

# DAEDALUS: a model to optimize social and economic activity while containing SARS-CoV-2 transmission

## Supplementary Material

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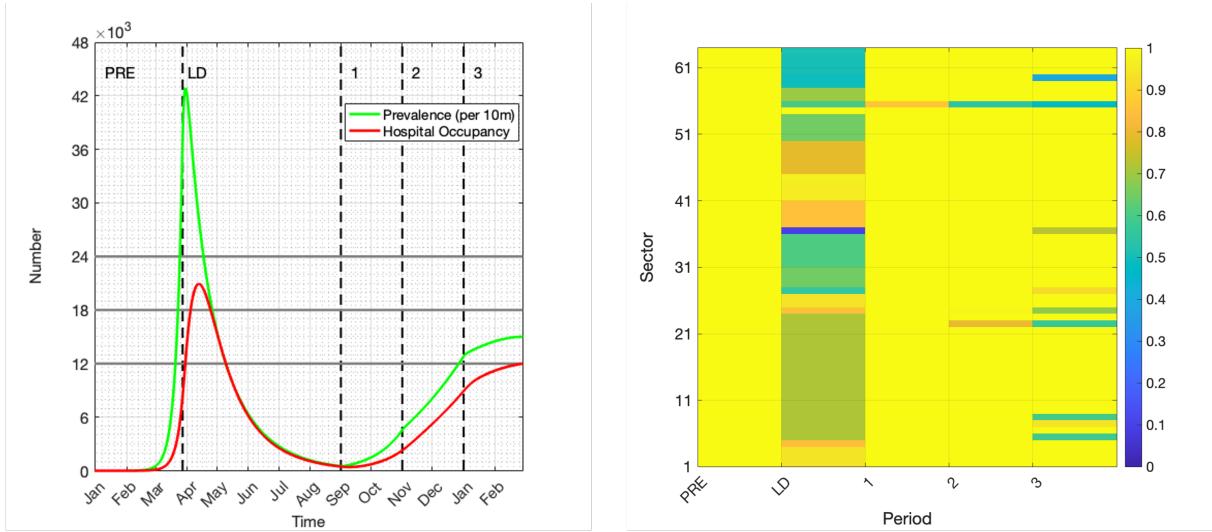


Figure S1: Optimal economic configuration under scenario A (GDP maximization), hospital capacity 12,000 beds. (A) Projected prevalence and hospital occupancy; (B) economic configuration across 63 economic sectors. GDP over six months £862bn.

Notes: Scenario A maximizes GDP via successive bi-monthly opening and closing of 63 sectors over a six-months intervention period, subject to epidemiological and economic constraints; any economic sector including the education sector may be closed down to 80% of observed closure during the lockdown period March – May 2020 but not lower to sustain essential services; model fitted to English hospitalization data from 20th March to 30th June 2020; (A) Projected daily infection prevalence and daily hospital occupancy between January and February. The three grey horizontal lines display alternative assumptions on maximum emergency hospital capacity for the treatment of COVID-19 patients. Here, hospital capacity is constrained at 12,000 beds (1st line from below); (B) Economic configuration (bi-monthly sector openings) associated with Scenario A GDP maximization. PRE is pre-pandemic period, LD is the lockdown period March – May 2020 in the UK, plotted for comparison based on data for closures of higher-level sector categories; Period 1 is September–October, period 2 is November–December, period 3 is January–February; sectors are listed on the vertical axis, and months on the horizontal axis. Openings vary between fully open as pre-pandemic (yellow, 1) to closed (blue, 80% of values observed during the lockdown period), with optimal openings for each month over the intervention period September to February indicated.

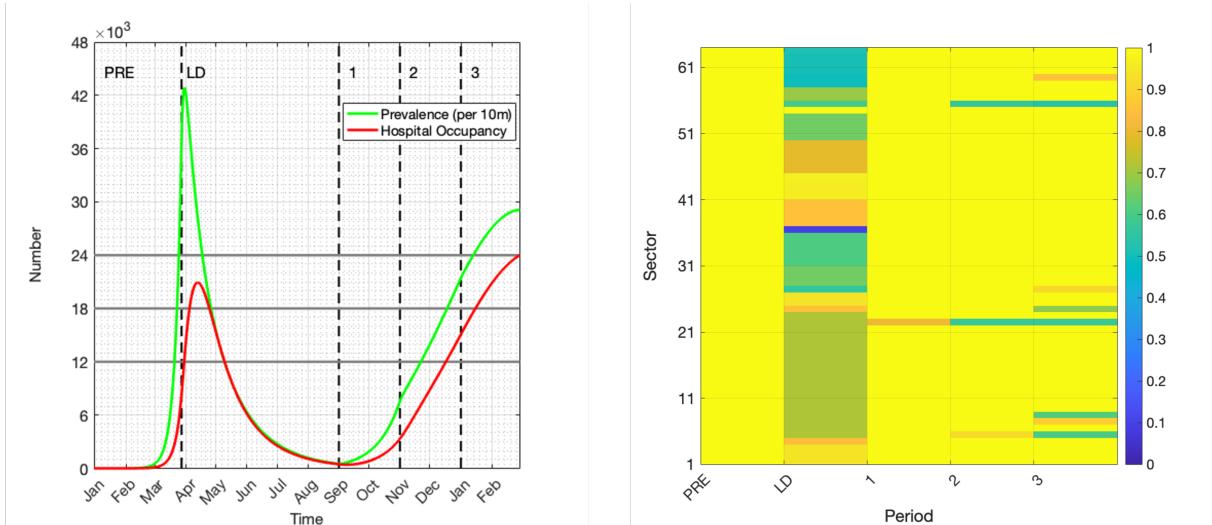


Figure S2: Optimal economic configuration under scenario A (GDP maximization), hospital capacity 24,000 beds. (A) Projected prevalence and hospital occupancy; (B) economic configuration across 63 economic sectors. GDP over six months £868bn.

Notes: Scenario A maximizes GDP via successive bi-monthly opening and closing of 63 sectors over a six-months intervention period, subject to epidemiological and economic constraints; any economic sector including the education sector may be closed down to 80% of observed closure during the lockdown period March – May 2020 but not lower to sustain essential services; model fitted to English hospitalization data from 20th March to 30th June 2020; (A) Projected daily infection prevalence and daily hospital occupancy between January and February. The three grey horizontal lines display alternative assumptions on maximum emergency hospital capacity for the treatment of COVID-19 patients. Here, hospital capacity is constrained at 24,000 beds (3rd line from below). (B) Economic configuration (bi-monthly sector openings) associated with Scenario A GDP maximization. PRE is pre-pandemic period, LD is the lockdown period March – May 2020 in the UK, plotted for comparison based on data for closures of higher-level sector categories; Period 1 is September–October, period 2 is November–December, period 3 is January–February; sectors are listed on the vertical axis, and months on the horizontal axis. Openings vary between fully open as pre-pandemic (yellow, 1) to closed (blue, 80% of values observed during the lockdown period), with optimal openings for each month over the intervention period September to February indicated.

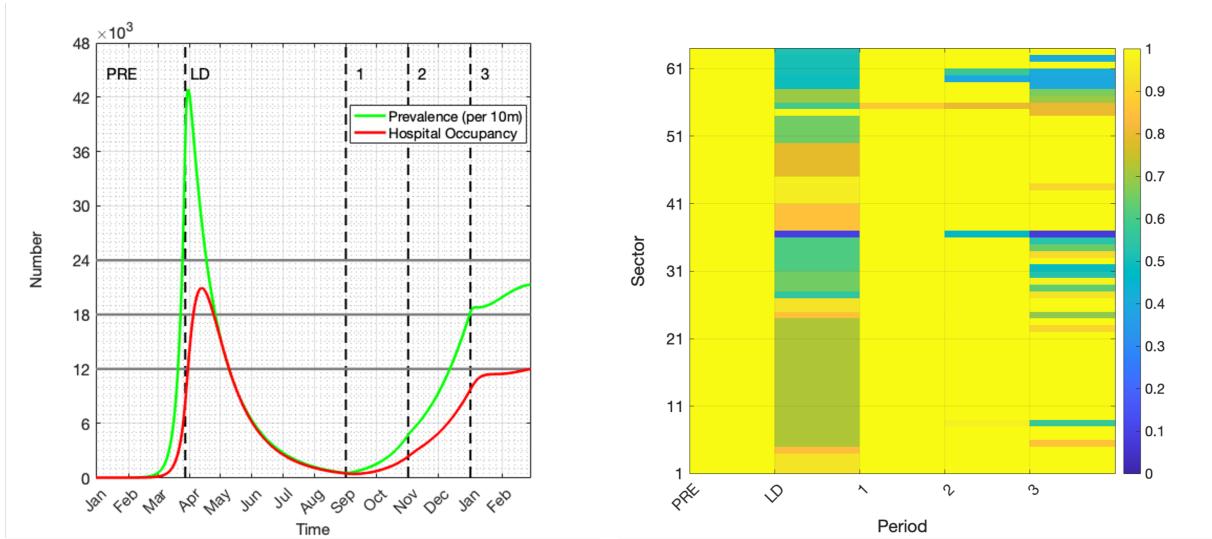


Figure S3: Optimal economic configuration under scenario B (education open), hospital capacity 12,000 beds. (A) Projected prevalence and hospital occupancy; (B) economic configuration across 63 economic sectors. GDP over six months £831bn.

Notes: Scenario B optimizes GDP via successive bi-monthly opening and closing of 63 sectors over a six-months intervention period, subject to epidemiological and economic constraints; any economic sector except for the education sector may be closed down to 80% of observed closure during the lockdown period March – May 2020 but not lower to sustain essential services; the education sector is constrained to stay open at or above 80% of pre-pandemic production levels; model fitted to hospitalization data for England from 20th March to 30th June 2020. (A) Projected daily infection prevalence and daily hospital occupancy between January and February. The three grey horizontal lines display alternative assumptions on hospital capacity. Here, hospital capacity is constrained at 12,000 beds (1st line from below). (B) Economic configuration (bi-monthly sector openings) associated with Scenario B ‘education open’. PRE is pre-pandemic period, LD is the lockdown period March – May 2020 in the UK, plotted for comparison based on data for closures of higher-level sector categories; Period 1 is September-October, period 2 is November-December, period 3 is January-February; sectors are listed on the vertical axis, and months on the horizontal axis. Openings vary between fully open as pre-pandemic (yellow, 1) to closed (blue, 80% of values observed during the lockdown period), with optimal openings for each month over the intervention period September to February indicated.

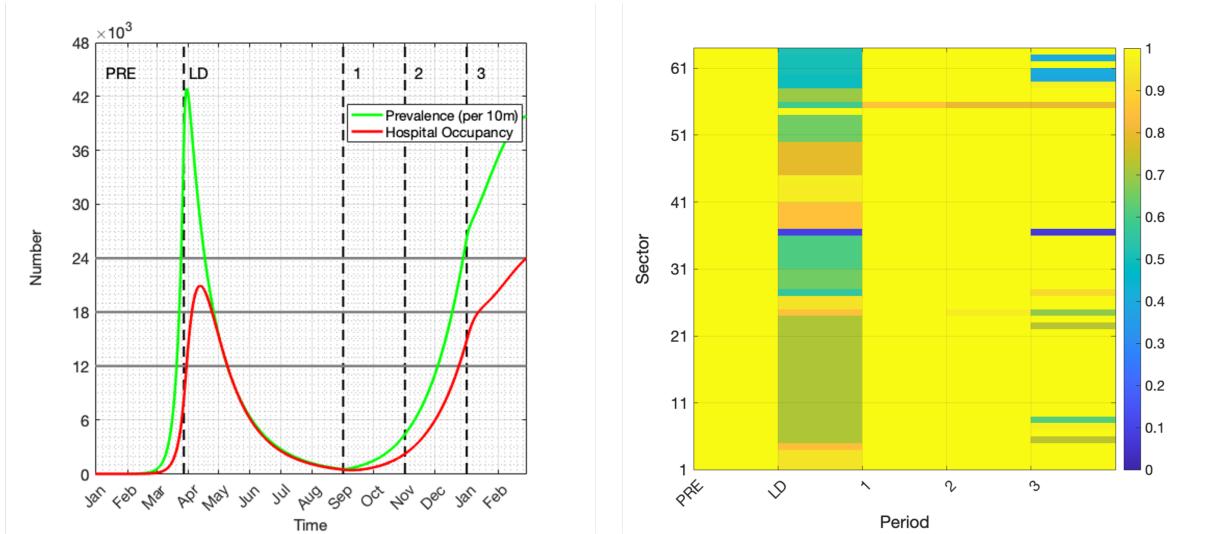


Figure S4: Optimal economic configuration under scenario B (education open), hospital capacity 24,000 beds: projected prevalence and hospital occupancy (left) and economic configuration across 63 economic sectors (right). GDP over six months £863bn.

Notes: Scenario B optimizes GDP via successive bi-monthly opening and closing of 63 sectors over a six-months intervention period, subject to epidemiological and economic constraints; any economic sector except for the education sector may be closed down to 80% of observed closure during the lockdown period March – May 2020 but not lower to sustain essential services; the education sector is constrained to stay open at or above 80% of pre-pandemic production levels; model fitted to hospitalization data for England from 20th March to 30th June 2020. (A) Projected daily infection prevalence and daily hospital occupancy between January and February. The three grey horizontal lines display alternative assumptions on hospital capacity. Here, hospital capacity is constrained at 24,000 beds (3rd line from below); (B) Economic configuration (bi-monthly sector openings) associated with Scenario B ‘education open’. PRE is pre-pandemic period, LD is the lockdown period March – May 2020 in the UK, plotted for comparison based on data for closures of higher-level sector categories; Period 1 is September–October, period 2 is November–December, period 3 is January–February; sectors are listed on the vertical axis, and months on the horizontal axis. Openings vary between fully open as pre-pandemic (yellow, 1) to closed (blue, 80% of values observed during the lockdown period), with optimal openings for each month over the intervention period September to February indicated.

