A network model of Italy shows that intermittent regional strategies can alleviate the COVID-19 epidemic

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Who am I?

- I am Professor of Systems and Control Engineering
- My group has 15+ years expertise in modeling and controlling **large-scale complex systems**
- From drones and robots to bacteria and cells…

A bit of history

- Following the COVID-19 outbreak in Lombardy, a strict national lockdown was enforced in March 2020
- All regions were shut down concurrently independently of their epidemic status
- A hot debate ensued

What intervention strategies?

Corriere, 21st April 2020

Conte annuncia: «In Italia riaperture dal 4 maggio, entro domenica un piano differenziato per zone»

SkyTG24, 17th April 2020

Coronavirus, De Luca: 'Pronto a chiudere i confini della Campania'

Coronavirus, scontro Nord-Sud sulla riapertura differenziata. Zaia: "Noi trattati da untori, ma la Campania fa meno tamponi del Veneto"

Il Fatto Quotidiano, 20th April 2020

• **Le reazioni** Fontana: "Dannosa una ripartenza per regioni". E lancia i Lombard bond

la Repubblica 19th April 2020

"Piano nazionale omogeneo per tutte le regioni", dice il premier.

nature COMMUNICATIONS

9th October 2020

nature COMMUNICATIONS

ARTICLE

Check for updates

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A network model of Italy shows that intermittent regional strategies can alleviate the COVID-19 epidemic

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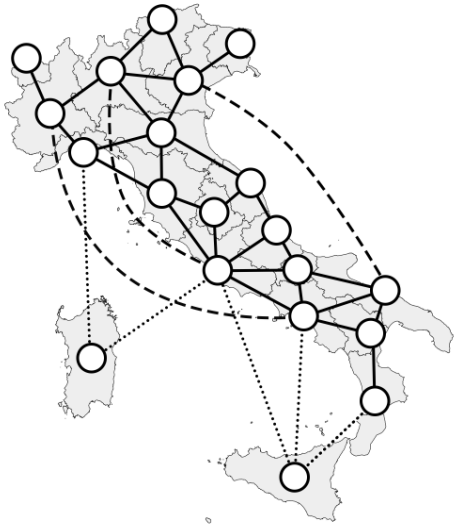
Our research questions

