

# Slums and Pandemics

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# Introduction

New coronavirus:

- Spread through close contact among people
- Recommendation: social distancing, more handwashing, face cover and avoid crowded places
- Problem in slums:
  - High density; poorer individuals; low access to health care
- Over 1 billion people live in slums (UN, 2020)

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- Over 1 billion people live in slums (UN, 2020)

This paper:

- Empirics: daily location of millions of mobile phones in Brazil
- Model: choice-theoretic heterogeneous-agent GE
- Quantitative:
  - Role of slums
  - Policies: lockdowns, cash transfers, public ICU beds



*Source:* Silvia Izquierdo/AP

## Empirics:

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- Social distance increases with NPIs
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### Policies:

- Public ICUs: both groups are better off
- Mild lockdowns mitigate demand for hospital beds
- Strict confinements mostly delay the pandemic
- Cash transfers: delay and benefits slum dwellers

# Modeling infectious diseases

**SIR** models in epidemiology (Kermack & McKendrick 1927,...):

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Number of additional infections caused by an infected person:

- $R \approx \underbrace{R_0}_{\substack{\text{Basic} \\ \text{Reproductive} \\ \text{Number}}} \times \text{Susceptible}_t$

- Covid-19:  $R_0 = 1.4-5$

Theory adding behavior to SIR models (seminal: Kremer (1996))

Earlier quantitative work:

- HIV: Greenwood, Kircher, Santos & Tertilt (2019, 2017, 2013), etc.

Economics and Covid-19 (fast-growing):

- Containment and behavior:
  - Eichenbaum, Rebelo & Trabandt (2020), Farboodi, Jarosch & Shimer (2020), Toxvaerd (2020), etc.
- Heterogeneity:
  - Brotherhood, Kircher, Santos & Tertilt (2020), Alon, Kim, Lagakos & VanVuren (2020), Kaplan, Moll & Violante (2020), Glover, Heathcote, Krueger & Rios-Rull (2020), etc.

Equilibrium models and slums:

- Cavalcanti, Da Mata & Santos (2019), Ferreira, Monge-Naranjo & Pereira (2016)

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Data source:

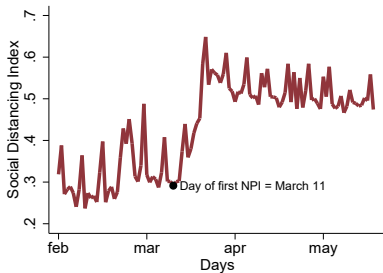
- Provided by Inloco (inloco.com.br)
- Track mobile phones with 3-meter accuracy
- About 60 million mobile phones in Brazil, ensuring privacy

Our data:

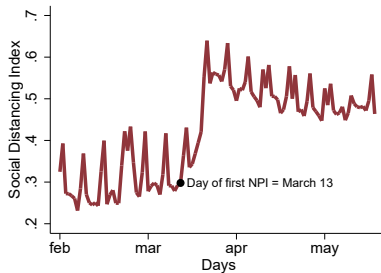
- Daily social distance index: % of phones away from home
- Feb 1 to May 30, 2020
- Non-overlapping hexagons for Sao Paulo (1,301) and Rio de Janeiro (841)
- Merge with socioeconomic data from census