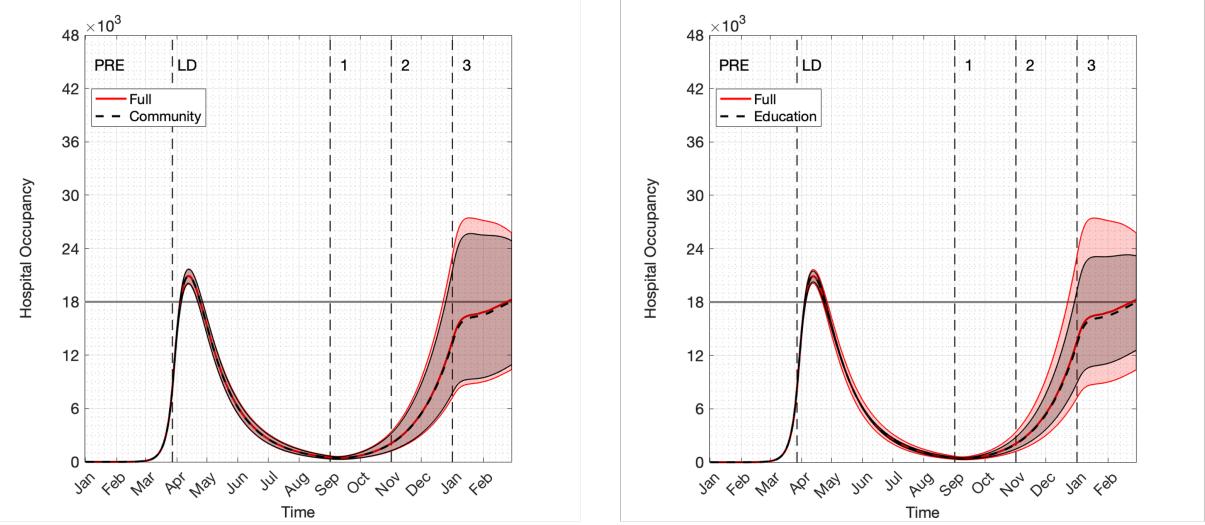


Figure S5: Sensitivity analyses on contact rates, Scenario B (education open),  $H=18,000$ : variation in community transmission only, excluding induced transmission as a result of sector openings (left); variation in age 1-4 and 5-19 as a result of opening the education sector (right).

Notes: We show the 5th and 95th percentiles of fitted and projected hospital occupancy when contact rates are varied by 5% standard deviations around their sector-specific means assuming contact rates are independently and normally distributed. This figure demonstrates that much of the uncertainty in projected occupancy arises from variation in the community and education sectors.

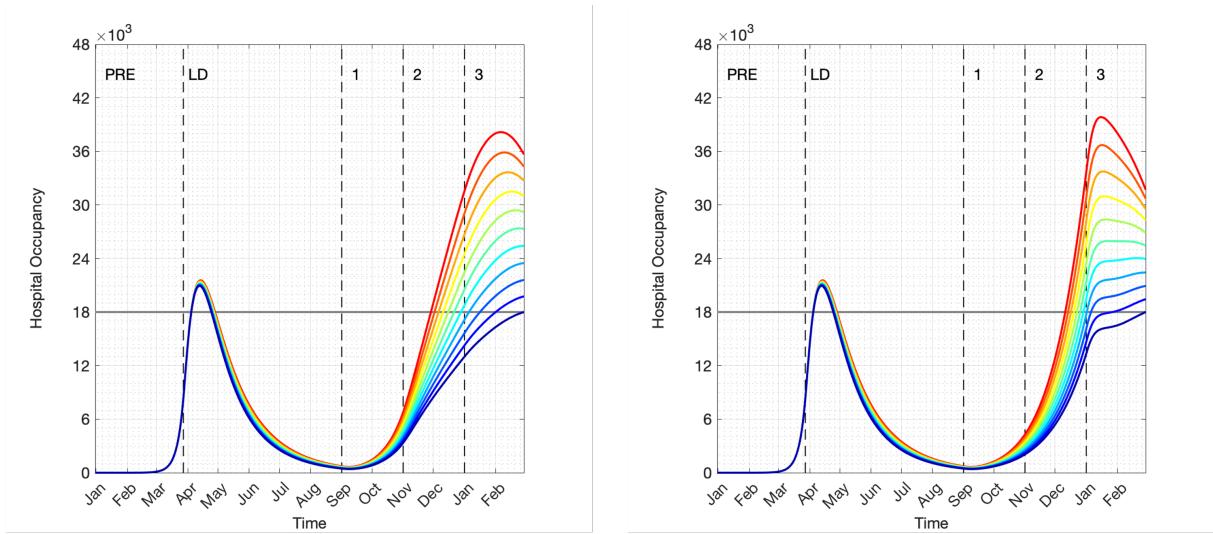


Figure S6: Sensitivity analyses on proportion of workers working from home, optimising for GDP in scenario A (left) and Scenario B (right)

Notes: We show fitted and projected hospital occupancy when the proportion of workers working from home is decreased in 2% steps from our baseline assumption of the work-from-home proportions observed during the lockdown period March – May 2020 (black) to 20% fewer workers working-from-home (red);  $H=18,000$  (horizontal grey line).

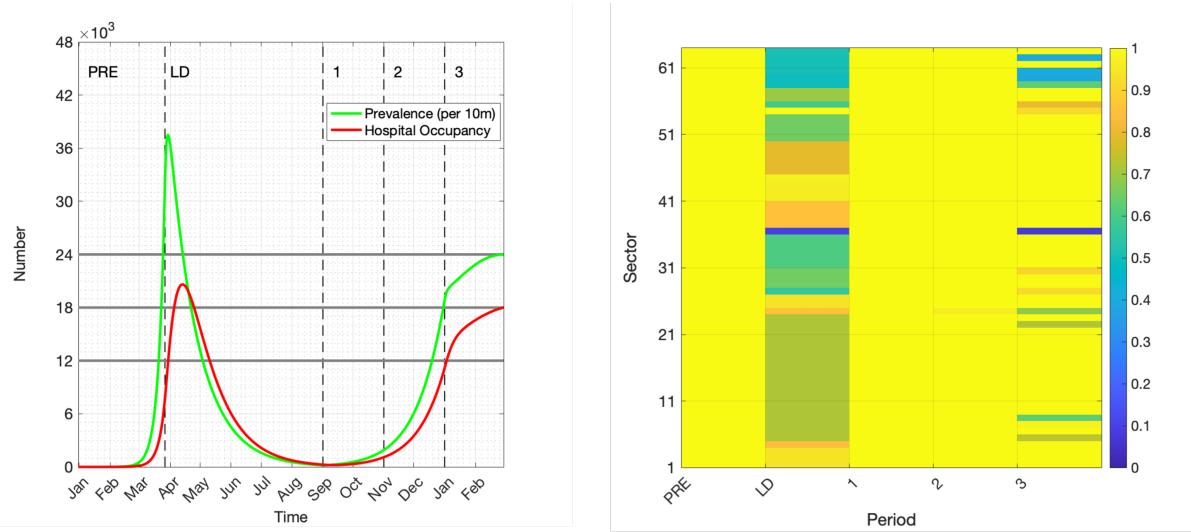


Figure S7: Optimization assuming 50% susceptibility of children under 16 years of age, scenario B (education open), 18,000 beds: projected prevalence and hospital occupancy (left) and economic configuration across 63 economic sectors (right). GDP over six months £864bn.

Notes: Scenario B optimizes GDP via successive bi-monthly opening and closing of 63 sectors over a six-months intervention period, subject to epidemiological and economic constraints; any economic sector except for the education sector may be closed down to 80% of observed closure during the lockdown period March – May 2020 but not lower to sustain essential services; the education sector is constrained to stay open at or above 80% of pre-pandemic production levels; model re-fitted to hospitalization data for England from 20th March to 30th June 2020 assuming children under 16 years of age have 50% less susceptibility to infection than adults ( $R_0=2.75$ , fitted  $\delta=0.6227$ , assumed  $\delta=0.79$ ); the re-fit to the initial epidemic results in the finding that there was more transmission between adults than children compared to the assumption of equal susceptibility. This implies that school closures have less impact on transmission dynamics for the projections. (A) Projected daily infection prevalence and daily hospital occupancy between January and February. The three grey horizontal lines display alternative assumptions on hospital capacity. Here, emergency spare hospital capacity is constrained at 18,000 beds (2nd line from below); (B) Economic configuration associated with Scenario B ‘education open’ assuming children under 16 years of age have 50% less susceptibility to infection. PRE is pre-pandemic period, LD is the lockdown period March – May 2020 in the UK, plotted for comparison based on data for closures of higher-level sector categories; Periods 1 to 3 are the months September to February; sectors are listed on the vertical axis, and bimonthly periods on the horizontal axis. Openings vary between fully open as pre-pandemic (yellow, 1) to closed (blue, 80% of values observed during the lockdown period), with optimal openings for each month over the intervention period September to February indicated.

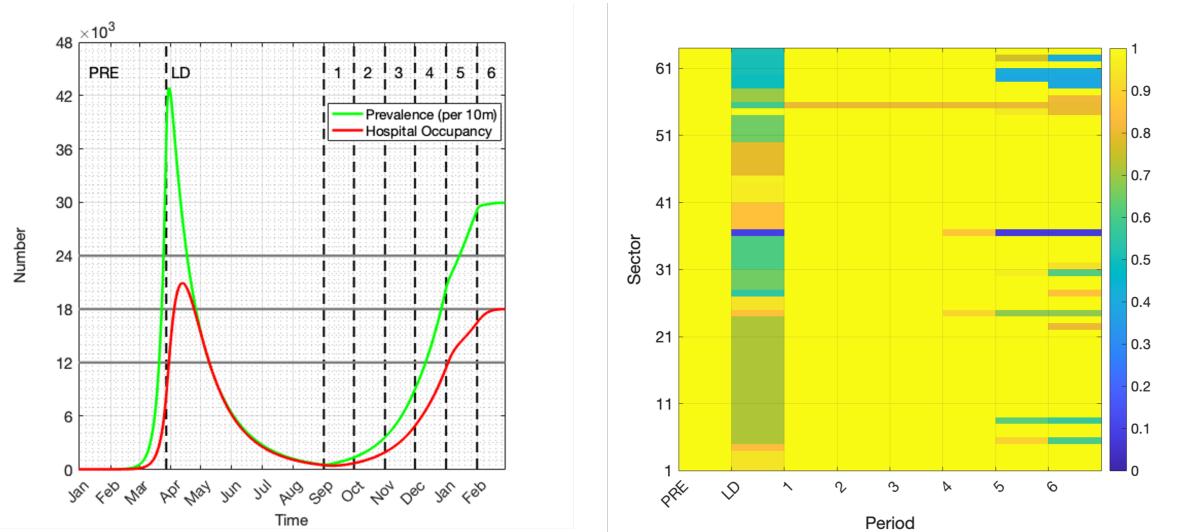


Figure S8: Scenario B (education open),  $H=18,000$  beds: optimization over 6 single-month periods. Projected prevalence and hospital occupancy (left) and economic configuration across 63 economic sectors (right). GDP over six months £855bn.

Notes: Scenario B optimizes GDP via successive monthly opening and closing of 63 sectors over a six-months intervention period, subject to epidemiological and economic constraints; this is in contrast to the baseline scenario whereby bi-monthly (i.e. every two months) opening and closing of 63 sectors over a six-months intervention period is allowed; any economic sector except for the education sector may be closed down to 80% of observed closure during the lockdown period March – May 2020 but not lower to sustain essential services; the education sector is constrained to stay open at or above 80% of pre-pandemic production levels; model fitted to hospitalization data for England from 20th March to 30th June 2020; (A) shows projected daily infection prevalence and daily hospital occupancy between January and February. The three grey horizontal lines display alternative assumptions on hospital capacity. Here, emergency spare hospital capacity is constrained at 18,000 beds (2nd line from below); (B) illustrates the economic configuration (monthly sector openings) associated with Scenario B ‘education open’. PRE is pre-pandemic period, LD is the lockdown period March – May 2020 in the UK, plotted for comparison based on data for closures of higher-level sector categories; Periods 1 to 6 are the months September to February; sectors are listed on the vertical axis, and months on the horizontal axis. Openings vary between fully open as pre-pandemic (yellow, 1) to closed (blue, 80% of values observed during the lockdown period), with optimal openings for each month over the intervention period September to February indicated.