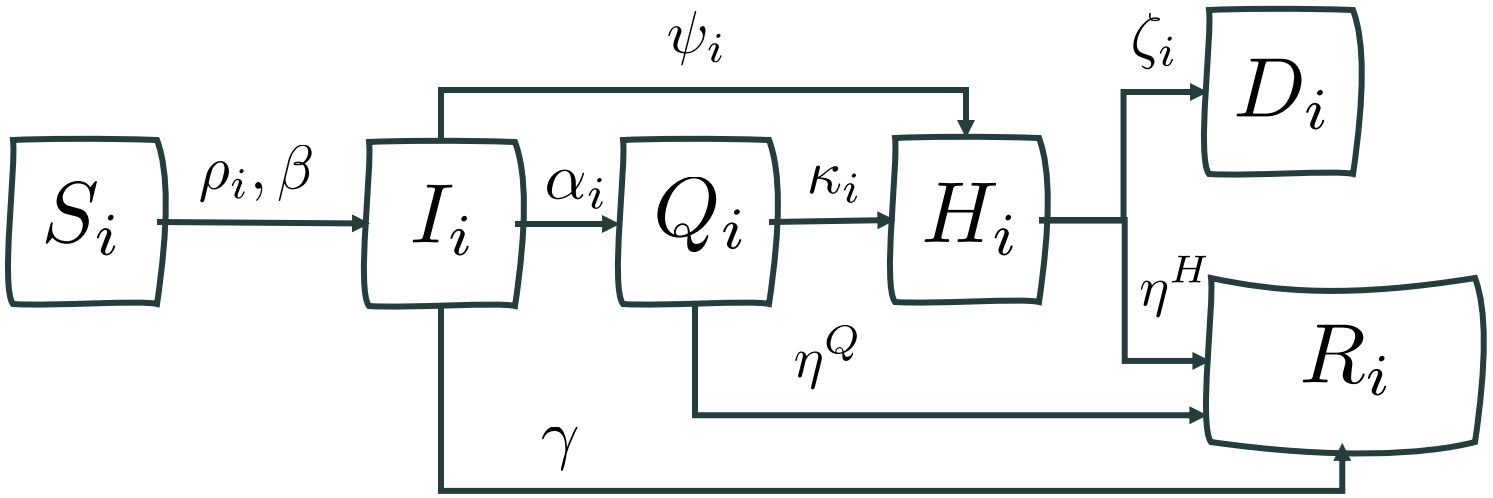
Our research questions

- **Do we need to shut down all regions concurrently independently from their epidemic status?**
- Can we envisage *regional* lockdown strategies to mitigate the COVID19 epidemic…
- … where each region automatically enforces or releases social distancing and other measures according to some indicators?
- Are such regional measures effective and do they cause lesser economic costs?

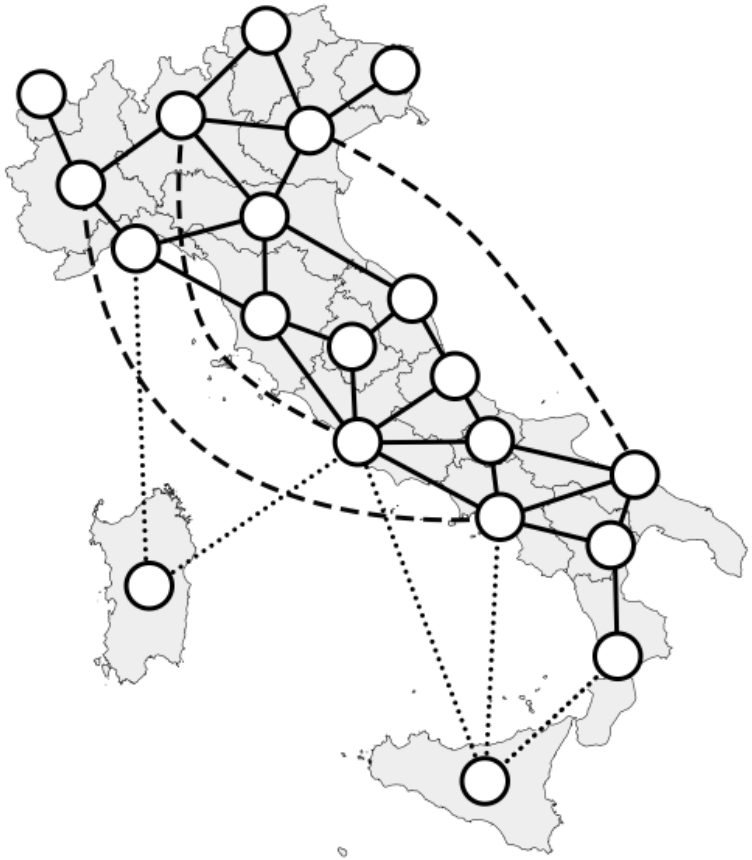
Modeling Italy as a complex system



A data-driven model of each region

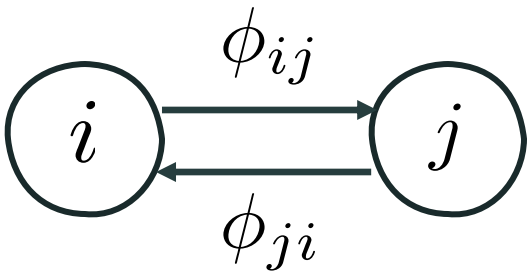


- We derived a mathematical model of the epidemic spread in each region…
- …and used data to calibrate and estimate all model parameters and unknowns



Constructing a network model

- Once each region was modelled, we introduced fluxes among regions and assessed their effects