# Social distance and NPIs

## Rio de Janeiro

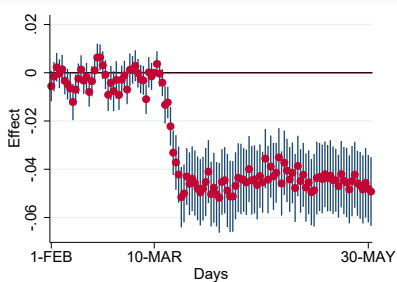


## Sao Paulo

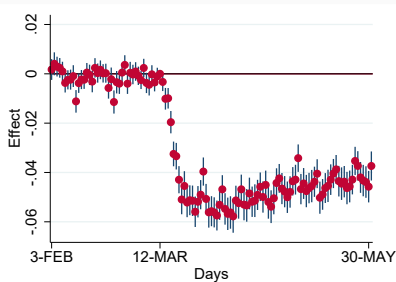


# Social distance: slums and other areas (reduced form)

Rio de Janeiro

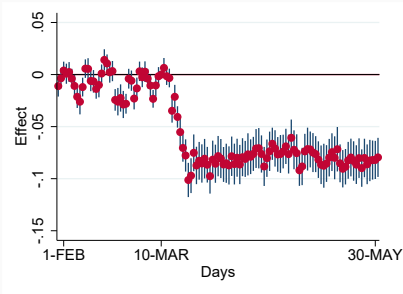


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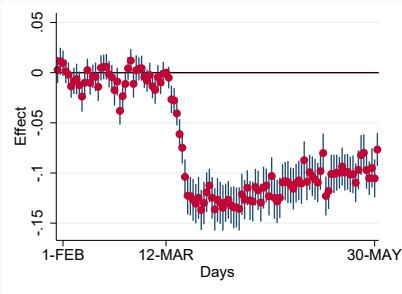


# Social distance: Share of slums (reduced form)

Rio de Janeiro



Sao Paulo



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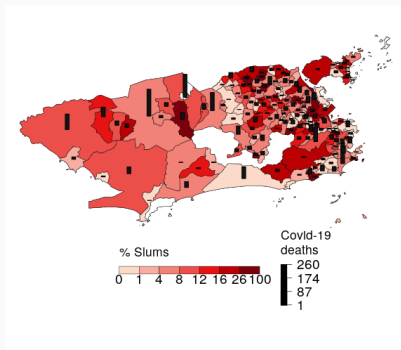
**Table 1:** Average impact of NPIs on social distancing

	Dependent variable: Social distancing index		
	(i)	(ii)	(iii)
Post × Slum	-0.0386*** (0.0050)	-0.0429*** (0.0021)	-0.0429*** (0.0021)
Post × Slum × Rio			0.0043 (0.0054)
Control group mean	0.2989	0.2820	0.2903
Hexagon FE	Yes	Yes	Yes
Time FE	Yes	Yes	Yes
Time FE × Rio	-	-	Yes
Observations	97,684	151,504	249,188
Number of Hexagons	841	1,301	2,142
City	Rio de Janeiro	Sao Paulo	Rio de Janeiro & Sao Paulo

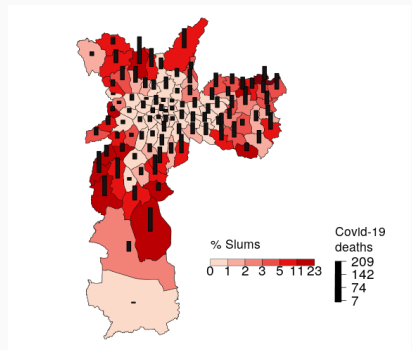


# Slums and Covid-19 fatalities

Rio de Janeiro



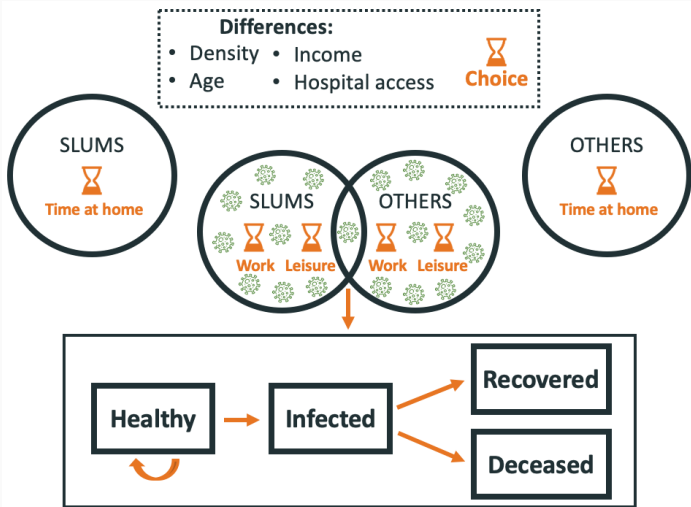
Sao Paulo



**Sao Paulo:** Hexagons with slums have 11% more hospitalizations and 10% more deaths by Covid-19 – and 36% more hospitalizations and 7% more deaths by other respiratory diseases



