Supplementary information. Population-level effectiveness of alternative approaches to preventing mental disorders in adolescents and young adults

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Supplementary appendix 1

Derivation of the equilibrium numbers of adolescents and young adults in the stocks N, V, S, and D

1.1. Derivation of the equilibrium values of N, V, S, and D

At equilibrium, the values of the stocks N, V, S, and D remain constant, i.e., their rates of change are equal to 0, so we have the equilibrium conditions

$$\frac{dN}{dt} = (1-\phi)g - uN^* - (\lambda+\mu)N^* = 0$$

$$\frac{dV}{dt} = \phi g - [1+h(\theta-1)]uV^* - (\lambda+\alpha\mu)V^* = 0$$

$$\frac{dS}{dt} = uN^* + [1+h(\theta-1)]uV^* - iS^* - (\lambda+\beta\mu)S^* = 0$$

$$\frac{dD}{dt} = iS^* - (\lambda+\gamma\mu)D^* = 0,$$

where t is time (in years), N^*, V^*, S^*, and D^* are the equilibrium values of N, V, S, and D, and all other notation is the same as in Fig. 1 of the paper. Solving the first equilibrium condition for N^* and the second equilibrium condition for V^*, we obtain $N^* = (1-\phi)g/(u+\lambda+\mu)$ and $V^* = \phi g/[u+h(\theta-1)u+\lambda+\alpha\mu]$. Substituting these expressions for N^* and V^* into the third equilibrium condition and solving for S^* gives us the following

$$S^* = \frac{(1-\phi)g[u+h(\theta-1)u+\lambda+\alpha\mu]u + \phi g(u+\lambda+\mu)[1+h(\theta-1)]u}{[u+h(\theta-1)u+\lambda+\alpha\mu](u+\lambda+\mu)(i+\lambda+\beta\mu)},$$

which can be substituted into the fourth equilibrium condition to obtain the equilibrium number of adolescents and young adults with full-threshold mental disorders

$$D^* = \frac{i(1-\phi)g[u+h(\theta-1)u+\lambda+\alpha\mu]u + i\phi g(u+\lambda+\mu)[1+h(\theta-1)]u}{[u+h(\theta-1)u+\lambda+\alpha\mu](u+\lambda+\mu)(i+\lambda+\beta\mu)(\lambda+\gamma\mu)}.$$

1.2. Determining equilibrium stability

The stability of the equilibrium state (N^*, V^*, S^*, D^*) can be determined from the eigenvalues of the Jacobian matrix

$$J = \begin{bmatrix} \frac{\partial(dN/dt)}{\partial N} & \frac{\partial(dN/dt)}{\partial V} & \frac{\partial(dN/dt)}{\partial S} & \frac{\partial(dN/dt)}{\partial D} \\ \frac{\partial(dV/dt)}{\partial N} & \frac{\partial(dV/dt)}{\partial V} & \frac{\partial(dV/dt)}{\partial S} & \frac{\partial(dV/dt)}{\partial D} \\ \frac{\partial(dS/dt)}{\partial N} & \frac{\partial(dS/dt)}{\partial V} & \frac{\partial(dS/dt)}{\partial S} & \frac{\partial(dS/dt)}{\partial D} \\ \frac{\partial(dD/dt)}{\partial N} & \frac{\partial(dD/dt)}{\partial V} & \frac{\partial(dD/dt)}{\partial S} & \frac{\partial(dD/dt)}{\partial D} \end{bmatrix}$$

$$= \begin{bmatrix} -u-(\lambda+\mu) & 0 & 0 & 0 \\ 0 & -[1+h(\theta-1)]u-(\lambda+\alpha\mu) & 0 & 0 \\ u & [1+h(\theta-1)]u & -i-(\lambda+\beta\mu) & 0 \\ 0 & 0 & i & -(\lambda+\gamma\mu) \end{bmatrix}.$$

J is a lower triangular matrix, so its eigenvalues are equal to the diagonal elements $-u-(\lambda+\mu)$, $-[1+h(\theta-1)]u-(\lambda+\alpha\mu)$, $-i-(\lambda+\beta\mu)$, and $-(\lambda+\gamma\mu)$. As the parameters u, i, λ, μ, α, β, and γ are positive and $1+h(\theta-1)$ is equal to or greater than 1, all four eigenvalues are negative, so that (N^*, V^*, S^*, D^*) is always stable (i.e., we expected that N, V, S, and D will return to their equilibrium values when the system is disturbed).

Supplementary appendix 2

Empirical values for ϕ and θ (i.e., the proportion of adolescents turning 12 years at increased risk of mental illness and the relative risk of symptom onset, respectively)

Table S1. Empirical estimates of ϕ and θ for a diverse selection of risk-modifying factors (see panel D of Fig. 2).