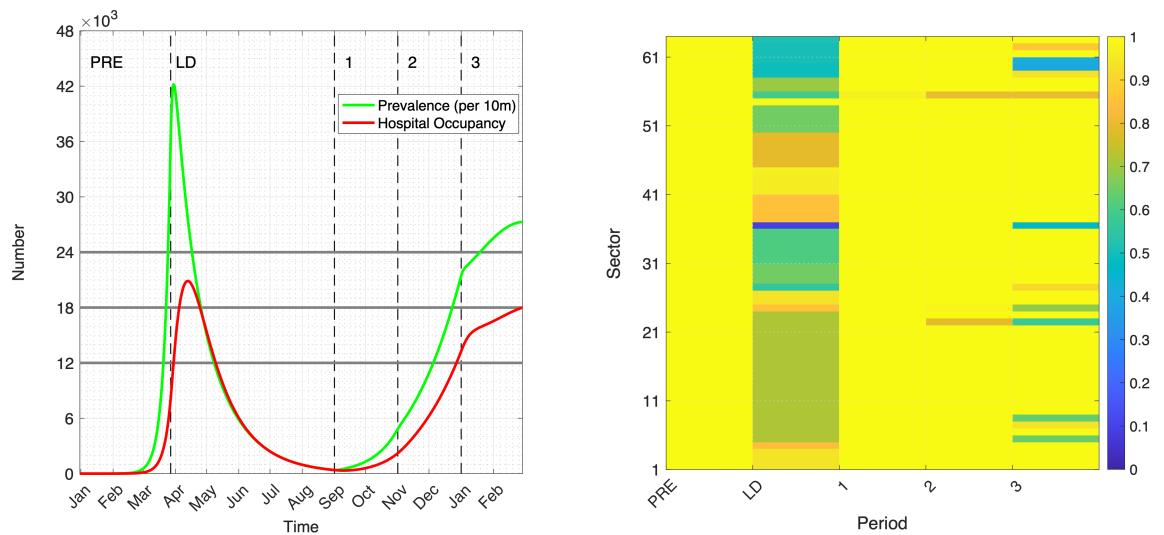


Figure S9: Optimal economic configuration under scenario B (education open), hospital capacity 18,000 beds with decreasing productivity of labour: projected prevalence and hospital occupancy (left) and economic configuration across 63 economic sectors (right). GDP over six months £869bn.

Note:  $\alpha=0.59$  following [1], instead of  $\alpha=1$  as in the main specification

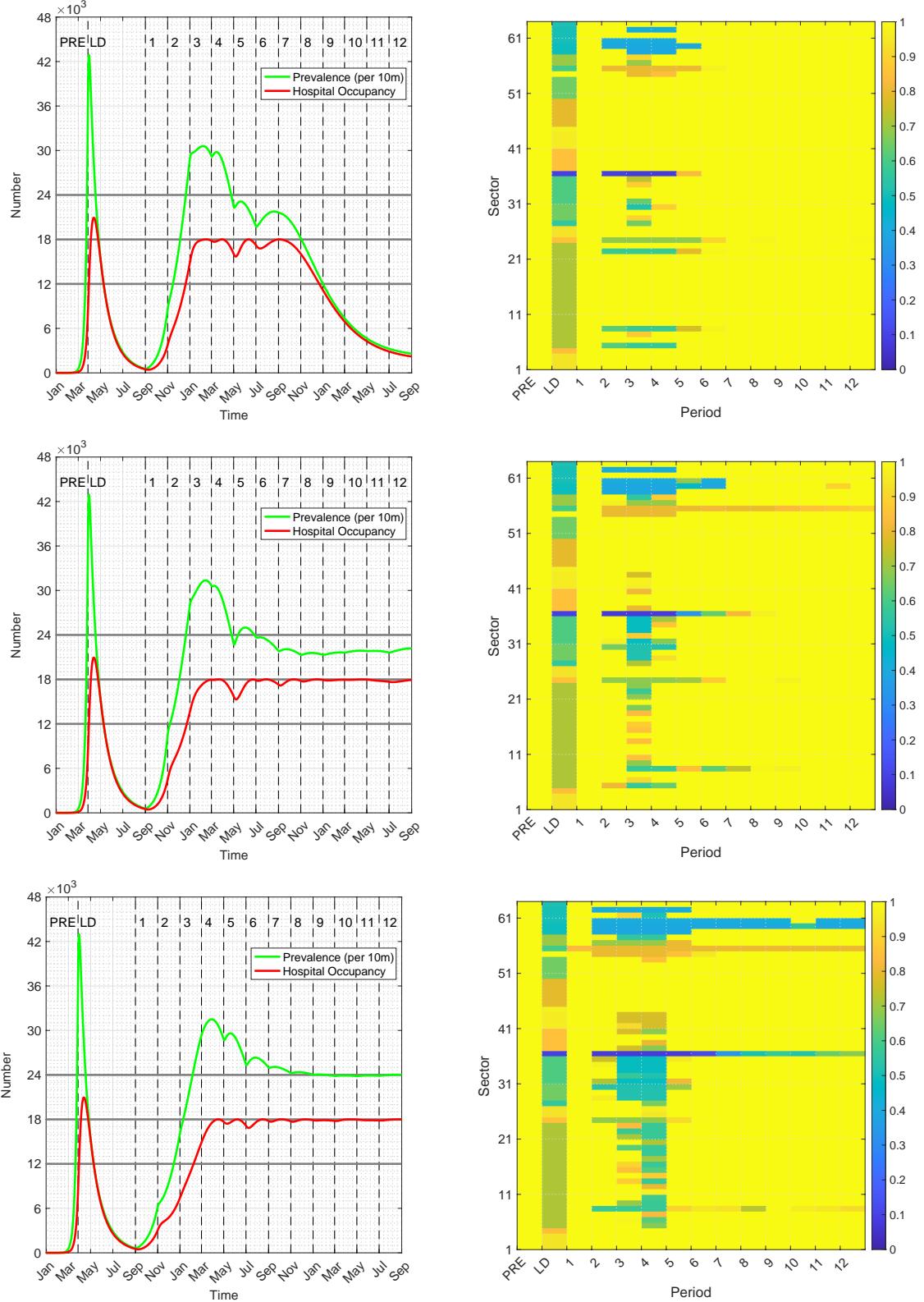


Figure S10: Optimal economic configuration under scenario B (education open), hospital capacity 18,000 beds with waning immunity and 24-month planning horizon. We fix mean duration of immunity at 1095 days (3 years, top row), 365 days (1 year, middle) and 240 days (8 months, bottom). GDP over 24 months £3,457bn, £3,384bn and £3,279bn respectively.

Notes:  $0.8 \leq x_{\text{education}} \leq 1$ ;  $\delta = 0.72$  over planning horizon; 2-month decision periods.

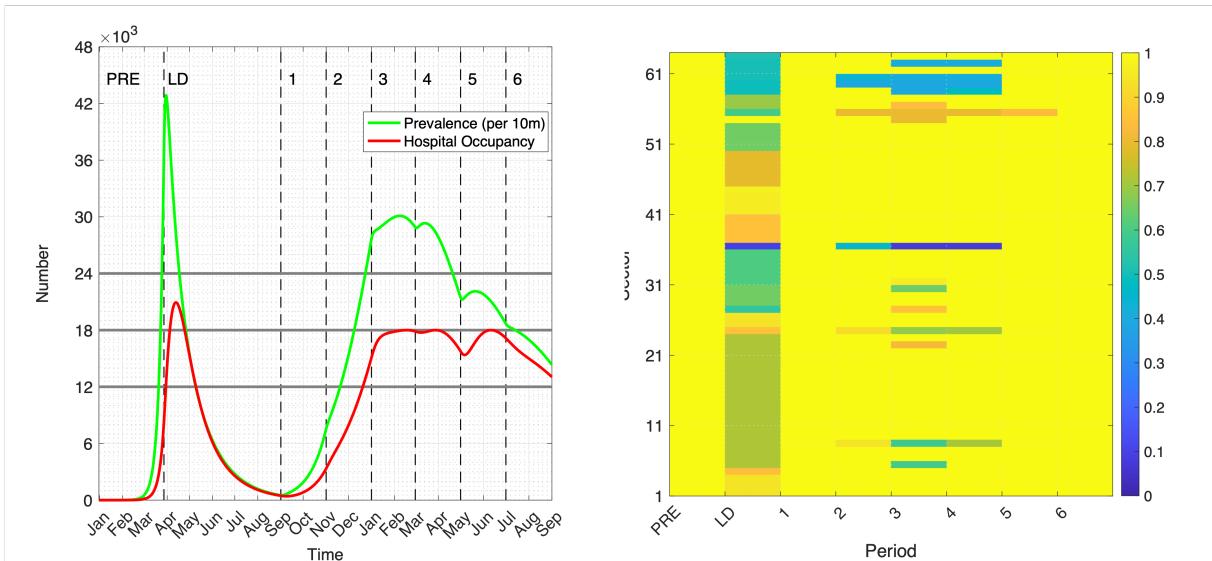


Figure S11: Optimal economic configuration under scenario B (education open), hospital capacity 18,000 beds over a 12 months planning horizon: projected prevalence and hospital occupancy (left) and economic configuration across 63 economic sectors (right). GDP over twelve months £1,711bn.

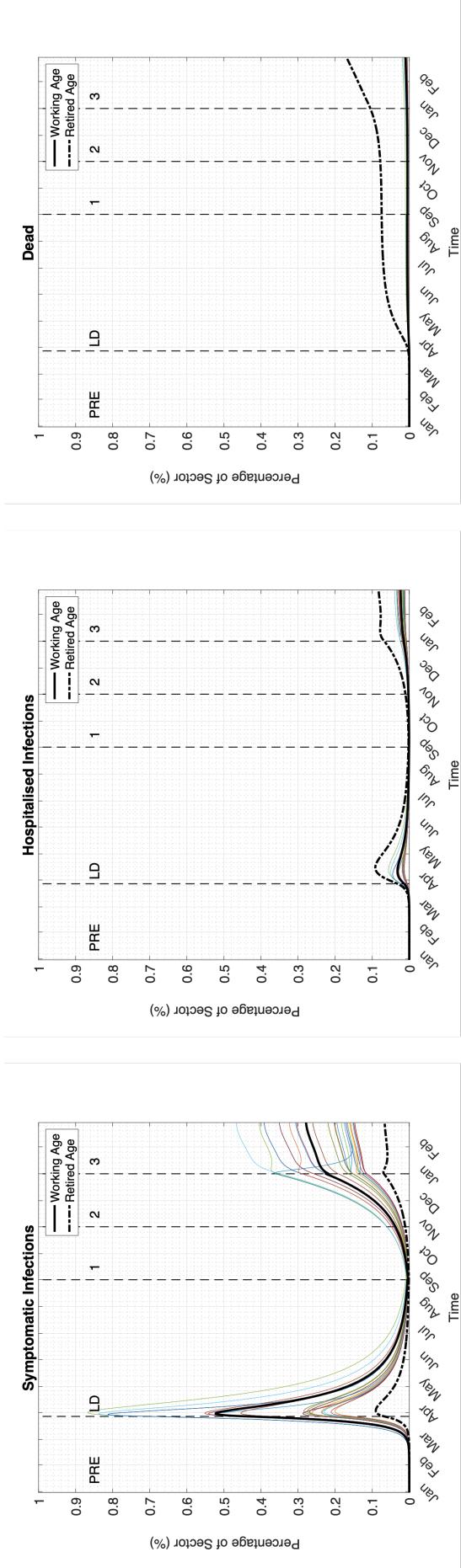


Figure S12: Percentage of symptomatic infections, hospitalization and deaths by sector over time for Scenario B.

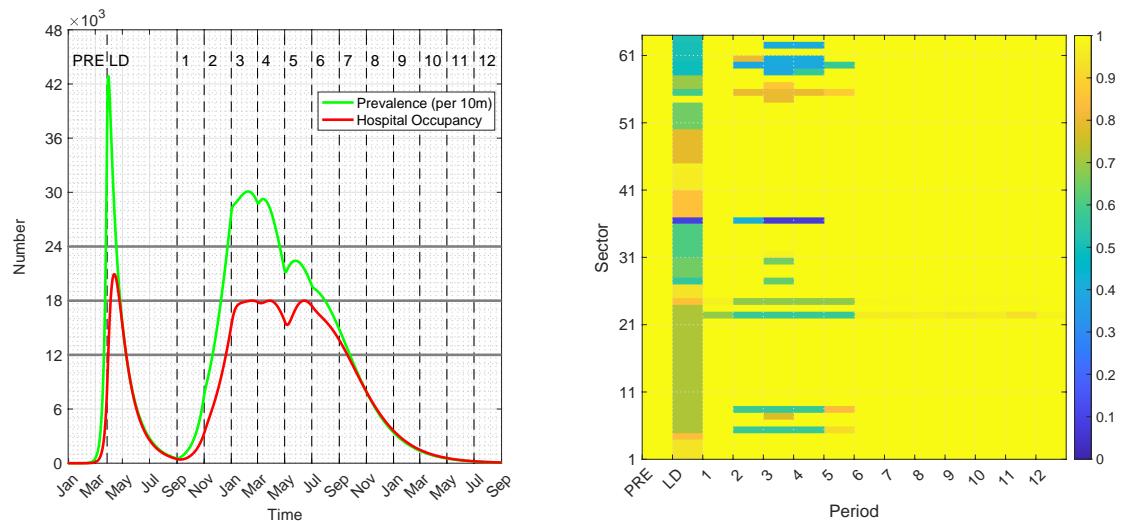


Figure S13: Optimal economic configuration under scenario B (education open), hospital capacity 18,000 beds: 24-month planning horizon. Projected prevalence and hospital occupancy (left); economic configuration across 63 economic sectors (right). GDP over 24 months £3,476bn.

Notes:  $0.8 \leq x_{education} \leq 1$ ;  $\delta = 0.72$  over planning horizon; 2-month decision periods.