# Model overview

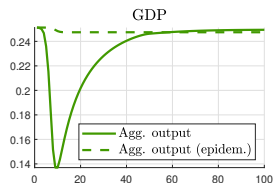
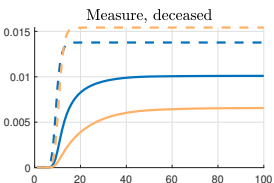
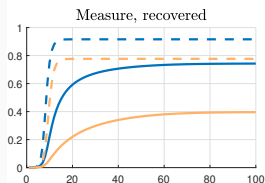
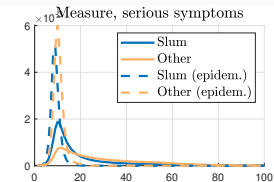
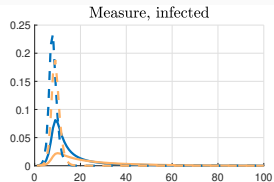
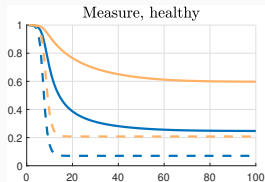


# Fitting the Model to the Data - Model period is one week

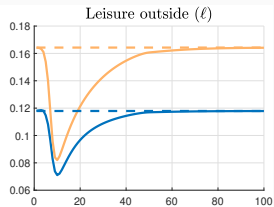
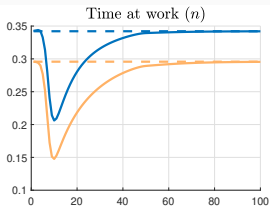
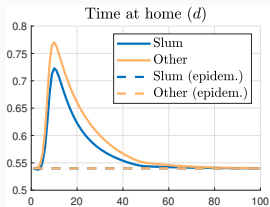
**Table 2:** Moments – model vs. data

Moment	Model	Data (ranges)
Share of individuals living in slums	22%	22%
Pop. density in slums/Pop. density in non-slum areas	4.5	4.5
Relative hourly labor income of individuals in slums	27.7%	27.7%
$R_0$ , Covid-19	2.5	1.6-4
% of infected in critical care	3.6	3.6
Weeks in critical care	3.5	3-6
% in critical care who die	20.24	10.6-31.8
Hours/day interacting while in ICU	3.8	7.6 (controlled)
Hours of work per week	34.2	34.2
Hours of outside activities per week	17.2	17.2
% of income on goods outside	27.28	27.28
% $\uparrow$ in time @ home – mild symptoms	26	26 (Influenza)
% $\uparrow$ in time @ home – outset of Covid-19	15.7	15.7
% of non-slum agents with priv. insurance	15.21	15.21

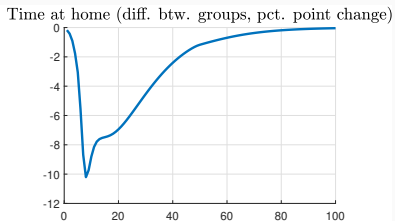
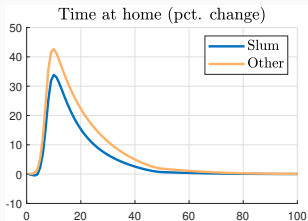
# Baseline results