Risk-modifying factor	ϕ	θ	Reference
Substantiated childhood maltreatment	0.1092	3.11	Abajobir et al. (2017)
Sexual minority	0.0636	5.43	Amos et al. (2020)
Socioeconomic disadvantage	0.2	1.6738	Barros et al. (2018)
Parental generalised anxiety disorder (GAD)	0.1016	1.93	Beesdo et al. (2010)
Parental death	0.0233	1.46	Björkenstam et al. (2017)
Parental separation	0.2469	1.58	Björkenstam et al. (2017)
Parental criminality	0.0415	1.78	Björkenstam et al. (2017)
Residential instability	0.0135	1.89	Björkenstam et al. (2017)
Household receiving public assistance	0.045	1.95	Björkenstam et al. (2017)
Parental substance abuse	0.0301	2.09	Björkenstam et al. (2017)
Parental psychiatric morbidity	0.051	2.11	Björkenstam et al. (2017)
Child welfare intervention	0.0136	2.79	Björkenstam et al. (2017)
Childhood trauma	0.188	1.2171	Copeland et al. (2018)
Male sex	0.513	1.0602	Dalsgaard et al. (2020)
Race/ethnicity - non-Hispanic black	0.1742	1.2221	Georgiades et al. (2018)
Race/ethnicity - Hispanic	0.1208	1.2272	Georgiades et al. (2018)
Parental divorce or separation	0.309	1.4253	Gilman et al. (2003)
Residential instability	0.379	1.4717	Gilman et al. (2003)
Not in education, employment, or training (NEET)	0.1157	1.68	Goldman-Mellor et al. (2016)
Not in education, employment, or training (NEET)	0.1195	1.2894	Gutiérrez-García et al. (2017)
Physical injury requiring medical care	0.1115	1.38	Jenness et al. (2017)
Hospitalisation for infection	0.31	1.84	Köhler-Forsberg et al. (2019)
Maternal bacterial infection during pregnancy	0.2269	1.8	Lee et al. (2020)
Bullying (victim)	0.262	2.14	Lereya et al. (2015)
Maternal depressive disorder	0.304	2.261	Marmorstein et al. (2004)
Parental substance abuse	0.0631	1.86	Martikainen et al. (2018)
Substantiated childhood sexual abuse	0.0143	3.36	Mills et al. (2016)
Polygenic risk score (decile 10)	0.1	1.5189	Musliner et al. (2019)
Polygenic risk score (deciles 9-10)	0.2	1.5058	Musliner et al. (2019)
Polygenic risk score (deciles 8-10)	0.3	1.5214	Musliner et al. (2019)
Polygenic risk score (deciles 7-10)	0.4	1.524	Musliner et al. (2019)
Polygenic risk score (deciles 6-10)	0.5	1.5301	Musliner et al. (2019)
Polygenic risk score (deciles 5-10)	0.6	1.5716	Musliner et al. (2019)
Polygenic risk score (deciles 4-10)	0.7	1.5737	Musliner et al. (2019)
Polygenic risk score (deciles 3-10)	0.8	1.653	Musliner et al. (2019)
Polygenic risk score (deciles 2-10)	0.9	1.8511	Musliner et al. (2019)
Parental post-traumatic stress disorder	0.146	1.75	Nielsen et al. (2019)
Temporary separation from parents	0.1335	1.18	Räikkönen et al. (2011)
Bullying (victim)	0.0642	2.1	Sourander et al. (2007)
Bullying (both bully and victim)	0.0276	4.5	Sourander et al. (2007)
Maternal antenatal depression	0.1172	1.85	Srinivasan et al. (2020)
Maternal postnatal depression	0.0751	2.09	Srinivasan et al. (2020)
Physical inactivity	0.0919	1.1964	Wu et al. (2018)

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Supplementary appendix 3

Population-level effectiveness of multi-component prevention programs for youth mental disorders