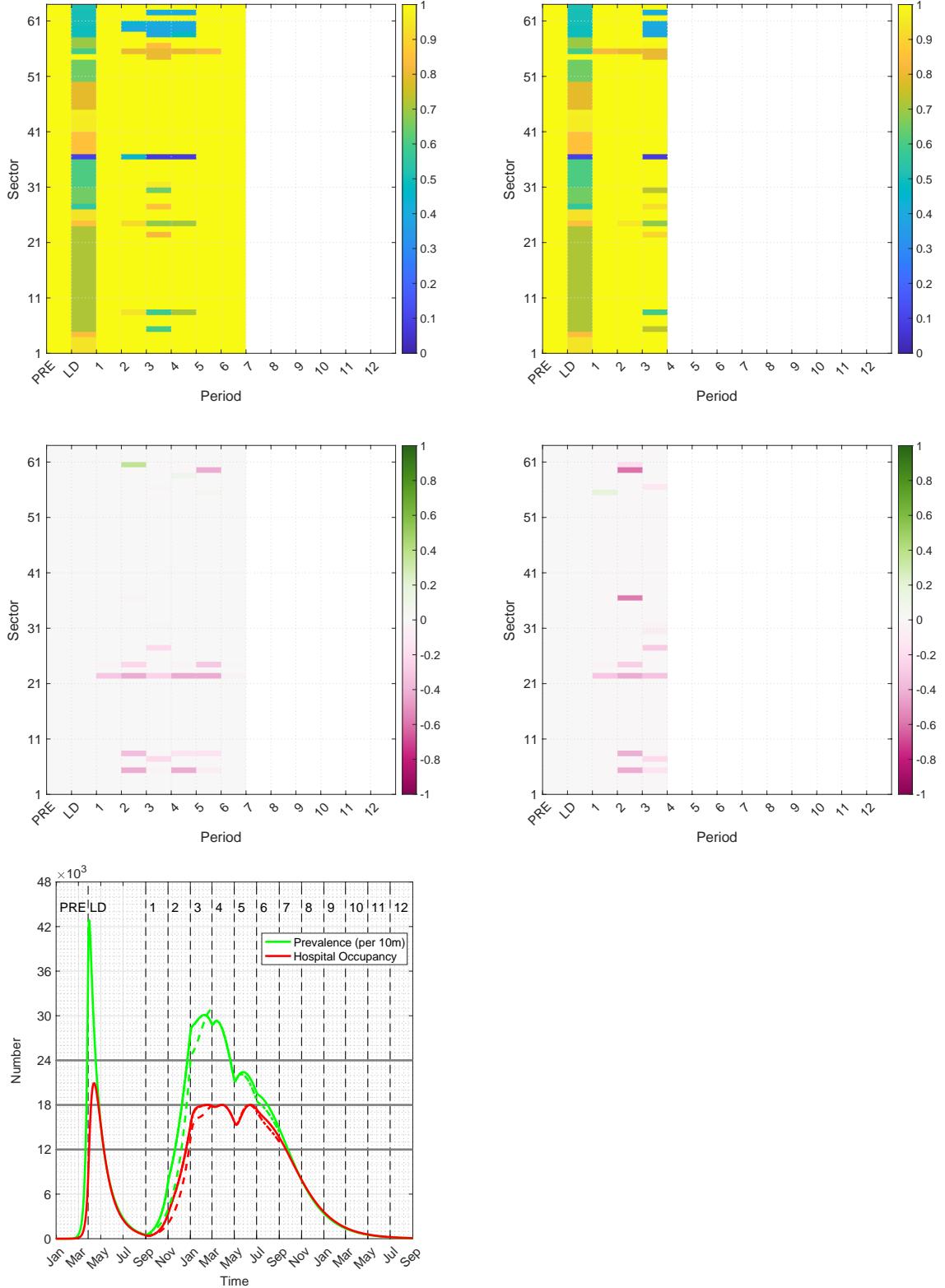


Figure S14: Optimal economic configurations under scenario B (education open), hospital capacity 18,000 beds: 12-month (top left) and 6-month (top right) planning horizons. The middle plots show the difference between the 24-month optimal configuration (figure S13) and the 12-month (middle left) and 6-month (middle right) optimal configurations. The bottom plot shows disease prevalence and hospital occupancy for 6- (dashed lines), 12- (dash-dotted lines) and 24- (solid lines) month configurations. The 24- and 12- month solutions are identical until June 2021, and that the 6-month solution is plotted only until March 2020.

Notes:  $0.8 \leq x_{\text{education}} \leq 1$ ;  $\delta = 0.72$  over planning horizon; 2-month decision periods.

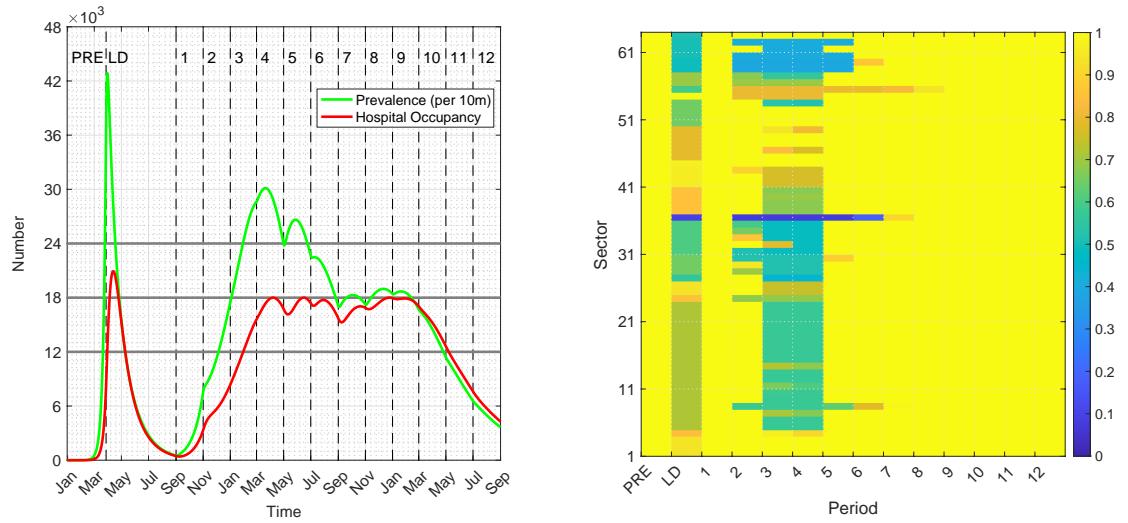


Figure S15: Optimal economic configuration under scenario B (education open), hospital capacity 18,000 beds: 24-month planning horizon with an increasing NPI modifier (decreasing adherence). The parameter  $\delta$  increases in equal steps from 0.72 to 1 over the 12 decision periods. GDP over 24 months £3,299bn.

Notes: Notes:  $0.8 \leq x_{education} \leq 1$ ; 2-month decision periods.

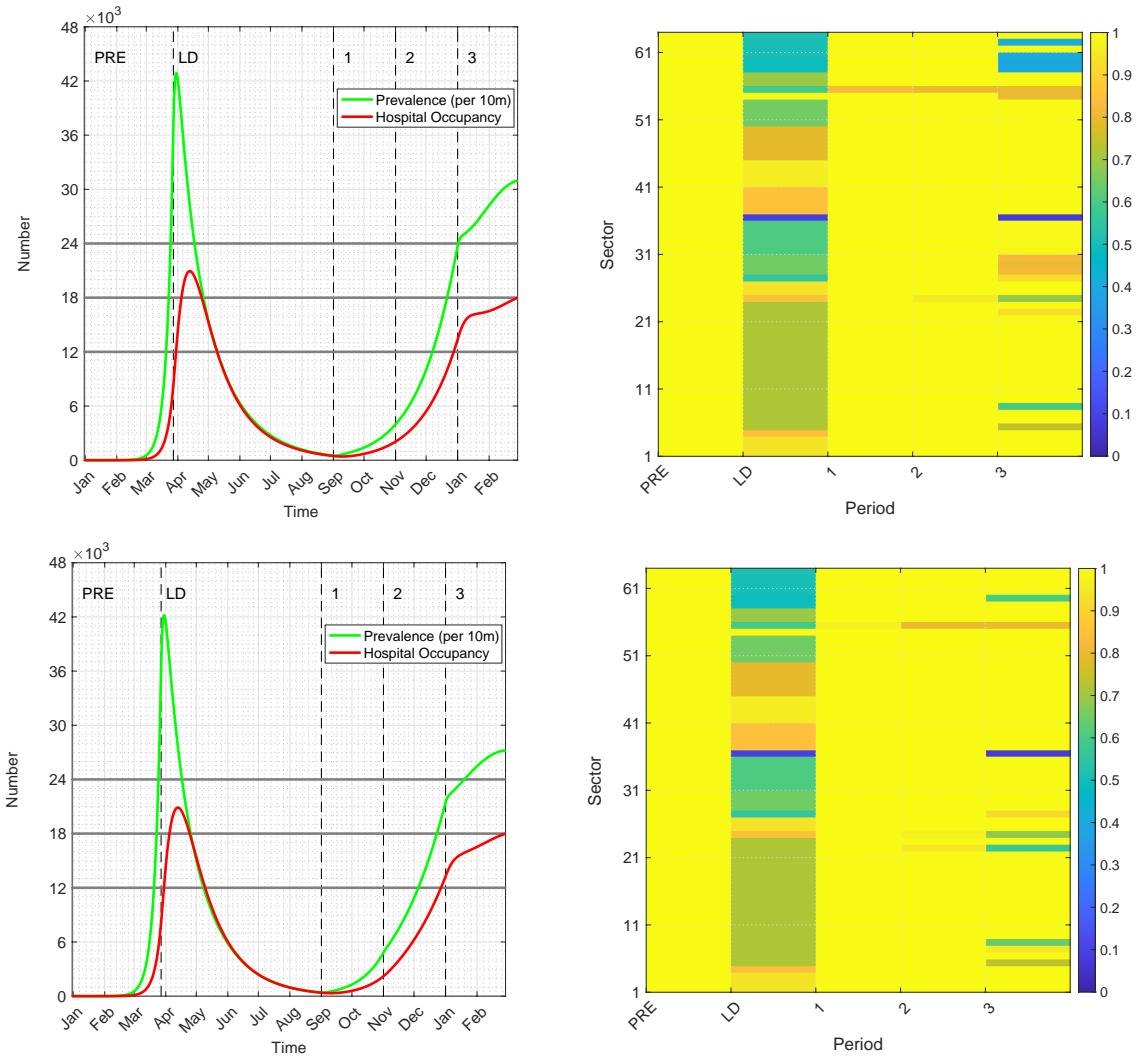


Figure S16: Optimal economic configuration under scenario B (education open), hospital capacity 18,000 beds: 6-month planning horizon, optimising for employment. Elasticity  $\alpha = 1$  (top row) and  $\alpha = 0.59$  (bottom).

Notes:  $0.8 \leq x_{education} \leq 1$ ;  $\delta = 0.72$  over planning horizon; 2-month decision periods. GDP over 6 months £852bn and £867bn respectively.

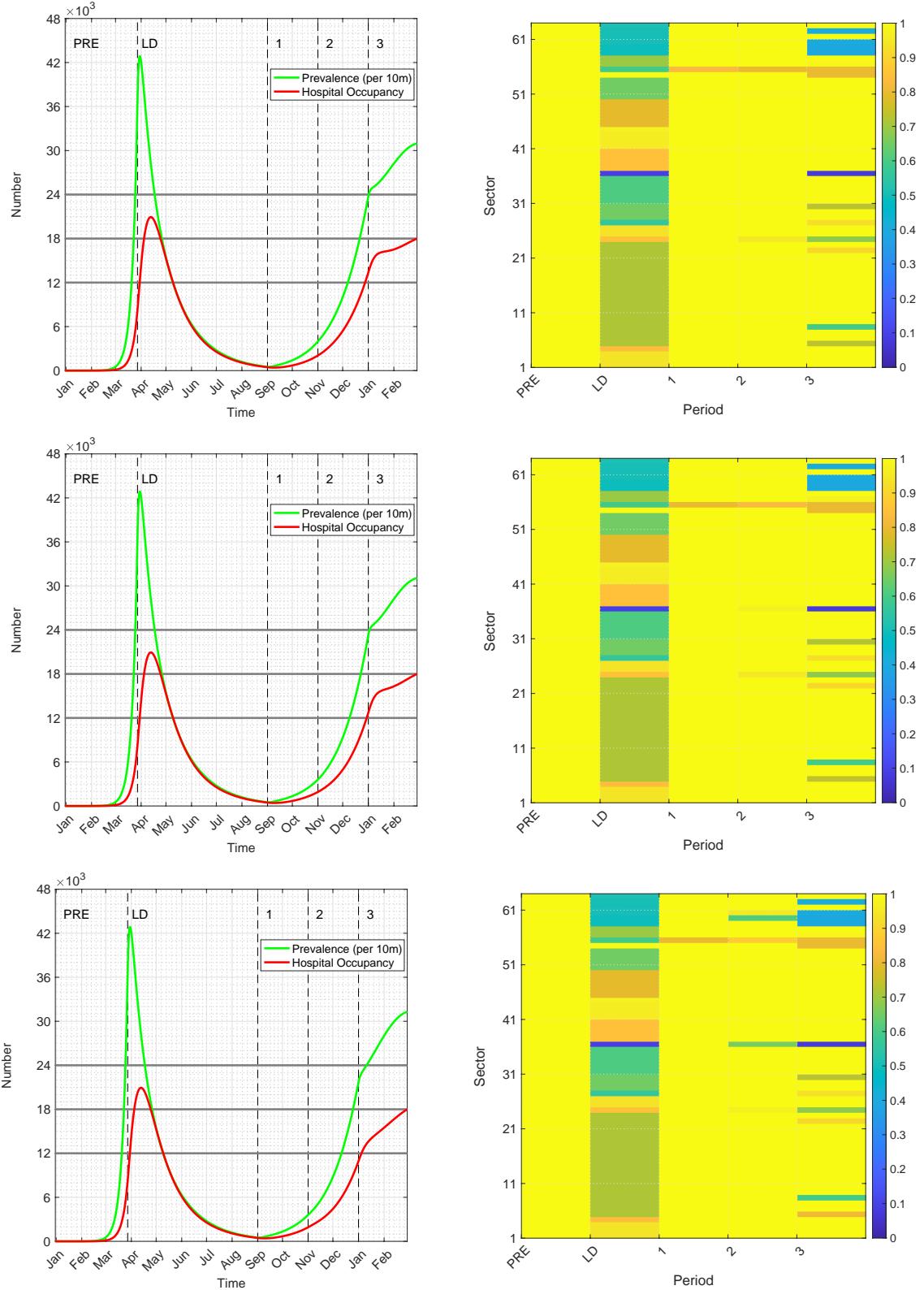


Figure S17: Optimal economic configuration under scenario B (education open), hospital capacity 18,000 beds: 6-month planning horizon, optimising for GDP less years of life lost (YLL) valued in monetary terms. The value of a statistical life year (VSL) is proportional to gross national income per capita (GNI pc): 50\*GNI pc (top row), 100\*GNI pc (middle), and 160\*GNI pc (bottom). GDP over 6 months £854bn, £853bn and £851bn respectively.