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	Benchmark	Epidem.	No slum	Homog. densities	Homog. wage rates	Homog. age struct.
Wks to peak srsly ill (slum)	10.00	9.00	–	15.00	10.00	10.00
Wks to peak srsly ill (other)	11.00	10.00	14.00	14.00	11.00	11.00
Dead p/ 1,000 1year (slum)	10.04	13.78	–	6.32	8.87	13.49
Dead p/ 1,000 1year (other)	6.35	15.43	6.87	6.86	6.78	6.57
Dead p/ 1,000 1year (all)	7.16	15.06	6.87	6.74	7.25	8.11
Dead p/ 1,000 LR (slum)	10.11	13.78	–	6.53	9.07	13.68
Dead p/ 1,000 LR (other)	6.57	15.43	7.47	7.30	7.13	6.83
Dead p/ 1,000 LR (all)	7.35	15.06	7.47	7.13	7.56	8.34
Immune in LR (slum), %	74.33	91.60	–	51.78	70.11	72.37
Immune in LR (other), %	39.69	77.66	46.01	44.72	43.03	40.76
Immune in LR (all), %	47.36	80.75	46.01	46.28	49.03	47.76
GDP at peak - rel to BM	1.00	1.82	1.48	1.23	1.29	1.03
GDP 1year - rel to BM	1.00	1.14	1.17	1.00	1.17	0.99
Hrs @ home (slum) - peak	80.95	60.48	–	69.19	86.38	83.22
Hrs @ home (other) - peak	86.28	60.48	78.00	80.00	82.26	84.90
Value - healthy (slum)	1968.10	1962.10	–	1976.60	4305.90	1960.20
Value - healthy (other)	4317.40	4283.10	4315.00	4315.30	4315.60	4316.50
Value - healthy (all)	3797.00	3769.00	4315.00	3797.20	4313.50	3794.50



# Baseline Model versus Epidemiological Model

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# Role of Slums

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# Decomposing the Role of Slums: Population Density

	Benchmark	Epidem.	No slum	Homog. densities	Homog. wage rates	Homog. age struct.
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# Decomposing the Role of Slums: Inequality

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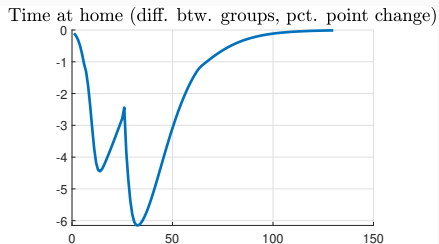
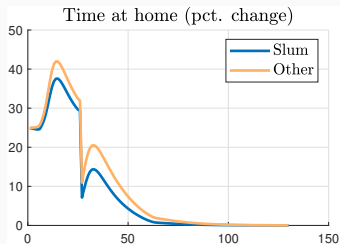
# Policy experiments

- All ICU beds made public
- Shelter-at-home policies; i.e. lockdowns
- Cash transfers

# All hospital beds used by the public system

	Benchmark	All beds public
Wks to peak srsly ill (slum)	10.00	10.00
Wks to peak srsly ill (other)	11.00	11.00
Dead p/ 1,000 1year (slum)	10.04	6.84
Dead p/ 1,000 1year (other)	6.35	4.82
Dead p/ 1,000 1year (all)	7.16	5.27
Dead p/ 1,000 LR (slum)	10.11	6.85
Dead p/ 1,000 LR (other)	6.57	4.86
Dead p/ 1,000 LR (all)	7.35	5.30
Immune in LR (slum), %	74.33	77.03
Immune in LR (other), %	39.69	42.89
Immune in LR (all), %	47.36	50.46
GDP at peak - rel to BM	1.00	1.02
GDP 1year - rel to BM	1.00	1.04
Hrs @ home (slum) - peak	80.95	80.26
Hrs @ home (other) - peak	86.28	85.01
Value - healthy (slum)	1968.10	1974.90
Value - healthy (other)	4317.40	4325.80
Value - healthy (all)	3797.00	3805.10