PORTMOBILITY
VIAGGI DA MARE

TRENITALIA
GRUPPO FERROVIE DELLO STATO ITALIANE

ENAC
ENTE NAZIONALE PER L'AVIAZIONE CIVILE

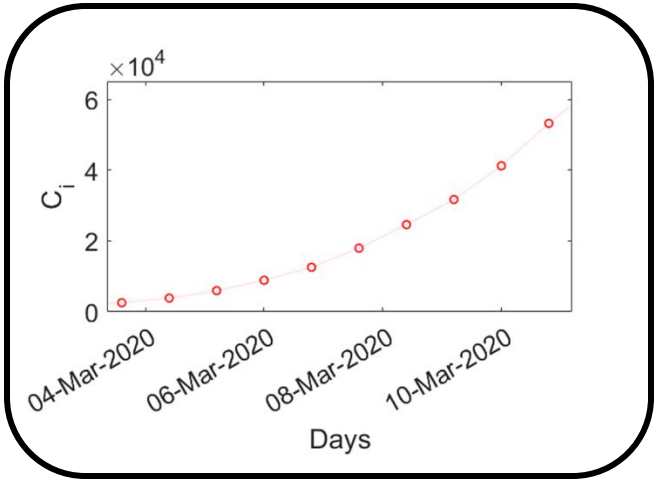
Skyscanner

MINISTERO
DELL'INTERNO

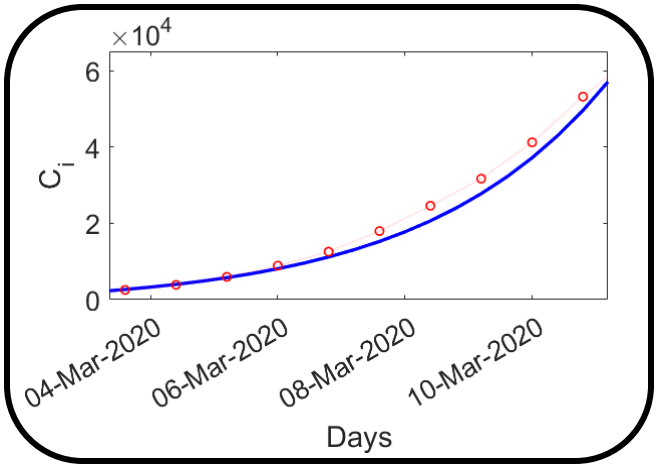
Estimating the fluxes

We estimated fluxes by using publicly available data on trains, air traffic and capacity, key ferries routes

Identification method



$$\dot{S}_i = -\hat{\rho}_i \beta S_i I_i, \qquad S_i(0) = N_i - I_i(0) - C_i(0)$$
$$\dot{I}_i = \hat{\rho}_i \beta S_i I_i - (\hat{\tau} + \gamma) I_i, \qquad I_i(0) = \hat{I}_{i,0}$$
$$\dot{C}_i = \hat{\tau} I_i, \qquad C_i(0) = C_{i,0}$$



