1+2} = 4 \cdot \mu^2_{1},}$$

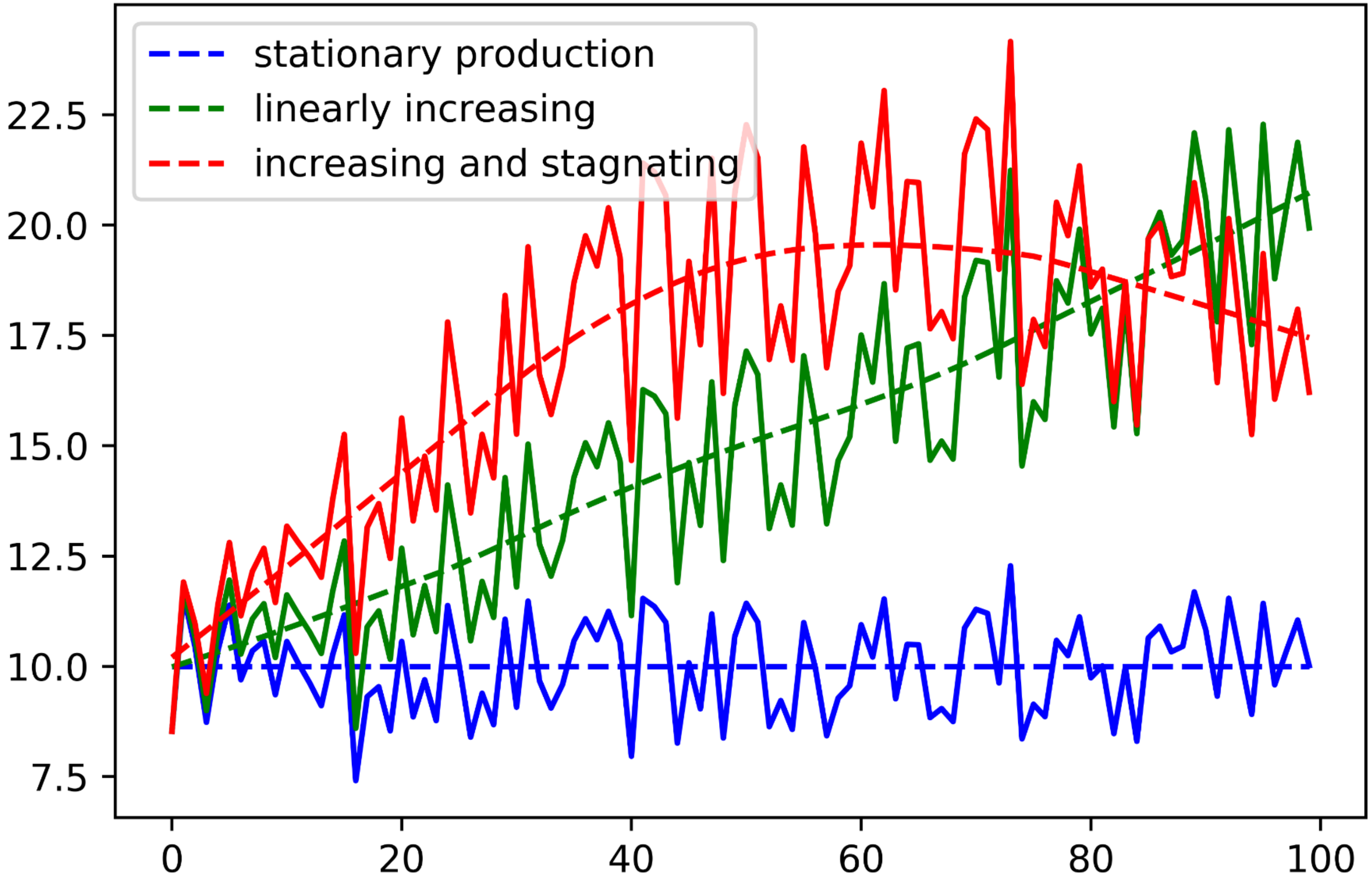
$$\boldsymbol{\sigma^2_{1+2}} = \sigma^2_1 + \sigma^2_2 = \boldsymbol{2 \cdot \sigma^2_1}$$

$$\boldsymbol{R_{p,1+2} = 2 \cdot R_{p,1}}$$

then by induction.

Real time-series

Using the fact that the indicator depends on the ratio between μ and σ and not on the individual terms, it is possible to normalize by the running mean / non-linear fit



Reg. Environ. Change 2020

Accuracy

Monte Carlo simulation

σ_{Rc} / R_c	σ/μ = 5% (R_c = 400)	σ/μ = 10% (R_c = 100)	σ/μ = 20% (R_c = 25)	σ/μ = 30% (R_c =11.1)	σ/μ = 50% (R_c=4)
n= 10	63%	64%	65%	67%	73%
n= 20	37%	38%	38%	39%	44%
n= 30	28%	29%	29%	30%	34%
n= 40	24%	24%	25%	26%	29%
n= 50	21%	21%	22%	23%	26%
n= 100	15%	15%	15%	16%	18%

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