# Shelter-at-home policies





# Shelter-at-home policies

	Benchmark	Immediate lockdown				6-week late
		25%, all	25%, slums	25%, non-slum	75%, all	lockdown
		26 weeks	26 weeks	26 weeks	35 weeks	25%, all 26 weeks
Wks to peak srsly ill (slum)	10.00	14.00	13.00	11.00	66.00	11.00
Wks to peak srsly ill (other)	11.00	16.00	14.00	12.00	67.00	12.00
Dead p/ 1,000 1year (slum)	10.04	9.21	9.13	10.00	0.00	8.68
Dead p/ 1,000 1year (other)	6.35	5.84	6.92	5.28	0.00	5.26
Dead p/ 1,000 1year (all)	7.16	6.58	7.41	6.33	0.00	6.02
Dead p/ 1,000 LR (slum)	10.11	9.51	9.29	10.19	10.10	9.29
Dead p/ 1,000 LR (other)	6.57	6.48	7.22	5.91	6.56	6.34
Dead p/ 1,000 LR (all)	7.35	7.15	7.68	6.86	7.35	7.00
Immune in LR (slum), %	74.33	73.58	70.96	76.68	74.36	73.29
Immune in LR (other), %	39.69	40.32	42.96	38.18	39.67	40.57
Immune in LR (all), %	47.36	47.69	49.16	46.71	47.35	47.82
GDP at peak - rel to BM	1.00	0.96	1.12	0.86	0.99	0.95
GDP 1year - rel to BM	1.00	0.87	0.98	0.89	0.47	0.87
Hrs @ home (slum) - peak	80.95	83.18	84.40	79.79	80.19	83.76
Hrs @ home (other) - peak	86.28	85.87	81.83	89.56	85.95	86.16
Value - healthy (slum)	1968.10	1964.40	1964.20	1968.20	1863.20	1964.40
Value - healthy (other)	4317.40	4312.90	4315.30	4314.80	4213.00	4313.30
Value - healthy (all)	3797.00	3792.70	3794.50	3795.00	3692.50	3793.10

# Cash transfers

	Benchmark	Only financial aid			Aid and 25% lockdown for all		
		300R\$, all	300R\$, slums	600R\$, slums	300R\$, all	300R\$, slums	600R\$, slums
		26 weeks	26 weeks	26 weeks	26 weeks	26 weeks	26 weeks
Wks to peak srsly ill (slum)	10.00	15.00	14.00	32.00	32.00	32.00	32.00
Wks to peak srsly ill (other)	11.00	16.00	15.00	19.00	33.00	33.00	33.00
Dead p/ 1,000 1year (slum)	10.04	8.99	8.94	8.81	9.01	8.96	9.07
Dead p/ 1,000 1year (other)	6.35	6.40	6.94	6.89	5.49	5.98	5.88
Dead p/ 1,000 1year (all)	7.16	6.97	7.39	7.31	6.27	6.64	6.59
Dead p/ 1,000 LR (slum)	10.11	9.28	9.16	9.15	9.54	9.40	9.58
Dead p/ 1,000 LR (other)	6.57	6.91	7.30	7.36	6.48	6.72	6.70
Dead p/ 1,000 LR (all)	7.35	7.43	7.71	7.76	7.15	7.32	7.34
Immune in LR (slum), %	74.33	71.90	70.69	70.33	73.58	72.44	72.27
Immune in LR (other), %	39.69	41.95	43.41	43.96	40.35	41.39	41.55
Immune in LR (all), %	47.36	48.58	49.45	49.80	47.71	48.27	48.36
GDP at peak - rel to BM	1.00	1.16	1.24	1.30	1.10	1.20	1.12
GDP 1year - rel to BM	1.00	0.94	0.99	0.98	0.84	0.89	0.91
Hrs @ home (slum) - peak	80.95	78.61	80.46	77.55	78.85	77.99	80.36
Hrs @ home (other) - peak	86.28	77.74	77.99	80.32	83.88	82.00	84.49
Value - healthy (slum)	1968.10	1985.60	1985.70	1998.80	1982.40	1982.60	1996.70
Value - healthy (other)	4317.40	4322.20	4315.70	4315.60	4320.70	4315.10	4316.70
Value - healthy (all)	3797.00	3804.60	3799.60	3802.40	3802.80	3798.50	3802.80