Notes:  $0.8 \leq x_{education} \leq 1$ ;  $\delta = 0.72$  over planning horizon; 2-month decision periods.

Table S1: Economic activities classified under Sector Industry Classification P (56 Education).

Code 85100: Pre-primary education	Church schools at nursery and primary level
List of activities classified inside the UK SIC	Hospital schools at nursery and primary level
Code 85100	
	Kindergartens
	Nursery schools
	Preprimary education
Code 85200: Primary education	Infant schools
List of activities classified inside the UK SIC	Junior schools
Code 85200	
	Middle schools deemed primary
	Preparatory schools
	Primary and preprimary education
	Primary education
	Primary schools
	Special schools at primary and preprimary level
Code 85310: General secondary education	Church schools at secondary level
List of activities classified inside the UK SIC	Sixth form colleges
Code 85310	
	Secondary schools
	Secondary modern schools
	Secondary level education
	School examination board
	Public schools
	Hospital schools at secondary level
	Grammar schools
	Convent schools at secondary level
	Comprehensive schools
	Special schools at secondary level
Code 85320: Technical and vocational secondary education	Agricultural college
List of activities classified inside the UK SIC	Management training establishment
Code 85320	
	Military school
	Music teacher (own account)
	Nautical school
	Royal Academy of Dramatic Art
	School of arts and crafts
	School of speech and drama
	Secretarial college
	Seminary

	Technical and vocational adult education (excl. cultural, sports, recreation education and the like)
	Technical and vocational education
	Technical and vocational secondary education
	Technical college
	Tertiary college
	Tourist guide instruction
	Tuition for ships licences for commercial certificates and permits
	Instruction for chefs, hoteliers and restaurateurs
	Government training centre
	Apprentice school
	Arts and crafts school
	Ballet school
	City and Guilds of London Institute
	Civil service college
	Tuition for ships licences for commercial certificates and permits
	Instruction for chefs, hoteliers and restaurateurs
	Government training centre
	Apprentice school
	Arts and crafts school
	Ballet school
	City and Guilds of London Institute
	Civil service college
Code 85410: Post-secondary non-tertiary education	College of nursing
List of activities classified inside the UK SIC Code 85410	Higher education (sub degree level)
	Postsecondary nontertiary vocational education
	School of languages
	Vocational education at postsecondary nontertiary level
Code 85421: First-degree level higher education	College of higher education (degree level)
List of activities classified inside the UK SIC Code 85421	University college
	University
	Universities Central Council on Admissions
	Theological college specialising in higher education course

	Study leading to a one year post graduate certificate of education (PGCE)
	Polytechnics
	Performing arts schools providing tertiary education
	Open University
	Military college
	Medical school
	Law college
	Higher education at the first degree level
	Graduate school for business studies
	Firstdegree level higher education
	Dental college or school
	Council for National Academic Awards
	Correspondence college specialising in higher education courses (degree level)
	University medical or dental school
Code 85422: Post-graduate level higher education	Higher education at postgraduate level
List of activities classified inside the UK SIC Code 85422	Postgraduate college
Code 85510: Sports and recreation education	Bridge instructor
List of activities classified inside the UK SIC Code 85510	Teachers of sport
	Swimming instruction
	Sports and recreation education
	Sport and game schools
	Ski instructor (own account)
	Riding school
	Martial arts instruction
	Instructors of sport
	Gymnastics instruction
	Coaches of sport
	Chess instructor
	Card game instruction
	Yoga instruction
Code 85520: Cultural education	Art instruction
List of activities classified inside the UK SIC Code 85520	Photography schools (except commercial)
	Performing arts schools (except academic)
	Fine arts schools (except academic)

	Dancing schools and dance instructor activities
	Dancing school
	Dancing master
	Dancing academy (ballroom)
	Cultural education
	Piano teachers and other music instruction
Code 85530: Driving school activities	Driving instruction
List of activities classified inside the UK SIC	Driving school activities
Code 85530	
	Flying school activities (not type rating)
	Flying schools not issuing commercial certificates and permits
	Sailing schools not issuing commercial certificates and permits
	School of motoring
	Ship licence tuition (not commercial certificates)
	Shipping schools not issuing commercial certificates and permits
Code 85590: Other education n.e.c.	Academic tutoring
List of activities classified inside the UK SIC	National institute for adult continuing education
Code 85590	
	Other adult and other education n.e.c.
	Private training providers
	Professional examination review courses
	Public speaking training
	Religious instruction
	Speed reading instruction
	Survival training
	Teacher n.e.c.
	Mentally handicapped adult training
	Lifeguard training
	Adult education centre
	Adult education residential college
	Computer training
	Continuation school
	Correspondence college (not leading to degree level qualifications)
	Council for Accreditation of Correspondence Colleges
	Day continuation school

	Language instruction and conversational skills instruction
	Learning centres offering remedial courses
	Workers Educational Association
Code 85600: Educational support activities	Educational consulting
List of activities classified inside the UK SIC Code 85600	Educational guidance counselling activities
	Educational support activities
	Educational testing activities
	Educational testing evaluation activities
	Organisation of student exchange programmes
	Scholastic agent
	School agent

Source: <https://www.siccode.co.uk/section/p>

Table S2: Average daily contacts in the community (A), worker-to-worker (B) and consumer-to-worker (C) for a fully-open economy by high-level industry sector grouping

	Matrix A: Community contacts	Matrix B: Worker-to-worker contacts	Matrix C: Consumer-to- worker contacts
<b>Community</b>			
0 – 4 years old	4.0		
5 – 19 years old	11.2		
20 – 64 years old	4.8		
65+ years old	3.3		
<b>Economic sectors</b>			
Agriculture [A]	6.0	0.5	0
Production [B-E]	6.0	3.5	0.5
Construction [F]	6.0	1.0	1.0
Distribution, transport, hotels and restaurants [G-I]	6.0	0.8	15.0
Information and communica- tion [J]	6.0	2.0	2.0
Financial and insurance [K]	6.0	3.8	6.5
Real estate [L]	6.0	3.8	6.5
Professional and support ac- tivities [M-N]	6.0	2.0	3.0
Government, health & educa- tion [O-Q]	6.0	0	30.0
Other services [R-T]	6.0	1.5	1.0

Note: the same contact rates were applied to all subsectors.

Table S3: Average number of contacts in the hospitality and education sectors, adjusted by age group.

Age group	Contact rate
Hospitality sector	
0 - 4	0.0
5 - 19	0.5
20 - 64	1.0
65+	1.5
Education sector	
0-4	1.4
5-19	6.2

Table S4: Epidemiological parameters.

Parameter	Explanation	Value	Reference
$R_0$	Basic reproductive number	2.75	Fitted (ONS hospitalisations)
$t_{LD}$	Start of first lockdown period in the UK (lockdown onset)	87.6062 (day of year) 28th March	Fitted (ONS hospitalisations)
$\delta_{LD}$	Effectiveness of first lockdown in reducing transmission	0.5650	Fitted (ONS hospitalisations)
$T_E = 1/\sigma$	Latent period	4.6	Knock et al. (2020)
$T_R^1 = 1/\gamma_1$	Infectious period (asymptomatic)	2.1	Knock et al. (2020)
$T_R^2 = 1/\gamma_2$	Infectious period (symptomatic)	4.2105 (0-4) 4.0088 (5-19) 4.1450 (20-64) 8.3947 (65+)	Knock et al. (2020)
$T_R^3 = 1/\gamma_3$	Duration of hospital stay (recovery)	11.2159 (0-4) 11.1878 (5-19) 11.5160 (20-64) 13.1442 (65+)	Knock et al. (2020)
R	Relative infectiousness of asymptomatic cases	0.58	Byambasuren et al. (2020)
$p_1$	Proportion of cases that are symptomatic	0.60	Knock et al. (2020)
H	Hospitalisation rate (determined from , proportion of sym cases hospitalised, and time to hospitalisation)	0.0111 (0-4) 0.0005 (5-19) 0.0078 (20-64) 0.1163 (65+)	Knock et al. (2020)
$\mu$	Death rate (determined from and duration of hospital stay leading to death)	0.0009 (0-4) 0.0007 (5-19) 0.0033 (20-64) 0.0140 (65+)	Knock et al. (2020)

Note: Knock et al. 2020 MRC GIDA report 41: The 2020 SARS-CoV-2 epidemic in England: key epidemiological drivers and impact of interventions; Byambasuren et al. 2020 Estimating the extent of asymptomatic COVID-19 and its potential for community transmission: Systematic review and meta-analysis

Table S5: Closures of the education sector under Scenarios A (GDP maximization) and LDA (lockdown).

LDA*	A: max occupancy 12,000 beds			A: max occupancy 18,000 beds			A: max occupancy 24,000 beds			Sector division	
	Sept/Oct	Nov/Dec	Jan/Feb	Sept/Oct	Nov/Dec	Jan/Feb	Sept/Oct	Nov/Dec	Jan/Feb		
0.59	0.86	0.54	0.48	1	0.48	0.48	1	0.56	0.53	56	Education

Note: shown are closures (1: open, 0: fully closed) of the education sector in percentage compared to pre-pandemic level of production; each column shows bi-monthly periods of fixed closures of the education sector; \*Under scenario LDA, the closure values for all sectors except for the education sector are the same as in LDB.

Table S6: Closures of economic sectors under Scenarios B (education open) and LDB (lockdown except education).

LDB	B (12,000)				B (18,000)				B (24,000)				Sectors	Sections and divisions	Descriptions
	Sept-Oct	Sept-Dec	Nov/Dec	Jan/Feb	Sept/Oct	Nov/Dec	Jan/Feb	Sept/Oct	Nov/Dec	Jan/Feb	[A]	1			
0.94	1	1	1	1	1	1	1	1	1	1	[A]	1	Crop and animal production, hunting and related service activities		
0.94	1	1	1	1	1	1	1	1	1	1	[A]	2	Forestry and logging		
0.94	1	1	1	1	1	1	1	1	1	1	[A]	3	Fishing and aquaculture		
0.84	1	1	1	1	1	1	1	1	1	1	[B-E]	4	Mining and quarrying		
0.72	1	1	0.86	1	1	0.73	1	1	0.73	[B-E]	5	Manufacture of food products, beverages and tobacco products			
0.72	1	1	1	1	1	1	1	1	1	[B-E]	6	Manufacture of textiles, wearing apparel and leather products			
0.72	1	1	1	1	1	1	1	1	0.98	[B-E]	7	Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials			
0.72	1	0.97	0.57	1	1	0.59	1	1	0.62	[B-E]	8	Manufacture of paper and paper products			
0.72	1	1	1	1	1	1	1	1	1	[B-E]	9	Printing and reproduction of recorded media			
0.72	1	1	1	1	1	1	1	1	1	[B-E]	10	Manufacture of coke and refined petroleum products			
0.72	1	1	1	1	1	1	1	1	1	[B-E]	11	Manufacture of chemicals and chemical products			
0.72	1	1	1	1	1	1	1	1	1	[B-E]	12	Manufacture of basic pharmaceutical products and pharmaceutical preparations			

0.72	1	1	1	1	1	1	1	1	[B-E]	13	Manufacture of rubber and plastic products	
0.72	1	1	1	1	1	1	1	1	[B-E]	14	Manufacture of other non-metallic mineral products	
0.72	1	1	1	1	1	1	1	1	[B-E]	15	Manufacture of basic metals	
0.72	1	1	1	1	1	1	1	1	[B-E]	16	Manufacture of fabricated metal products, except machinery and equipment	
0.72	1	1	1	1	1	1	1	1	[B-E]	17	Manufacture of computer, electronic and optical products	
0.72	1	1	1	1	1	1	1	1	[B-E]	18	Manufacture of electrical equipment	
0.72	1	1	1	1	1	1	1	1	[B-E]	19	Manufacture of machinery and equipment not, elsewhere, classified.	
0.72	1	1	1	1	1	1	1	1	[B-E]	20	Manufacture of motor vehicles, trailers and semi-trailers	
0.72	1	1	1	1	1	1	1	1	[B-E]	21	Manufacture of other transport equipment	
0.72	1	1	0.9	1	1	0.91	1	1	0.73	[B-E]	22	Manufacture of furniture; other manufacturing
0.72	1	1	1	1	1	1	1	1	[B-E]	23	Repair and installation of machinery and equipment	
0.85	1	1	0.68	1	0.95	0.68	1	0.96	0.68	[B-E]	24	Electricity, gas, steam and air conditioning supply
0.94	1	1	1	1	1	1	1	1	[B-E]	25	Water collection, treatment and supply	
0.94	1	1	1	1	1	1	1	1	[B-E]	26	Sewerage; waste collection, treatment and disposal activities; materials recovery; remediation activities and other waste management services	