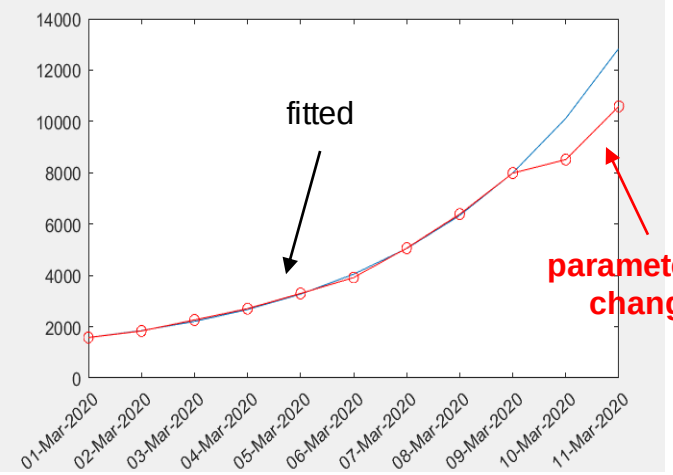
Constrained Nonlinear Optimization

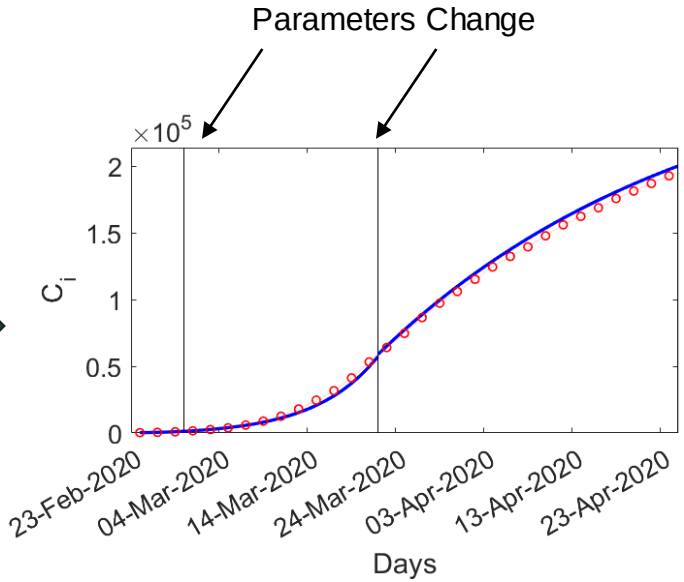
fmincon (Optimization Toolbox)

$$\hat{\rho}_i, \hat{\tau}, \hat{I}_i, T_k$$

Breakpoint identification

- The procedure self-determines the breakpoints where notable parameter changes are observed





Breakpoints identified using Chow statistical test

(Econometrics Toolbox)

Identification of the remaining parameters

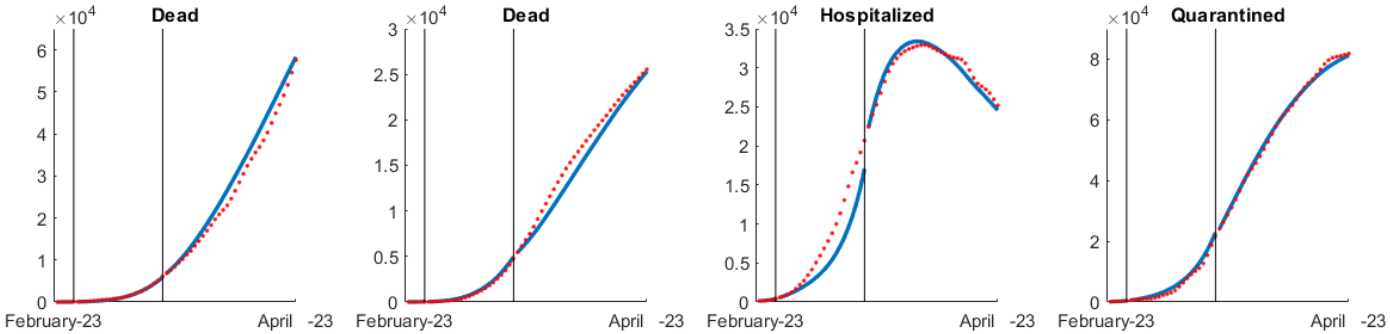
$+ \quad \hat{\rho}_i, \hat{\tau}, \hat{I}_i, T_k$

$$\begin{aligned}
\dot{H}_i &= \hat{\psi}_i \hat{I}_i - \hat{\eta}^H H_i + \hat{\kappa}_i Q_i - \hat{\zeta}_i H_i & H_i(0) &= H_{i,0} \\
\dot{R}_i^M &= \hat{\eta}^Q Q_i + \hat{\eta}^H H_i & R_i^M(0) &= R_{i,0}^M \\
\dot{D}_i &= \hat{\zeta}_i \; H_i & D_i(0) &= D_{i,0}
\end{aligned}$$

Constrained Least-squares identification

lsqlin (Optimization Toolbox)

$\hat{\psi}_i, \hat{\kappa}_i, \hat{\zeta}_i, \hat{\eta}^{Q,H}$



Example: Lombardy

$\rho\beta$	α	ψ	ζ	T	$H\%$
0,499	0,020	0,050	0,026	27 Feb – 2 Mar	0,15
0,268	0,038	0,032	0,034	2 Mar – 21 Mar	1,23
0,081	0,043	0,027	0,030	21 Mar – 8 Apr	1,21
0,047	0,052	0,018	0,019	13 Apr - 21 Apr	0,63