# Conclusions

## Slums:

- High-density areas populated by poorer and younger individuals
- Faster spread of diseases such as Covid-19 - but not necessarily more death rates (although still higher in our model)

## This paper:

- Rich daily location data: slum dwellers → less social distance
- Model:
  - More infections (and deaths) in slums
  - World wo slums: distributional health effects
- Policies:
  - Reallocation of ICUs: all groups better off
  - Shelter-at-home: delay; small overall effects, redistribution
  - Cash transfers: delay; small effects (or backfire); redistribution

Extra slides

Discrete time

[Back](#)

# Model environment

Discrete time

[Back](#)

Different groups ( $g$ ): Slums/*favelas* ( $f$ ) and others ( $o$ )

# Model environment

Discrete time

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Different groups ( $g$ ): Slums/*favelas* ( $f$ ) and others ( $o$ )

Health status ( $j$ ):

- healthy ( $h$ )
- infected ( $i$ ): recovery ( $\phi(0, g)$ ) or serious symptoms ( $\alpha(g)$ )
- symptoms ( $s$ ): recovery ( $\phi(1, g)$ ) or death ( $\delta_t(g)$ )
- recovered ( $r$ ): immune forever

# Model environment

Discrete time

Back

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- recovered ( $r$ ): immune forever

Slums:

- Higher population density ( $\xi_g$ )
- Younger individuals: ( $\phi(0, g)$ ), ( $\alpha(g)$ ), ( $\phi(1, g)$ ), ( $\delta_t(g)$ )
- Poorer individuals ( $w(g)$ )
- Harder access to ICU
  - Death prob:  $\delta_t(g)$



# Households

Time: work  $n$ , leisure outside  $\ell$ , leisure at home  $d$

Time constraint (TC):  $n + \ell + d = 1$

Leisure goods outside the house  $a$ :

$$a(x, \ell) = [\theta x^{\rho} + (1 - \theta)\ell^{\rho}]^{1/\rho}$$

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Preferences:

$$u(c, a, d; j, g, p) = \ln c + \gamma \ln a + [\lambda_d + \lambda(j) + \lambda_p(j, g)] \ln(d) + b$$

Discount factor  $\beta$

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Budget constraint (BC):

$$c + x = w_p(g) + w(g)n$$

Prob of infection:

$$\pi(n+l, \Pi_t(g)) = (n+l)\Pi_t(g)$$

Details:

$$\begin{aligned}\hat{\Pi}_t(g) &= (1 - \zeta)\Pi_0 \sum_{\tilde{g} \in \{f, o\}, j \in \{i, s\}} (n_t(j, \tilde{g}) + l_t(j, \tilde{g})) M_t(j, \tilde{g}) \\ &+ \zeta \Pi_0 \sum_{j \in \{i, s\}} \frac{1}{\zeta_g} (n_t(j, g) + l_t(j, g)) M_t(j, g).\end{aligned}$$

$$\Pi_t(g) = 1 - e^{-\hat{\Pi}_t(g)}$$

Healthy:

$$V_t(h, g) = \max_{c, x, n, \ell, d} u(c, a(x, \ell), d; h, g, p_t) + \beta \{ [1 - \pi(n + \ell, \Pi_t(g))] V_{t+1}(h, g) + \pi(n + \ell, \Pi_t(g)) V_{t+1}(i, g) \}$$

subject to (TC) and (BC).

# Decision making

Healthy:

$$V_t(h, g) = \max_{c, x, n, \ell, d} u(c, a(x, \ell), d; h, g, p_t) + \beta \{ [1 - \pi(n + \ell, \Pi_t(g))] V_{t+1}(h, g) + \pi(n + \ell, \Pi_t(g)) V_{t+1}(i, g) \}$$

subject to (TC) and (BC).

