COVID-Town: An Integrated Economic-Epidemiological Agent-Based Model

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Research question

How does the pandemic and (actually used or potential) containment policies shape outcomes in the following interconnected dimensions:

- Public health
- Economy
- Care work
- Leisure

→ Model-based approach to explain and project
Simple ABMs / SIR models

Predominant models (especially in the beginning): simple ABMs, SIR models

Easy to set up and understand, but RL-interactions are not random and other RL-characteristics hard to incorporate → possibly biased results
Complex ABMs

A recent generation of ABMs addresses these weaknesses:
E.g. Aleta et al. (2020), Bicher et al. (2020), Kerr et al. (2020)
Use statistical data to model households and work networks, (random) leisure interactions
Method and model

Integrated economic-epidemiological agent-based model (ABM)

→ A virtual economy called COVID-Town populated by virtual people and firms, aka „agents“

→ Agents differ wrt economic and epidemiological characteristics (social class, age, employment and family status)

→ Are connected in a social network and act according to boundedly rational rules (→ activity model)

→ Calibrated with empirical data (time use, demography, firm demography, household composition, wages, employment etc.)

→ Exposed to a COVID-19 outbreak and various policy scenarios
Epidemiological ABMs with economic part

• Vermeulen et al. (2020): impact on labor supply
• Silva et al. (2020): economic-epidemiological ABM resembling Brazil
• Dignum et al. (2020): Combines epidemiological, microeconomic, macroeconomic, cultural, transport, epistemic model
• Basurto et al. (2020): combines extended SIR-type epidemiological and agent-based macroeconomic models
• Delli Gatti and Reissl (2020): combines epidemiological ABM with the CATS macroeconomic ABM
Main differences to the ASSOCC model

- Higher number of agents (baseline calibration 82000 human agents) → allowing for (limited) replication of the empirical tendencies
- More/different agent heterogeneity (especially wrt workers)
- More focused towards the economy and heterogeneity in virus transmission
- Tried to calibrate as many parameters as possible empirically
- Less submodels (e.g. no cultural, needs model)
- Agents do not react endogenously to viral spread, endogenous reaction towards containment policies limited to economic sphere
The Model

• The model is discrete-time 1 day = 3 phases, week from Monday until Sunday
• People move to *explicitly modeled places* (e.g. workplace, hospital, school, home, leisure facility) and may become infected
• Model is developed specifically for COVID-19 → Stylized facts which are important in this pandemic are modeled explicitly (e.g. presence of *intergenerational households, retirement homes, leisure facilities* etc.)
Economic Model

Households

- Children
- Teachers
- Service Workers
- Firm owners

- Pensioners
- Blue-Collar Workers
- White-Collar Workers
- Health Care Workers

Schools

Government

Factories

Consumption goods market

Offices

Commercial Leisure Facilities

Hospitals
Economic Model

Leisure market:
Fully disaggregated, heterogeneous (wrt to attractiveness) firms engage in price competition

Consumption goods market:
Aggregated, human agents and government consume, two types of homogenous (wrt productivity) firms produce and are price takers

Three types of segregated labor markets
Activity model I

Home
- fm 3
- family member 1
- fm 2

Work / School
- colleague 1
- colleague 1
- customer

Leisure
- friend 1
- friend 2
- stranger
Activity Model II

Which phase?

- **Phase 1**
  - Agents go home
  - Care giver is updated
  - Shift 1 workers go to their workplace
  - Agents who did not do a nightshift and do not work make and try to execute leisure plans
  - Workers produce

- **Phase 2**
  - Agents go home
  - Shift 2 workers go to their workplace
  - Agents who do not work make and try to execute leisure plans
  - Agents receive income
    - Agents consume
    - Infections are processed
    - Disease progresses
    - Statistics are updated
    - Policies are updated

- **Night**
  - Agents go home
  - Night shift workers go to their workplace
  - Commercial leisure facilities set their prices in response to their visits in the last week
  - Firms hire or fire in response to their rate of profit in the last week

Start new day

(Only Sun)

(Only Mon-Fri)

Start new phase
Leisure behavior

Stay at home  ?  Meet a friend

Visit non-commercial leisure facility  Visit commercial leisure facility

Heterogeneous preferences based on age-specific time use data
Epidemiological Model

Standard model from the literature (LMIC report of the Imperial College)
Infectiousness, detection rate are calibrated to match empirical data
Initial calibration

- Demography, household composition, observed leisure behavior (time use, number of friends), wages, wage replacement, employment, hospital capacities, retirement homes, company profits, taxes from German (mainly statistical) data

- Income of firm owners, consumption and government spending calibrated for a closed economy in circular flow with balanced budget (at least in t=0)

- Age-specific medical characteristics according to Imperial College (2020)

- 1 agent represents 1k real-world Germans
Epidemiological calibration

**Challenge**: several unknowns!

**Known**: reported infections and deaths
Reported infections are lagging and miss the dark figure
Deaths may be underreported (excess mortality!)

**Approach**: Assume that reported deaths equal actual deaths
(excess mortality in Germany during the first wave equals approximately the COVID-deaths)
Assume that RKI nowcasting eliminates the time lag problem and that the dark figure with respect to RKI nowcasting is constant
→ Find a dark figure for which simulated deaths fit to reported deaths and simulated infections fit to estimated infections
→ Model’s detection parameter has to reflect the dark figure
Validation

- COVID-Town loess
- COVID-Town quantile reg.
- Empirical

- COVID-Town quantile regression
- RKI Nowcast (estimated empirical) x 3

Day

Total dead in thousand

New daily infections in thousand
Let’s take a look at the model
Main results (first paper)

• Early introduction of containment measures key to control the virus

• German timing of lockdown measures minimized economic losses, but infections and deaths could have been lower, if the measures were introduced earlier.

• Anticyclical fiscal policy key to mitigate the economic fallout: keep employment up in lower risk sectors. Does not come at the cost of additional deaths
The Future

• Longer term scenarios: what if Germany had adopted another containment strategy?

• Inequality in economic and health outcomes

... possibly more
The End

More details and results: WP (MPRA, arxiv)
If you want to
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The End II

Thank you for your attention!

Looking forward to your comments and questions!
# Epidemiological scenarios

| Date               | Baseline scenario                                      | Rapid action                               | Delayed Action                              |
|--------------------|---------------------------------------------------------|--------------------------------------------|---------------------------------------------|
| 02.03.2020 (day 0) | Increased sanitary standards at hospitals, isolation, family isolation, workplace isolation |                                             |                                             |
| 09.03.2020 (day 7) | -                                                       | schools, comm. leisure fac., SD            |                                             |
| 16.03.2020 (day 14)| schools, comm. leisure fac., SD                        | contact ban, teleworking mandatory         |                                             |
| 23.03.2020 (day 21)| contact ban, teleworking mandatory                      | -                                          | schools, comm. leisure fac., SD            |
| 30.03.2020 (day 28)| -                                                       | -                                          | contact ban, teleworking mandatory          |

Sources: Bundesregierung (2020a, 2020b), Welt (2020), Description: schools = schools closure, comm. Leisure fac. = commercial leisure facilities close, SD = social distancing
Results

|                          | baseline | rapid action | delayed action |
|--------------------------|----------|--------------|----------------|
| Dead in thousand         | 9 (5.656)| 3.493 (2.661)| 25.825 (14.034)|
| Consumption goods output lost in % | 3.42 (0.17) | 3.48 (0.09) | 3.49 (0.41) |
Fiscal policy scenarios

Zero-deficit: government purchases restricted to government savings
Fixed government purchase: constant throughout the simulation