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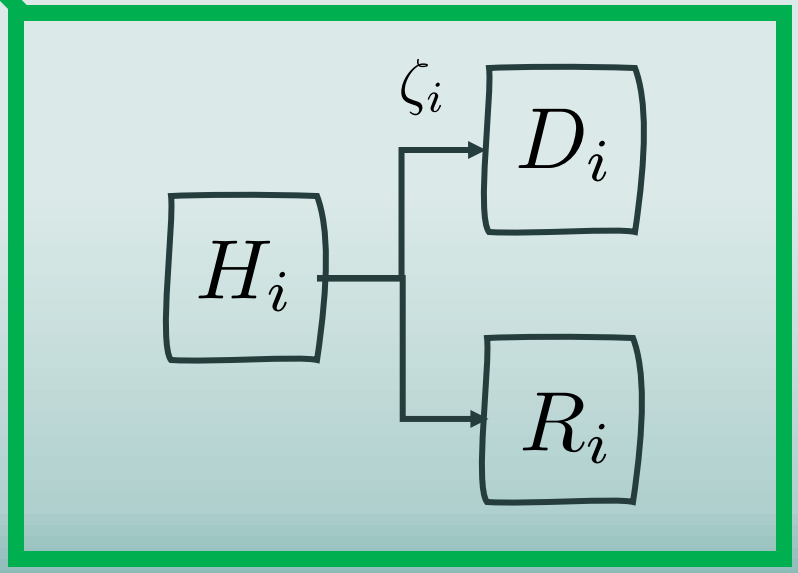
8/03/2020



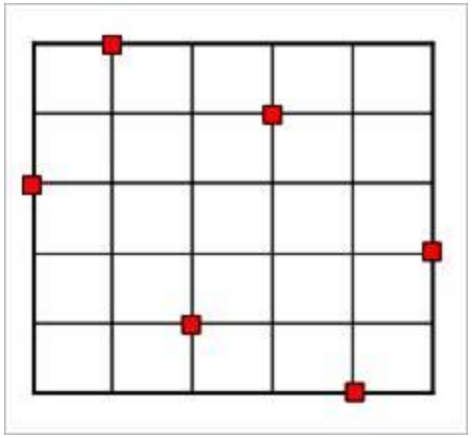
Regional mitigation strategies

- **Goal:** introduce automatic *feedback* measures to avoid saturation of the regional health services while mitigating the epidemic spread
- *When its regional health system becomes under pressure*, a