Infected:

$$V_t(i, g) = \max_{c, x, n, \ell, d} u(c, a(x, \ell), d; i, g, p_t) + \beta \phi(0, g) V_{t+1}(r, g) + \beta (1 - \phi(0, g)) [\alpha(g) V_{t+1}(s, g) + (1 - \alpha(g)) V_{t+1}(i, g)]$$

subject to (TC) and (BC).

Symptoms:

$$V_t(s, g) = \beta [\phi(1, g)V_{t+1}(r, g) + (1 - \phi(1, g))(1 - \delta_t(g))V_{t+1}(s, g)]$$

subject to (TC) and (BC).

Symptoms:

$$V_t(s, g) = \beta [\phi(1, g)V_{t+1}(r, g) + (1 - \phi(1, g))(1 - \delta_t(g))V_{t+1}(s, g)]$$

subject to (TC) and (BC).

Recovered:

$$V_t(r, g) = \max_{c, x, n, \ell, h} u(c, a(x, \ell), d; r, g, p_t) + \beta V_{t+1}(r, g)$$

subject to (TC) and (BC).



## Hospital access and death probabilities

Hospital users (public and private):

$$U_{pub} = M_t(s, f) + (1 - \psi)M_t(s, o)$$

$$U_{priv} = \psi M_t(s, o)$$

Death prob (measure of hospital beds  $Z$ ):

$$\delta(f) = \tilde{\delta}_1(f) \min \left\{ \frac{Z_{pub}}{U_{pub}}, 1 \right\} + \tilde{\delta}_2(f) \max \left\{ \frac{U_{pub} - Z_{pub}}{U_{pub}}, 0 \right\},$$

$$\begin{aligned} \delta(o) = & \psi \left[ \tilde{\delta}_1(o) \min \left\{ \frac{Z_{priv}}{U_{priv}}, 1 \right\} + \tilde{\delta}_2(o) \max \left\{ \frac{U_{priv} - Z_{priv}}{U_{priv}}, 0 \right\} \right] \\ & + (1 - \psi) \left[ \tilde{\delta}_1(o) \min \left\{ \frac{Z_{pub}}{U_{pub}}, 1 \right\} + \tilde{\delta}_2(o) \max \left\{ \frac{U_{pub} - Z_{pub}}{U_{pub}}, 0 \right\} \right]. \end{aligned}$$

Output:

$$Q_t = \sum_{j,g} w(j,g) n_t(j,g) M_t(j,g)$$

Laws of motion:

$$\mathcal{M}_{t+1} = T(\mathcal{M}_t, \mathcal{N}_t, \Pi_t(o), \Pi_t(f)).$$

Example: law of motion for healthy individuals of a group  $g$

$$M_{t+1}(h,g) = M_t(h,g) [1 - \pi(n_t(h,g) + \ell_t(h,g), \Pi_t(g))].$$

A *rational-expectations equilibrium* in this economy with initial number of agents  $M_0(j, g)$  consists of a sequence of infection and death rates  $\{\Pi_t(g), \delta_t(g)\}_{t=0}^{\infty}$  and equilibrium time allocations  $\{n_t(j, g), \ell_t(j, g)\}_{t=0}^{\infty}$  such that:

- these time allocations are part of the solutions to the individual optimization problems, and
- the resulting laws of motion and their aggregation indeed give rise to the sequence  $\{\Pi_t(g), \delta_t(g)\}_{t=0}^{\infty}$ .