0.56	1	1	0.94	1	1	0.93	1	1	0.92	[F]	27	Construction
0.65	1	1	0.63	1	1	1	1	1	1	[G-I]	28	Wholesale and retail trade and repair of motor vehicles and motorcycles
0.65	1	1	0.98	1	1	1	1	1	1	[G-I]	29	Wholesale trade, except of motor vehicles and motorcycles
0.65	1	1	0.52	1	1	0.73	1	1	1	[G-I]	30	Retail trade, except of motor vehicles and motorcycles
0.61	1	1	0.49	1	1	1	1	1	1	[G-I]	31	Land transport and transport via pipelines
0.61	1	1	1	1	1	1	1	1	1	[G-I]	32	Water transport
0.61	1	1	0.91	1	1	1	1	1	1	[G-I]	33	Air transport
0.61	1	1	0.64	1	1	1	1	1	1	[G-I]	34	Warehousing and support activities for transportation
0.61	1	1	0.53	1	1	1	1	1	1	[G-I]	35	Postal and courier activities
0.09	1	0.46	0.08	1	1	0.08	1	1	0.08	[G-I]	36	Accommodation and food service activities
0.85	1	1	1	1	1	1	1	1	1	[J]	37	Publishing activities
0.85	1	1	1	1	1	1	1	1	1	[J]	38	Motion picture, video and television programme production, sound recording and music publishing activities; programming and broadcasting activities
0.85	1	1	1	1	1	1	1	1	1	[J]	39	Telecommunications
0.85	1	1	1	1	1	1	1	1	1	[J]	40	Computer programming, consultancy and related activities; information service activities
0.96	1	1	1	1	1	1	1	1	1	[K]	41	Financial service activities, except insurance and pension funding

0.96	1	1	1	1	1	1	1	1	[K]	42	Insurance, reinsurance and pension funding, except compulsory social security
0.96	1	1	0.91	1	1	1	1	1	[K]	43	Activities auxiliary to financial services and insurance activities
0.97	1	1	1	1	1	1	1	1	[L]	44&45	Real estate activities & imputed rents of owner-occupied dwellings <sup>4</sup>
0.79	1	1	1	1	1	1	1	1	[M-N]	46	Legal and accounting activities; activities of head offices; management consultancy activities
0.79	1	1	1	1	1	1	1	1	[M-N]	47	Architectural and engineering activities; technical testing and analysis
0.79	1	1	1	1	1	1	1	1	[M-N]	48	Scientific research and development
0.79	1	1	1	1	1	1	1	1	[M-N]	49	Advertising and market research
0.79	1	1	1	1	1	1	1	1	[M-N]	50	Other professional, scientific and technical activities; veterinary activities
0.65	1	1	1	1	1	1	1	1	[M-N]	51	Rental and leasing activities
0.65	1	1	1	1	1	1	1	1	[M-N]	52	Employment activities
0.65	1	1	1	1	1	1	1	1	[M-N]	53	Travel agency, tour operator reservation service and related activities
0.65	1	1	1	1	1	1	1	1	[M-N]	54	Security and investigation activities; services to buildings and landscape activities; office administrative, office support and other business support activities
1.01	1.01	1.01	0.8	1.01	1.01	0.8	1.01	1.01	[O-Q]	55	Public administration and defence; compulsory social security
0.8	0.87	0.8	0.8	0.83	0.8	0.8	0.86	0.8	[O-Q]	56	Education

0.69	1	1	0.69	1	1	0.99	1	1	1	[O-Q]	57	Human health activities
0.69	1	1	0.66	1	1	1	1	1	1	[O-Q]	58	Social work activities
0.49	1	1	0.39	1	1	0.39	1	1	0.97	[R-T]	59	Creative, arts and entertainment activities; libraries, archives, museums and other cultural activities; gambling and betting activities
0.49	1	0.39	0.39	1	1	0.39	1	1	0.39	[R-T]	60	Sports activities and amusement and recreation activities
0.51	1	0.57	0.4	1	1	0.4	1	1	0.4	[R-T]	61	Activities of membership organisations
0.51	1	1	1	1	1	1	1	1	1	[R-T]	62	Repair of computers and personal and household goods
0.51	1	1	0.4	1	1	0.4	1	1	0.4	[R-T]	63	Other personal service activities
0.51	1	1	1	1	1	1	1	1	1	[R-T]	64	Activities of households as employers; undifferentiated goods- and services-producing activities of households for own use

Note: shown are closures (1: open, 0: fully closed) of all economic sector in percentage compared to pre-pandemic level of production under scenarios B and LDB; The two months denote periods of fixed economic configurations required under scenario B; the education is open at 80% pre-pandemic production under scenario B; \*Under scenario LDA, the closure values for all sectors except for the education sector are the same as in LDB, see Tab. S3.

Table S7: Total hospital bed days from September to February

Scenario	Total bed days
LDA	55,283
A, $\underline{H} = 12,000$	1,032,144
A, $\underline{H} = 18,000$	1,525,885
A, $\underline{H} = 24,000$	1,817,212
LDB	223,880
B, $\underline{H} = 12,000$	1,057,365
B, $\underline{H} = 18,000$	1,404,549
B, $\underline{H} = 24,000$	1,667,348
FO	5,344,024

Note: Cumulate bed days of COVID-19 patients over the intervention period under all scenarios.

Table S8: Loss in Gross Value Added under all scenarios.

LDA	LDB	A	A	A	B	B	B	B	B	Sections and division	Sector description
313	313	0	0	0	0	0	0	0	0	[A]	Crop and animal production, hunting and related service activities
15	15	0	0	0	0	0	0	0	0	[A]	Forestry and logging
16	16	0	0	0	0	0	0	0	0	[A]	Fishing and aquaculture
797	797	0	0	0	0	0	0	0	0	[B-E]	Mining and quarrying
3815	3815	1868	2114	2146	641	1200	1200	1129	44	[B-E]	Manufacture of food products, beverages and tobacco products
742	742	0	0	0	0	0	0	0	0	[B-E]	Manufacture of textiles, wearing apparel and leather products
476	476	34	54	63	0	0	14	0	0	[B-E]	Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials
663	663	316	310	303	355	316	296	313	372	[B-E]	Manufacture of paper and paper products
586	586	0	0	0	0	0	0	0	0	[B-E]	Printing and reproduction of recorded media
280	280	0	0	0	0	0	0	0	0	[B-E]	Manufacture of coke and refined petroleum products
1620	1620	0	0	0	0	0	0	0	0	[B-E]	Manufacture of chemicals and chemical products

1629	1629	0	0	0	0	0	0	0	0	[B-E]	12	Manufacture of basic pharmaceutical products and pharmaceutical preparations
1069	1069	0	0	0	0	0	0	0	0	[B-E]	13	Manufacture of rubber and plastic products
797	797	0	0	0	0	0	0	0	0	[B-E]	14	Manufacture of other non-metallic mineral products
592	592	0	0	0	0	0	0	0	0	[B-E]	15	Manufacture of basic metals
2037	2037	0	0	0	0	0	0	0	0	[B-E]	16	Manufacture of fabricated metal products, except machinery and equipment
1789	1789	0	0	0	0	0	0	0	0	[B-E]	17	Manufacture of computer, electronic and optical products
661	661	0	0	0	0	0	0	0	0	[B-E]	18	Manufacture of electrical equipment
1528	1528	0	0	0	0	0	0	0	0	[B-E]	19	Manufacture of machinery and equipment not elsewhere classified.
2165	2165	0	0	0	0	0	0	0	0	[B-E]	20	Manufacture of motor vehicles, trailers and semi-trailers
1274	1274	0	0	0	0	0	0	0	0	[B-E]	21	Manufacture of other transport equipment
1103	1103	813	1196	1358	123	120	353	128	104	[B-E]	22	Manufacture of furniture; other manufacturing
1569	1569	0	0	0	0	0	0	0	0	[B-E]	23	Repair and installation of machinery and equipment

1906	1906	1439	1388	1370	1390	1580	1526	1575	1302	[B-E]	24	Electricity, gas, steam and air conditioning supply
221	221	0	0	0	0	0	0	0	0	[B-E]	25	Water collection, treatment and supply
469	469	0	0	0	0	0	0	0	0	[B-E]	26	Sewerage; waste collection, treatment and disposal activities; materials recovery; remediation activities and other waste management services
24100	24100	1442	1538	1606	1067	1308	1482	1342	850	[F]	27	Construction
5218	5218	0	0	0	1831	0	0	0	2388	[G-I]	28	Wholesale and retail trade and repair of motor vehicles and motorcycles
13101	13101	0	0	0	246	0	0	0	2313	[G-I]	29	Wholesale trade, except of motor vehicles and motorcycles
15095	15095	0	0	0	6906	3871	0	3012	8178	[G-I]	30	Retail trade, except of motor vehicles and motorcycles
5762	5762	0	0	0	2513	0	0	177	2513	[G-I]	31	Land transport and transport via pipelines
1156	1156	0	0	0	0	0	0	0	0	[G-I]	32	Water transport
941	941	0	0	0	68	0	0	0	197	[G-I]	33	Air transport
3875	3875	0	0	0	1179	0	0	0	1560	[G-I]	34	Warehousing and support activities for transportation
2507	2507	0	0	0	995	0	0	0	1094	[G-I]	35	Postal and courier activities
28806	28806	2877	330	0	15508	9801	9801	10527	21457	[G-I]	36	Accommodation and food service activities

885	885	0	0	0	0	0	0	0	0	[J]	37	Publishing activities
1264	1264	0	0	0	0	0	0	0	0	[J]	38	Motion picture, video and television programme production, sound recording and music publishing activities; programming and broadcasting activities
2175	2175	0	0	0	0	0	0	0	0	[J]	39	Telecommunications
4088	4088	0	0	0	0	0	0	0	0	[J]	40	Computer programming, consultancy and related activities; information service activities
1396	1396	0	0	0	0	0	0	0	0	[K]	41	Financial service activities, except insurance and pension funding
533	533	0	0	0	0	0	0	0	0	[K]	42	Insurance, reinsurance and pension funding, except compulsory social security
444	444	0	0	0	343	0	0	0	854	[K]	43	Activities auxiliary to financial services and insurance activities
3779	3779	0	0	0	0	0	0	0	0	[L]	44&	Real estate activities & imputed rents of owner-occupied dwellings <sup>4</sup>
6897	6897	0	0	0	0	0	0	0	0	[M-N]	46	Legal and accounting activities; activities of head offices; management consultancy activities
2185	2185	0	0	0	0	0	0	0	0	[M-N]	47	Architectural and engineering activities; technical testing and analysis
2160	2160	0	0	0	0	0	0	0	0	[M-N]	48	Scientific research and development

2520	2520	0	0	0	0	0	0	0	0	[M-N]	49	Advertising and market research
1549	1549	0	0	0	0	0	0	0	0	[M-N]	50	Other professional, scientific and technical activities; veterinary activities
3989	3989	0	0	0	0	0	0	0	0	[M-N]	51	Rental and leasing activities
4642	4642	0	0	0	0	0	0	0	0	[M-N]	52	Employment activities
1666	1666	0	0	0	0	0	0	0	0	[M-N]	53	Travel agency, tour operator reservation service and related activities
6049	6049	0	0	0	0	0	0	0	0	[M-N]	54	Security and investigation activities; services to buildings and landscape activities; office administrative, office support and other business support activities
0	0	0	0	0	0	3020	3020	0	1915	4466	[O-Q]	55
19589	9655	17995	16856	14661	8455	9214	8748	9655	9655	[O-Q]	56	Public administration and defence; compulsory social security
13718	13718	0	0	4573	214	0	1375	4573	4573	[O-Q]	57	Human health activities*
6285	6285	0	0	0	2316	0	0	0	3048	[O-Q]	58	Social work activities
4070	4070	0	0	1621	1621	81	811	1621	1621	[R-T]	59	Creative, arts and entertainment activities; libraries, archives, museums and other cultural activities; gambling and betting activities
2523	2523	1005	519	246	2010	1005	1005	2010	2010	[R-T]	60	Sports activities and amusement and recreation activities
1777	1777	0	0	0	1226	714	714	714	1427	[R-T]	61	Activities of membership organisations

613	613	0	0	0	0	0	0	0	0	[R-T]	62	Repair of computers and personal and household goods
4476	4476	0	0	0	1797	1797	1797	1260	1797	[R-T]	63	Other personal service activities
1206	1206	0	0	0	0	0	0	0	0	[R-T]	64	Activities of households as employers; undifferentiated goods- and services-producing activities of households for own use
229171	219237	27789	24305	21753	58183	35781	27017	34938	71823			total GVA loss (compared to FO)

Note: For all scenarios GVA loss is reported in £ millions against a fully open economy (FO);

In scenario A any economic sector -including the education sector- may be closed down to 80% of observed closure during the lockdown period but not lower to sustain essential services;

in scenario B the education sector is open at 80% throughout and all other sectors may be closed down to 80% of observed closure during the lockdown period;

in scenario LDA all economic sectors are closed to levels observed closure during the lockdown period March - May 2020;

in scenario LDB all economic sectors except for the education sector are closed to levels of observed closure during the lockdown period and the education sector is operational at 80%;

three alternative assumptions on spare emergency hospital capacity for COVID-19 patients in scenarios A and B (12,000, 18,000, 24,000);

all scenarios assume changes in economic configuration every 2 months except for B (6x1, 18,000) which allows changes every month;

all scenarios including FO assume that stringency of NPIs and self-productive behavior reduce transmission substantially ( $\delta=0.72$  except for scenario B ( $\delta=0.76$ , 18,000) which assumes weak stringency of non-pharmaceutical interventions and/or little self-protective behavior in the population.