region enforces a lockdown and prevents travel to/from other regions
- e.g. when the number of patients requiring ICU treatment crosses a certain threshold

How we implemented our solutions

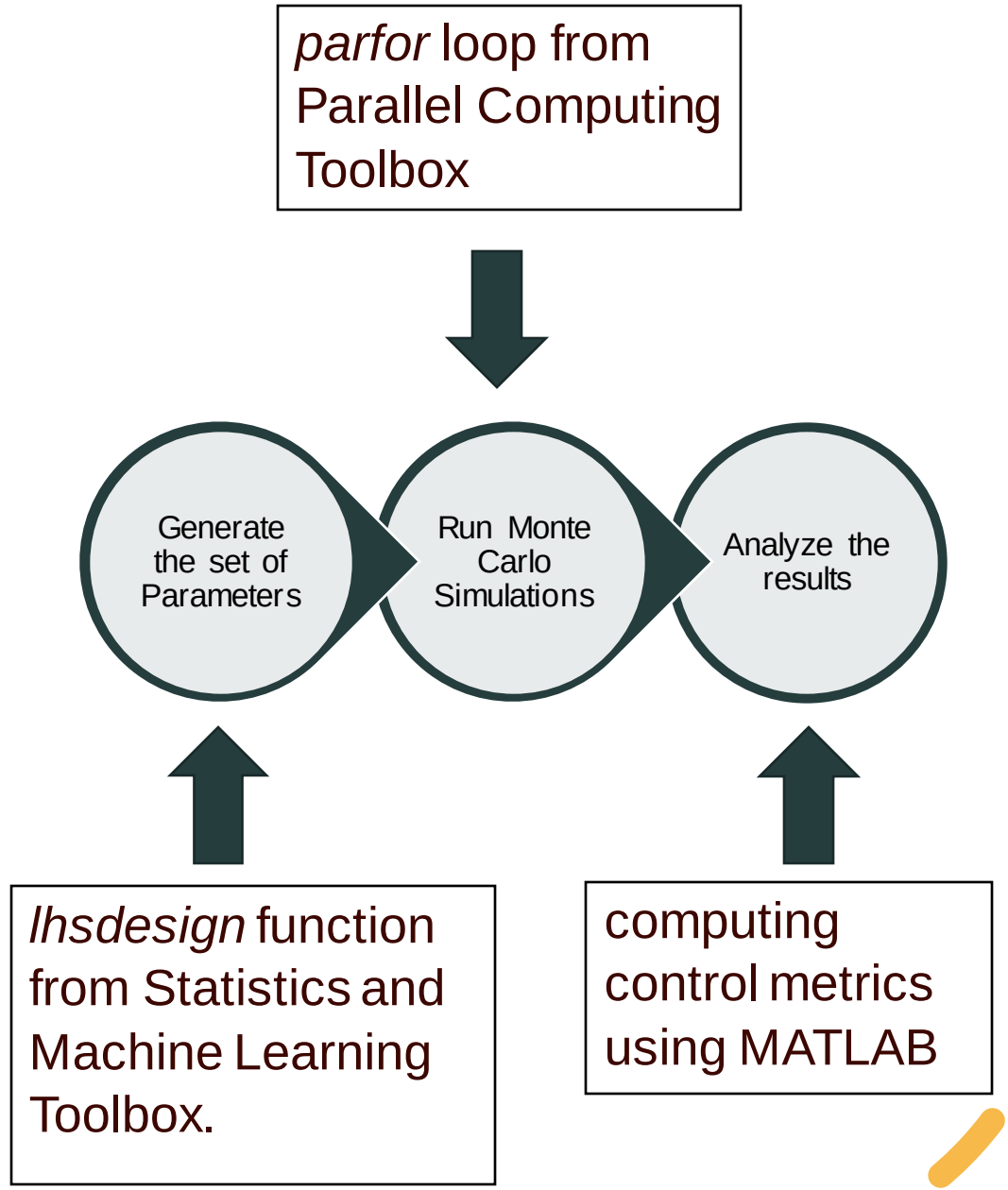
- We tested the robustness of our controller via a Monte Carlo simulation campaign
- All parameters' sets are generated using a Latin hypercube sampling