# Parameters (Rio de Janeiro) - City Parameters

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Parameter	Value	Interpretation
<b>Panel A: City parameters (6 parameters)</b>		
$\sum_j M_0(j, f)$	0.222	Fraction of people living in slums (calibrated)
$w(o)$	1	Wage rate of non-slum agents (calibrated)
$w(f)$	0.277	Wage rate of slum agents (calibrated)
$\xi_f$	0.065	Frac. of space assigned to slums (calibrated)
$\xi_o$	0.934	Frac. of space assigned to areas wo slums (calibrated)
$\zeta$	0.334	Prop. of time spent within group (calibrated)

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# Parameters (Rio de Janeiro) - Disease Parameters

Parameter	Value	Interpretation
<b>Panel B: Disease parameters (15 parameters)</b>		
$\Pi_0$	11.43	Infectiousness of Covid-19 (internatly estimated)
$\alpha(o), \alpha(f)$	1	Prob. (serious symptoms   no recovery from mild) (calibrated)
$\phi(0, o)$	0.971	Prob. of recovery from mild Covid-19, other (calibrated)
$\phi(0, f)$	0.979	Prob. of recovery from mild Covid-19, slum (calibrated)
$\phi(1, o), \phi(1, f)$	0.284	Prob. of recovery from serious Covid-19 (calibrated)
$\tilde{\delta}_1(o)$	0.118	Wkly death rate, other; critically ill with ICU (calibrated)
$\tilde{\delta}_1(f)$	0.073	Wkly death rate, slum; critically ill with ICU (calibrated)
$\tilde{\delta}_2(o), \tilde{\delta}_2(f)$	1.0	Wkly death rate; critically ill wo ICU (calibrated)
$\bar{\ell}$	0.158	Infections through the health care system (calibrated)
$\psi$	0.152	Prop. non-slum agents with priv. insurance (calibrated)
$Z_{pub}$	8.12e-5	Measure of beds in public system (calibrated)

# Parameters (Rio de Janeiro) - Preference Parameters

Parameter	Value	Interpretation
<b>Panel C: Preference parameters (7 parameters)</b>		
$\rho$	-1.72	Elast. of subst. bw leisure time and goods (calibrated)
$\theta$	0.108	Production of leisure goods (internally estimated)
$\gamma$	1.089	Rel. utility weight–leisure goods (internally estimated)
$\lambda_d$	2.453	Rel. utility weight–leisure at home (internally estimated)
$\lambda_a$	1.995	Rel. utility weight–leisure at home; infected (calibrated)
$\beta$	0.96 <sup>1/52</sup>	Discount factor (calibrated)
$b$	8.575	Value of being alive (internally estimated)

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# Different hospitalization rates

	Benchmark			
	$\frac{1-\phi(0.g)}{1}$	$\frac{1-\phi(0.g)}{2}$	$\frac{1-\phi(0.g)}{5}$	$\frac{1-\phi(0.g)}{10}$
Wks to peak srsly ill (slum)	10.00	10.00	11.00	11.00
Wks to peak srsly ill (other)	11.00	12.00	12.00	12.00
Srsly ill p/ 1,000 @ peak (slum)	1.88	1.28	0.73	0.47
Srsly ill p/ 1,000 @ peak (other)	0.77	0.64	0.46	0.32
Dead p/ 1,000 1year (slum)	10.04	5.07	2.00	0.92
Dead p/ 1,000 1year (other)	6.35	3.43	1.52	0.76
Dead p/ 1,000 1year (all)	7.16	3.80	1.63	0.80
Dead p/ 1,000 LR (slum)	10.11	5.08	2.00	0.92
Dead p/ 1,000 LR (other)	6.57	3.44	1.52	0.76
Dead p/ 1,000 LR (all)	7.35	3.80	1.63	0.80
Immune in LR (slum), %	74.33	76.44	80.58	83.14
Immune in LR (other), %	39.69	42.16	48.96	54.46
Immune in LR (all), %	47.36	49.75	55.97	60.81
Hrs @ home (slum) - peak	80.95	76.57	70.04	67.00
Hrs @ home (other) - peak	86.28	82.04	74.34	69.59
Hrs @ home (slum) - 6m	66.03	61.60	60.59	60.50
Hrs @ home (other) - 6m	69.40	62.80	60.73	60.52
Value - healthy (slum)	1968.10	1979.00	1985.60	1987.80
Value - healthy (other)	4317.40	4333.40	4343.10	4346.70
Value - healthy (all)	3797.00	3811.90	3820.90	3824.20