\*Measuring the GVA contribution of education and human health activities is problematic (Schreyer, Paul. 2010. Towards Measuring the Volume Output of Education and Health Services. Paris: OECD. doi:<https://doi.org/10.1787/5kmd34g1zk9x-en>)

Table S9: Closures of economic sectors under weak stringency of non-pharmaceutical interventions ( $\delta=0.76$ ), Scenario B (education open),  $H=18,000$ .

Sept/Oct	Nov/Dec	Jan/Feb	Section	Division Description
		[A]	1	Crop and animal production, hunting and related service activities
1	1	1	[A]	2 Forestry and logging
1	1	1	[A]	3 Fishing and aquaculture
1	1	1	[B-E]	4 Mining and quarrying
1	1	0.99	[B-E]	5 Manufacture of food products, beverages and tobacco products
1	1	1	[B-E]	6 Manufacture of textiles, wearing apparel and leather products
1	1	1	[B-E]	7 Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials
1	0.95	0.57	[B-E]	8 Manufacture of paper and paper products
1	1	1	[B-E]	9 Printing and reproduction of recorded media
1	1	1	[B-E]	10 Manufacture of coke and refined petroleum products
1	1	1	[B-E]	11 Manufacture of chemicals and chemical products
1	1	1	[B-E]	12 Manufacture of basic pharmaceutical products and pharmaceutical preparations
1	1	1	[B-E]	13 Manufacture of rubber and plastic products
1	1	1	[B-E]	14 Manufacture of other non-metallic mineral products
1	1	1	[B-E]	15 Manufacture of basic metals
1	1	1	[B-E]	16 Manufacture of fabricated metal products, except machinery and equipment

1	1	1	[B-E]	17	Manufacture of computer, electronic and optical products
1	1	1	[B-E]	18	Manufacture of electrical equipment
1	1	1	[B-E]	19	Manufacture of machinery and equipment not elsewhere classified.
1	1	1	[B-E]	20	Manufacture of motor vehicles, trailers and semi-trailers
1	1	1	[B-E]	21	Manufacture of other transport equipment
1	1	0.92	[B-E]	22	Manufacture of furniture; other manufacturing
1	1	1	[B-E]	23	Repair and installation of machinery and equipment
1	1	0.7	[B-E]	24	Electricity, gas, steam and air conditioning supply
1	1	1	[B-E]	25	Water collection, treatment and supply
1	1	1	[B-E]	26	Sewerage; waste collection, treatment and disposal activities; materials recovery; remediation activities and other waste management services
1	1	0.95	[F]	27	Construction
1	1	0.52	[G-I]	28	Wholesale and retail trade and repair of motor vehicles and motorcycles
1	1	0.82	[G-I]	29	Wholesale trade, except of motor vehicles and motor-cycles
1	0.91	0.52	[G-I]	30	Retail trade, except of motor vehicles and motorcycles
1	1	0.49	[G-I]	31	Land transport and transport via pipelines
1	1	1	[G-I]	32	Water transport
1	1	0.75	[G-I]	33	Air transport
1	1	0.53	[G-I]	34	Warehousing and support activities for transportation
1	1	0.49	[G-I]	35	Postal and courier activities

0.82	0.08	0.08	[G-I]	36	Accommodation and food service activities
1	1	1	[J]	37	Publishing activities
1	1	1	[J]	38	Motion picture, video and television programme production, sound recording and music publishing activities; programming and broadcasting activities
1	1	1	[J]	39	Telecommunications
1	1	1	[J]	40	Computer programming, consultancy and related activities; information service activities
1	1	1	[K]	41	Financial service activities, except insurance and pension funding
1	1	1	[K]	42	Insurance, reinsurance and pension funding, except compulsory social security
1	1	0.77	[K]	43	Activities auxiliary to financial services and insurance activities
1	1	1	[L]	44&45	Real estate activities & imputed rents of owner-occupied dwellings <sup>42</sup>
1	1	1	[M-N]	46	Legal and accounting activities; activities of head offices; management consultancy activities
1	1	1	[M-N]	47	Architectural and engineering activities; technical testing and analysis
1	1	1	[M-N]	48	Scientific research and development
1	1	1	[M-N]	49	Advertising and market research
1	1	1	[M-N]	50	Other professional, scientific and technical activities; veterinary activities
1	1	1	[M-N]	51	Rental and leasing activities
1	1	1	[M-N]	52	Employment activities

1	1	1	[M-N]	53	Travel agency, tour operator reservation service and related activities
1	1	1	[M-N]	54	Security and investigation activities; services to buildings and landscape activities; office administrative, office support and other business support activities
1	0.91	0.8	[O-Q]	55	Public administration and defence; compulsory social security
0.8	0.8	0.8	[O-Q]	56	Education*
1	1	0.69	[O-Q]	57	Human health activities*
1	1	0.56	[O-Q]	58	Social work activities
1	1	0.39	[R-T]	59	Creative, arts and entertainment activities; libraries, archives, museums and other cultural activities; gambling and betting activities
1	0.39	0.39	[R-T]	60	Sports activities and amusement and recreation activities
1	0.4	0.4	[R-T]	61	Activities of membership organisations
1	1	1	[R-T]	62	Repair of computers and personal and household goods
1	1	0.4	[R-T]	63	Other personal service activities
1	1	1	[R-T]	64	Activities of households as employers; undifferentiated goods- and services-producing activities of households for own use

Table S10: Workforce, total output, gross value added, and intermediate use and provision for 63 sectors, United Kingdom 2016.

UK Standard Industry Classification (SIC)	Standard Industry Classification (SIC) description	Classification (head-count)	Workforce (head-count)	Total output at basic prices (£ million)	Gross value added (£ million) <sup>1</sup>	Intermediate use as % output <sup>2</sup>	Intermediate provision as % output <sup>3</sup>
sections	divisions						
[A]	A	1	Crop and animal production, hunting and related service activities	275,986	24,120	10,055	0.59
[A]	A	2	Forestry and logging	18,131	1,344	477	0.44
[A]	A	3	Fishing and aquaculture	8,031	1,737	519	0.52
[B-E]	B	4	Mining and quarrying	96,622	28,797	10,075	0.47
[B-E]	C	5	Manufacture of food products, beverages and tobacco products	338,012	84,489	26,877	0.63
[B-E]	C	6	Manufacture of textiles, wearing apparel and leather products	70,706	10,507	5,231	0.39
[B-E]	C	7	Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials	54,489	6,684	3,354	0.34
[B-E]	C	8	Manufacture of paper and paper products	36,998	11,303	4,669	0.38
[B-E]	C	9	Printing and reproduction of recorded media	85,513	8,908	4,130	0.33
[B-E]	C	10	Manufacture of coke and refined petroleum products	18,773	19,875	1,974	0.22
							0.50

[B-E]	C	11	Manufacture of chemicals and chemical products	90,578	31,456	11,416	0.42	0.47
[B-E]	C	12	Manufacture of basic pharmaceutical products and pharmaceutical preparations	110,504	19,622	11,474	0.34	0.32
[B-E]	C	13	Manufacture of rubber and plastic products	120,505	20,633	7,533	0.37	0.65
[B-E]	C	14	Manufacture of other non-metallic mineral products	75,767	14,455	5,617	0.43	0.87
[B-E]	C	15	Manufacture of basic metals	62,633	14,587	4,170	0.40	0.84
[B-E]	C	16	Manufacture of fabricated metal products, except machinery and equipment	215,088	30,472	14,350	0.37	0.72
[B-E]	C	17	Manufacture of computer, electronic and optical products	144,594	21,174	12,605	0.38	0.44
[B-E]	C	18	Manufacture of electrical equipment	61,783	11,812	4,657	0.48	0.69
[B-E]	C	19	Manufacture of machinery and equipment not elsewhere classified	271,284	26,037	10,769	0.43	0.45
[B-E]	C	20	Manufacture of motor vehicles, trailers and semi-trailers	168,260	56,271	15,255	0.39	0.17
[B-E]	C	21	Manufacture of other transport equipment	170,185	28,932	8,975	0.61	0.34
[B-E]	C	22	Manufacture of furniture; other manufacturing	149,678	15,906	7,768	0.51	0.27
[B-E]	C	23	Repair and installation of machinery and equipment	202,188	24,204	11,058	0.41	0.93

[B-E]	D	24	Electricity, gas, steam and air conditioning supply	164,418	113,001	25,932	0.70	0.75
[B-E]	E	25	Water collection, treatment and supply	55,616	9,653	6,835	0.28	0.50
[B-E]	E	26	Sewerage; waste collection, treatment and disposal activities; materials recovery; remediation activities and other waste management services	108,686	28,328	14,525	0.37	0.47
[F]	F	27	Construction	2,253,195	273,756	108,902	1.18	0.97
[G-I]	G	28	Wholesale and retail trade and repair of motor vehicles and motorcycles	472,742	52,252	29,882	0.39	0.40
[G-I]	G	29	Wholesale trade, except of motor vehicles and motorcycles	746,139	146,245	75,022	0.42	0.54
[G-I]	G	30	Retail trade, except of motor vehicles and motorcycles	2,764,702	137,525	86,436	0.34	0.18
[G-I]	H	31	Land transport and transport via pipelines	739,338	62,340	29,304	0.45	0.70
[G-I]	H	32	Water transport	33,849	14,406	5,878	0.28	0.20
[G-I]	H	33	Air transport	63,149	22,531	4,787	0.45	0.55
[G-I]	H	34	Warehousing and support activities for transportation	371,528	41,213	19,711	0.49	0.78
[G-I]	H	35	Postal and courier activities	289,632	23,003	12,752	0.38	0.89
[G-I]	I	36	Accommodation and food service activities	1,725,001	120,457	63,576	0.41	0.17

[J]	J	37	Publishing activities	166,948	21,437	11,680	0.77	0.13
[J]	J	38	Motion picture, video and television programme production, sound recording and music publishing activities; programming and broadcasting activities	144,366	32,571	16,684	0.44	0.21
[J]	J	39	Telecommunications	160,904	45,181	28,715	0.24	0.47
[J]	J	40	Computer programming, consultancy and related activities; information service activities	764,447	88,744	53,962	0.44	0.80
[K]	K	41	Financial service activities, except insurance and pension funding	533,535	136,155	69,367	0.36	0.50
[K]	K	42	Insurance, reinsurance and pension funding, except compulsory social security	203,686	76,983	26,463	0.50	0.33
[K]	K	43	Activities auxiliary to financial services and insurance activities	479,385	35,271	22,066	0.29	0.27
[L]	L	44 & 45	Real estate activities & imputed rents of owner-occupied dwellings <sup>4</sup>	356,573	342,566	261,164	0.22	0.13
[M-N]	M	46	Legal and accounting activities; activities of head offices; management consultancy activities	1,065,069	100,641	65,533	0.30	0.69
[M-N]	M	47	Architectural and engineering activities; technical testing and analysis	590,015	41,080	20,766	0.51	0.69
[M-N]	M	48	Scientific research and development	119,815	42,019	20,527	1.20	0.50
[M-N]	M	49	Advertising and market research	187,546	37,152	23,946	0.30	0.85

[M-N]	M	50	Other professional, scientific and technical activities; veterinary activities	380,865	28,206	14,717	0.42	0.69
[M-N]	N	51	Rental and leasing activities	91,184	35,517	22,942	0.32	0.65
[M-N]	N	52	Employment activities	195,730	38,772	26,697	0.27	0.94
[M-N]	N	53	Travel agency, tour operator reservation service and related activities	96,562	24,212	9,581	0.57	0.32
[M-N]	N	54	Security and investigation activities; services to buildings and landscape activities; office administrative, office support and other business support activities	975,323	65,991	34,791	0.39	0.62
[O-Q]	O	55	Public administration and defence; compulsory social security	2,090,939	151,354	85,641	0.34	0.09
[O-Q]	P	56	Education	3,361,071	137,275	96,552	0.26	0.17
[O-Q]	Q	57	Human health activities	3,301,334	150,841	89,847	0.30	0.02
[O-Q]	Q	58	Social work activities	953,764	67,935	41,164	0.35	0.15
[R-T]	R	59	Creative, arts and entertainment activities; libraries, archives, museums and other cultural activities; gambling and betting activities	346,487	30,486	16,079	0.40	0.18
[R-T]	R	60	Sports activities and amusement and recreation activities	420,269	16,953	9,964	0.35	0.06
[R-T]	S	61	Activities of membership organisations	324,534	12,566	7,189	0.39	0.16

[R-T]	S	62	Repair of computers and personal and household goods	84,930	3,703	2,481	0.25	0.57
[R-T]	S	63	Other personal service activities	437,946	24,036	18,104	0.18	0.13
[R-T]	T	64	Activities of households as employers; undifferentiated goods- and services-producing activities of households for own use	82,486	4,961	4,961	0.00	0.00

Notes: <sup>1</sup> we maximize monthly gross value added in the optimization, i.e. annual GVA divided by 12;

<sup>2</sup>intermediate use excludes use of imports and excludes taxes (less subsidies) on products;

<sup>3</sup> intermediate provision excludes exports and gross capital formation;

<sup>4</sup> Sectors 44 and 45 are combined.