lhsdesign (Statistics and Machine LearningToolbox)

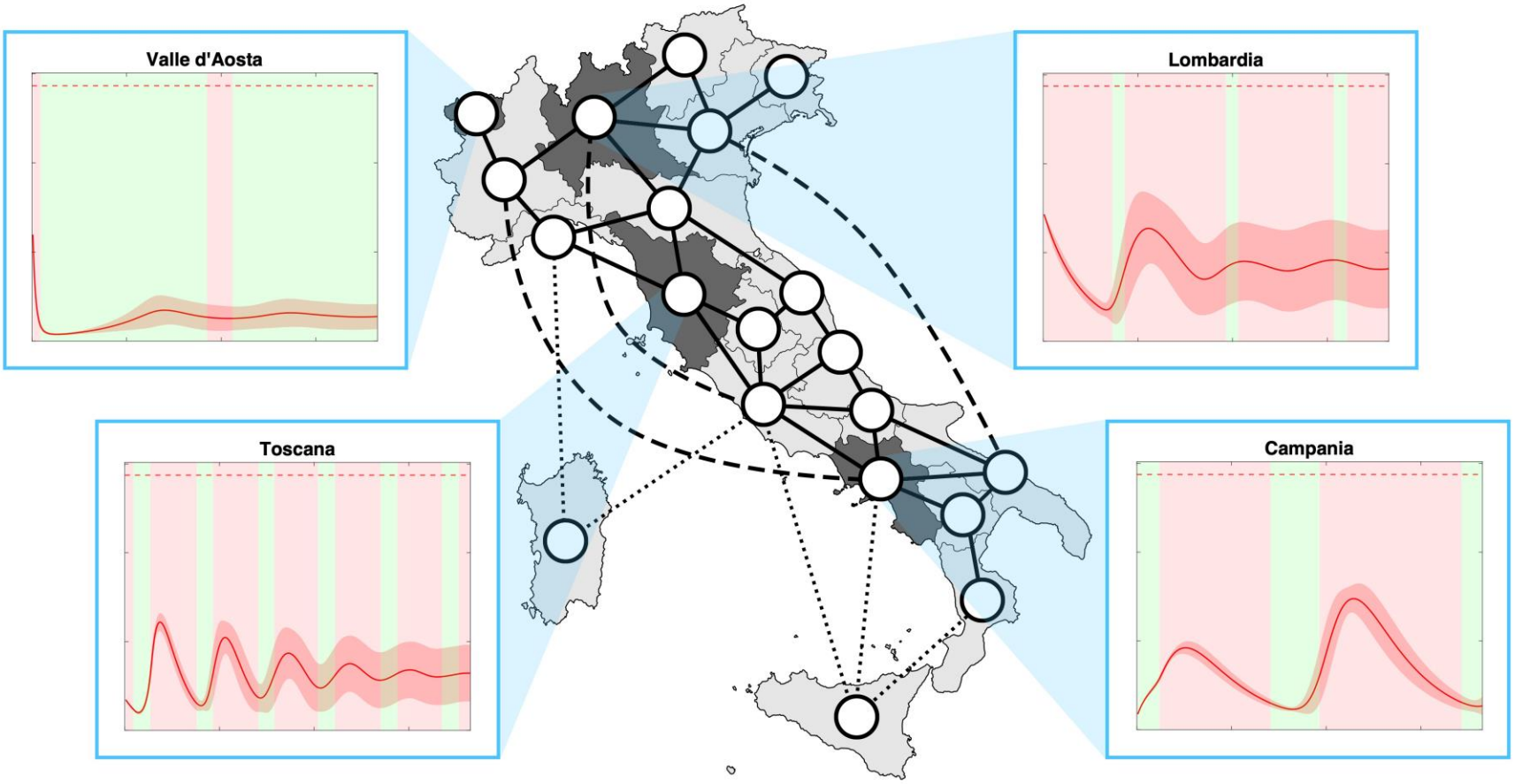


Widely scattered parameters

MATLAB was fundamental



A regional feedback strategy



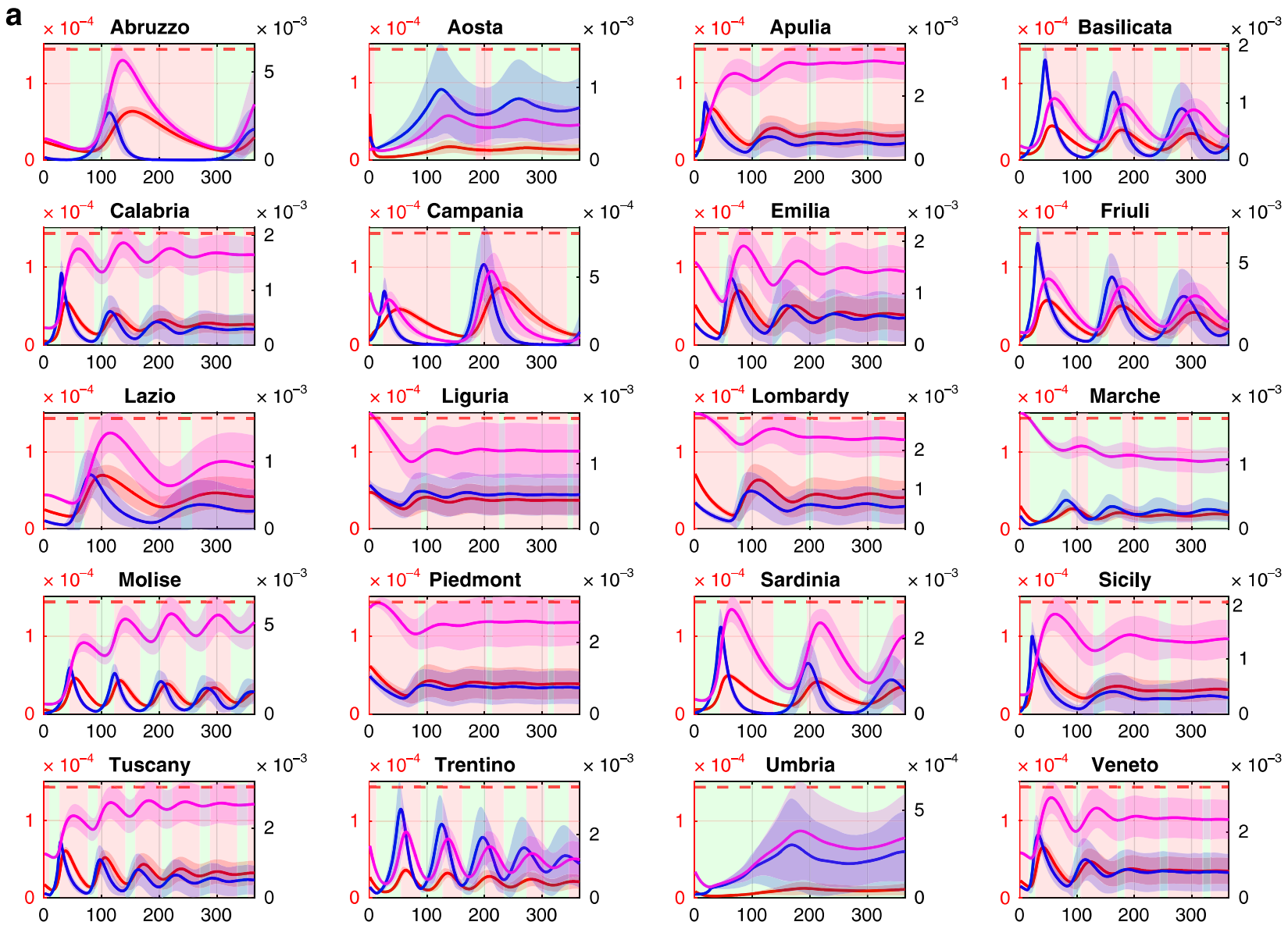

a
Abruzzo
Aosta
Apulia
Basilicata
Calabria
Campania
Emilia
Friuli
Lazio
Liguria
Lombardy
Marche
Molise
Piedmont
Sardinia
Sicily
Tuscany
Trentino
Umbria
Veneto
× 10−4
× 10−3
0
100
200
300

Table 2 Comparison of each of the simulated scenarios.

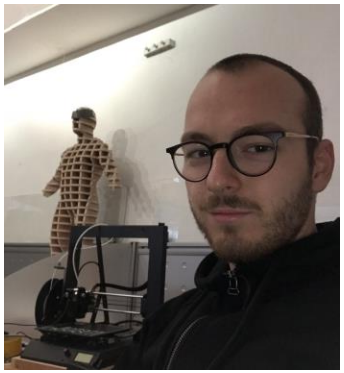
Simulation	Total cases	Total deaths	Maximum hospitalized	Days over hospital's capacity (nation)	Regions over hospital's capacity	Economic cost [M€]
All regions but Lombardy are locked down (Fig. 2)	10,550,000 ± 146,084	1,196,063 ± 97,122	137,640 ± 10,249	75.8 ± 2.7	3	503,355 ± 0
Intermittent regional measures (Fig. 3a, b)	1,986,601 ± 76,184	173,637 ± 3911	2801 ± 170	0 ± 0	0	509,142 ± 6606