Table S11: Observed production and labor market changes during lockdown in the United Kingdom (March-May 2020).

Standard Industry Classification (SIC) sections	SIC sections	SIC divisions	Proportion working from home <sup>1</sup>	Proportion of sector open ( $x_i^{LD}$ ) <sup>2</sup>
Agriculture [A]	A	1-3	0.47	0.94
Production [B-E]	B	4-26	0.47	0.84
	C		0.27	0.72
	D		0.47	0.85
	E		0.26	0.94
Construction [F]	F	27	0.36	0.56
Distribution, transport, hotels and restaurants [G-I]	G	28-36	0.36	0.65
	H		0.47	0.61
	I		0.17	0.09
Information and communication [J]	J	37-40	0.23	0.85
Financial and insurance [K]	K	41-43	0.47	0.96
Real estate [L]	L	44, 45	0.47	0.97
Professional and support activities [M-N]	M	46-54	0.86	0.79
	N		0.78	0.65
Government, health & education [O-Q]	O	55-58	0.47	1.00
	P		0.40	0.59
	Q		0.77	0.69
Other services [R-T]	R	59-64	0.30	0.49
	S		0.47	0.51
	T		0.57	0.51

Notes: <sup>1</sup>from the ONS ‘Business Impact of COVID-19 Survey’ (BICS) <https://www.ons.gov.uk/economy/economicoutputandproductivity/output/datasets/businessimpactofcovid19surveybicsresults>; the proportion working from home do not contribute to transmission at the workplace

<sup>2</sup> from the surveys conducted by the ONS for the monthly GDP estimate, see <https://www.ons.gov.uk/economy/grossdomesticproductgdp/bulletins/gdpmonthlyestimateuk/latest>; and <https://www.ons.gov.uk/economy/grossdomesticproductgdp/methodologies/grossdomesticproductgdpqmi>. For the lower bound in the optimization problem, we reduced surveyed lockdown values of production  $x_i^{LD}$  for all higher-level sectors except healthcare by 20% to account for misreporting and changes in production processes in reaction to the pandemic.

Table S12: Assumption on maximum emergency spare hospital capacity for the treatment of COVID-19 patients in the United Kingdom, 2020.

<u>H</u>	Explanation and reference
12,000	<u>H</u> reduced by one-third (-6000) of the maximum number of COVID-19 patients occupying hospital beds in England during the first peak in April 2020
18,000	<u>H</u> the same as the maximum number of COVID-19 patients occupying hospital beds in England during the first peak in April 2020
24,000	<u>H</u> increased by one-third (+6000) of the maximum number of COVID-19 patients occupying hospital beds in England during the first peak in April 2020

Table S13: Mapping of French into UK Business Sectors as defined in the UK IO tables.

French Business Sector	UK Business Sector
Agriculture, sylviculture, pêche	Agriculture [A]
Industrie agricole et alimentaire	Production [B-E]
Autre industrie*	Other services [R-T] + Information & communication [J]
Énergie	Production [B-E]
Construction	Construction [F]
Commerce	Distribution, transport, hotels and restaurants [G-I]
Activités financières et immobilières**	Financial and insurance [K] + real estate [L]
Services aux entreprises	Professional and support activities [M-N]
Services aux personnes*	Other services [R-T]
Éducation, santé, action social	Government, health & education [O-Q]
Administration	Professional and support activities [M-N]

Table S14: Construction of contact matrices from survey data.

Contact matrix	Definition and inclusion/exclusion criteria
A: community contacts	<ul style="list-style-type: none"> <li>• Any contact made at home, in a vehicle or other private place, retail outlet, public transport, leisure facilities, with loved ones in a closed place (“Chez des proches en lieux clos”), open place (park, street)</li> <li>• Disaggregated by age group (0 – 4; 5 – 19; 20 – 64; 65+)</li> <li>• Consumer-consumer contacts are added with respect to the proportion the hospitality and education sectors are opened</li> </ul>
B: Worker-to-worker contacts	<ul style="list-style-type: none"> <li>• Contacts made at work (office, studio, etc.) and which are reported to be made (almost) every day, or a few times per week</li> <li>• Disaggregated by sector</li> <li>• Individuals who stated that they are in employment</li> <li>• Individuals who are of working age (19 – 64)</li> </ul>
C: Consumers-to-worker contacts	<ul style="list-style-type: none"> <li>• Contacts made at work (office, studio, etc.) and which are reported to be a few times per month, a few times per year or less often, for the first time</li> <li>• Disaggregated by sector</li> <li>• Individuals who stated that they are in employment</li> <li>• Individuals who are of working age (19 – 64)</li> <li>• If more than 20 contacts are made by the individual, the survey respondent could state the total number of contacts made instead of listing all individual contacts. If this was the case, this number was used instead of the sum of individual contacts made</li> </ul>

## Methods S1: Construction of Contact Matrices

There are three ways we model reduction in transmission due to sector closures:

1. Moving individuals into a different compartment, and scaling the number of contacts linearly
2. Scaling contacts superlinearly only
3. Scaling contacts linearly only

and there are five scenarios where transmission is reduced:

- Worker absence due to sector closure (uses method 1)
- Worker absence due to working from home (uses method 2)
- Student absence due to school closure (uses method 3)
- Customer absence due to sector closure: impact on workers (uses method 1)
- Customer absence due to sector closure: impact on customers (uses method 3)

(1) Recall that the number of infections is proportional to susceptible times contact rate times proportion of population infectious ( $S_i * M_{i,j} * I_j / P_j$ ). When the number of people is reduced, the number of infections is reduced via both the number of people at risk ( $S_i$ ) and the number of contacts per person ( $M_{i,j}$ ). This is precisely how we model worker absence due to sector closure: the number of contacts per person is reduced according to the fraction who remain in the workplace, and the number susceptible are likewise reduced by redistributing workers according to the closure schedule. The result is superlinear scaling with respect to closure. The same method applies for worker contacts while travelling and worker contact with the general population.

(2) For the other type of worker absence, working from home, we do not move any people from their compartmental group, so we compensate by reducing the number of contacts further by the amount the compartment would have reduced to, i.e. the proportion of workers who remain ( $1 - p_{i,\tau}$ ). The same method applies for worker contacts while travelling.

(3) When workers work from home, each member of the population should interact with fewer workers each, which we approximate by scaling the number of contacts  $c_i$  down by  $(1 - p_{i,\tau})$ . This scaling is linear, reflecting that only the number of contacts per person changes, not the number of people making contacts.

Likewise, the linear scalings reflect fewer contacts per person in schools and hospitality settings, but we retain the same numbers of people who make contacts at all.

Contact matrices between groups  $i$  and  $j$  detail the number of contacts per day a person in group  $i$  expects to make with group  $j$  in such a way that exposes group  $i$  to infection from group  $j$ . In DAEDALUS, groups  $i$  and  $j$  are the  $N$  working sectors and the four non-work groups, and the contact matrices are created by adding different types of contacts together.

The overall  $(N + 4) \times (N + 4)$  contact matrix is described as  $M = A + B + C$ , where  $A$  contains contacts between community members,  $B$  contains contacts between workers, and  $C$  contains contacts from the whole population to workers.

**Matrix  $A$**  Matrix  $A$  can be decomposed further to its constituent parts, representing intra- and inter-household interactions ( $L$ ), school interactions ( $S$ ), hospitality interactions ( $H$ ) and travel interactions ( $T$ ):

$$A = A^{(L)} + A^{(S)} + A^{(H)} + A^{(T)}$$

Matrix  $A^{(L)}$  is estimated using as a basis the contact matrix for “all locations” from [2]. This is a 16-by-16 matrix ( $A^{(0)}$ ), for five-year age bands  $a$  up to age group 75+. We map it to a four-by-four matrix  $A^{(1)}$  corresponding to the four age groups  $g$  used in the DAEDALUS model, using population sizes,  $\hat{P}_a$ :

$$A_{g,g'}^{(1)} = k \frac{\sum_{a \in g} \hat{P}_a \sum_{a' \in g'} A_{a,a'}^{(0)}}{\sum_{a \in g} \hat{P}_a}.$$

Using  $P_g$  to represent the population sizes of the DAEDALUS age groups,

$$P_g = \sum_{a \in g} \hat{P}_a,$$

a single scalar  $k$  is found so that the average number of contacts across all age groups is 3.5, in order to match the average contacts per person in [3]:

$$\frac{\sum_g P_g \sum_{g'} A_{g,g'}^{(1)}}{\sum_g P_g} = 3.5.$$

Contacts from all groups  $j$  to working groups  $i$  depend on the age group of the group ( $g(i)$ ), and the fraction of the age-population represented in group  $i$ , where  $w_i^*$  is the number of people in group  $i$ :

$$A_{j,i}^{(L)} = A_{g(j),g(i)}^{(1)} \frac{w_i^*}{P_{g(i)}}$$

for  $i$  and  $j$  including all groups (working and non-working). Each group  $i$  contains people that belong to only one age group  $g$ . We refer to the age group of the people in group  $i$  as  $g(i)$ . Then  $P_{g(i)}$  is the number of people in the age group of group  $i$ , so  $P_{g(i)} = w_i^*$  for age groups 0

to 4, 5 to 19 and 65+, and  $P_{g(i)} = \sum_{i \in \{1, \dots, N, N+4\}} w_i^*$  for ages 20 to 64.

Diagonal matrix  $A^{(S)}$  counts the contacts in schools. It has entries of zero for groups  $g$  not in school, and a value of 1.4 for  $g=0$  to 4 years old, and a value of 6.2 for  $g=5$  to 19 year olds.

Then

$$A_{i,i}^{(S)} = x_{S,\tau} s_{g(i)}. \quad (1)$$

The value  $x_{S,\tau}$  is the extent to which schools are open in the period  $\tau$ , so that the number of contacts per person scales linearly according to closure.

Matrix  $A^{(H)}$  gives the contacts made in the hospitality sector. Each age group makes an average of 0, 0.5, 1 and 1.5 total contacts for age groups 0-4, 5-19, 20-64, and 65+, respectively [3]. These contacts are made proportional to population, so we can write

$$A_{i,i'}^{(H)} = x_{H,\tau} \frac{A_{g(i)}^{(H0)} w_{i'}^*}{\sum_j w_j^*} \quad (2)$$

with  $A^{(H0)} = \{0, 0.5, 1.5, 1\}$ .

The value  $x_{H,\tau}$  is the workforce-weighted average extent to which the hospitality sectors are open in the period  $\tau$ , so that the number of contacts per person scales linearly according to closure:

$$x_{H,\tau} = \frac{\sum_i x_{i\tau} w_i^*}{\sum_i w_i^*}$$

where we sum over only the hospitality sectors; for the UK,  $i \in \{36, 58, 59, 60, 62\}$ .

Matrix  $A^{(T)}$  counts contacts between working people, representing travel. It is assumed that there are 2.5 contacts per person working with all other people, but we only count those with other working groups (so that each person has less than 2.5 contacts on average), and share the contacts out proportionally among them:

$$A_{i,i'}^{(T)} = x_{i\tau} (1 - p_{i,\tau})^2 \frac{2.5 w_{i'}^*}{\sum_g P_g} \quad (3)$$

for  $i = 1, \dots, N$ .  $A_{i,i'}^{(T)} = 0$  for  $i > N$ .

$p_{i,\tau}$  is the proportion of workers from sector  $i$  working from home during period  $\tau$ , and  $(1 - p_{i,\tau})^2$  scales contacts between workers superlinearly to approximate the reduced transmission between commuting workers: there should be fewer contacts per person on average, and there should be fewer people having these contacts. We reduce the transmission rates within the groups as a proxy for moving the individuals out of the group.

Also in this equation,  $x_{i\tau}$  scales the number of contacts linearly with respect to sector closure. At the same time, the number of people in the compartments will have the same proportion,  $x_{i\tau}$ . This, in combination with the scaled contacts, leads to superlinear scaling.

**Matrix  $B$**  Matrix  $B$  is a diagonal matrix formed of estimated number of contacts per person per day within sectors, denoted  $b_i$ . Values are chosen to best match each (sub)sector to a sector for which numbers of contacts were estimated in [3]. Then

$$B_{i,i} = x_{i\tau}(1 - p_{i,\tau})^2 b_i, \quad (4)$$

for the  $i = 1, \dots, N$  working groups. ( $B_{i,i} = 0$  for  $i > N$ .) As before, there is superlinear scaling of contacts with respect to working from home. There is linear scaling with respect to sector closure: that is, there are fewer contacts per person, but we do not approximate there being fewer people having them. This is because the latter is accounted for in the movement of people out of the group upon its closure.

**Matrix  $C$**  Matrix  $C$  counts the number of contacts between all people in the population and the sectors, denoted  $c_i$  for  $i \in \{1, \dots, N\}$ . Contacts are shared proportionally across the whole population. Then

$$C_{i,i'} = x_{i\tau}(1 - p_{i,\tau}) \frac{c_i w_{i'}^*}{\sum_j^{N+4} w_j^*}, \quad (5)$$

for  $i' = 1, \dots, N + 4$ .  $C_{i,i'} = 0$  for  $i > N$ .

Here, there is linear scaling of  $C_{i,i'}$  with respect to working from home, and linear scaling with respect to sector closure, which becomes superlinear scaling for sectors as individuals are moved out of the compartment, as with matrix  $B$ .

## References

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