Intermittent national measure (Fig. 3c, S4)	2,162,539 ± 194,929	205,261 ± 10,854	4481 ± 277	0 ± 0	3	562,373 ± 12,809
Intermittent regional measures with increased testing (Fig. 4)	1,590,459 ± 69,118	128,644 ± 2690	2037 ± 102	0 ± 0	0	566,514 ± 12,258

Comparison with nationwide lockdown

Take home message

- Our work convincingly showed the benefits of regional rather than national NPIs to deal with the pandemic
- This is precisely the idea behind the strategy adopted in Italy since 3rd November 2020
- The use of the optimization algorithms provided by MATLAB *Optimization Toolbox* allowed us to quickly test our hypothesis with minimum effort
- The tools from MATLAB *Parallel Computing Toolbox* allowed us to easily write optimized code to be launched in parallel reducing noticeably the execution time



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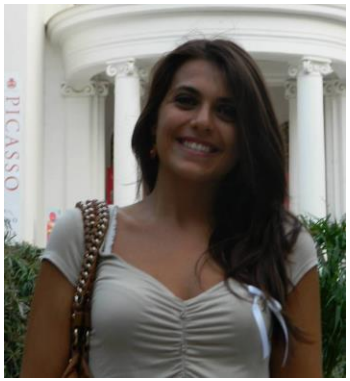


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