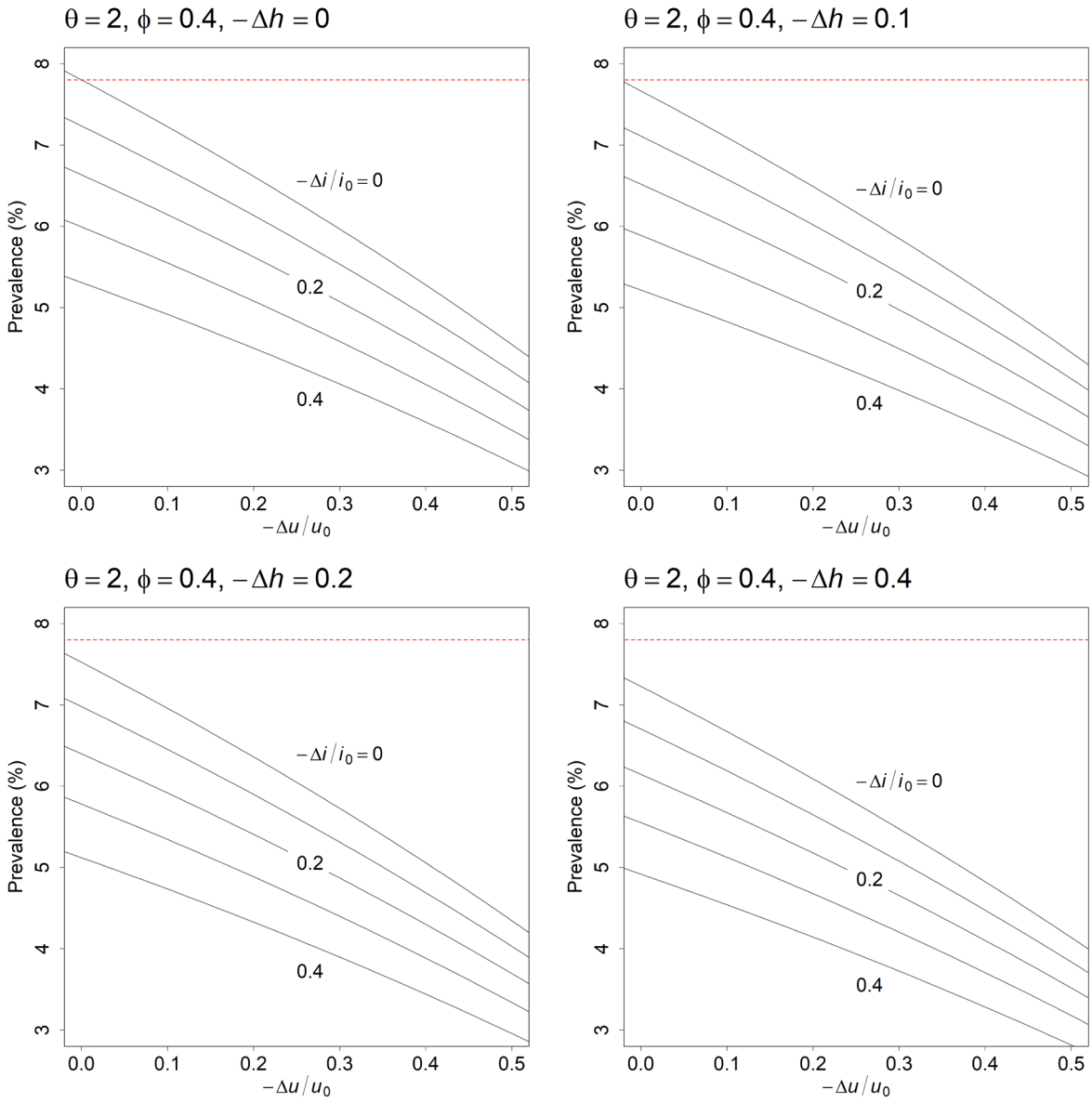

Fig. S1. Post-intervention equilibrium prevalence of full-threshold disorders for a multi-component prevention program incorporating universal, selective, and indicated interventions with varying individual-level effects ($-\Delta u/u_0$, $-\Delta h$, and $-\Delta i/i_0$, respectively). The red dashed line in the upper part of each plot corresponds to the equilibrium prevalence of full-threshold disorders prior to implementing the program (7.80% in all cases).

Supplementary appendix 4

Results of analyses using mental disorder prevalence estimates from the World Mental Health Surveys

For the analyses presented in the paper, we assumed values for the parameters u and i (i.e., the per capita rate of symptom onset for the non-vulnerable population and the per capita disease progression rate, respectively) yielding equilibrium proportions of adolescents and young adults with subthreshold symptoms and full-threshold disorders equal to empirical estimates for Australia, obtained by multiplying the prevalence of mental disorders for 16−24-year-olds in 2007 (26.4%; Australian Bureau of Statistics, 2008) by the proportions of adolescents and young adults presenting to headspace services allocated to clinical stages 1a−b and 2−4 (0.704 and 0.296, respectively; Mei et al., 2019). The extent to which our results depend on these parameter assumptions was assessed by repeating the analyses presented in Fig. 3 using disorder prevalence estimates from the World Health Organization's World Mental Health Surveys (Demyttenaere et al., 2004). Figs S2−S4 present the results of analyses for Nigeria, Japan, and the United States, respectively. In calculating u and i for each country, we equated mild−moderate mental disorders with clinical stages 1a−b (i.e., subthreshold symptoms) and severe mental disorders with clinical stages 2 and above (full-threshold disorders). Clearly, this approach is very rough; however, our aim here is to examine the impact of modifying our parameter assumptions, not to accurately estimate the prevalence of subthreshold and full-threshold symptoms. Although the three countries have widely varying values for the prevalence of severe disorders (Nigeria 0.4%, Japan 1.5%, United States, 7.7%) and the proportion of all disorders that are severe (Nigeria 8.5%, Japan 17.0%, United States, 29.3%), the results in Figs S2−S4 are qualitatively similar to one another and to those in Fig. 3 of the paper.

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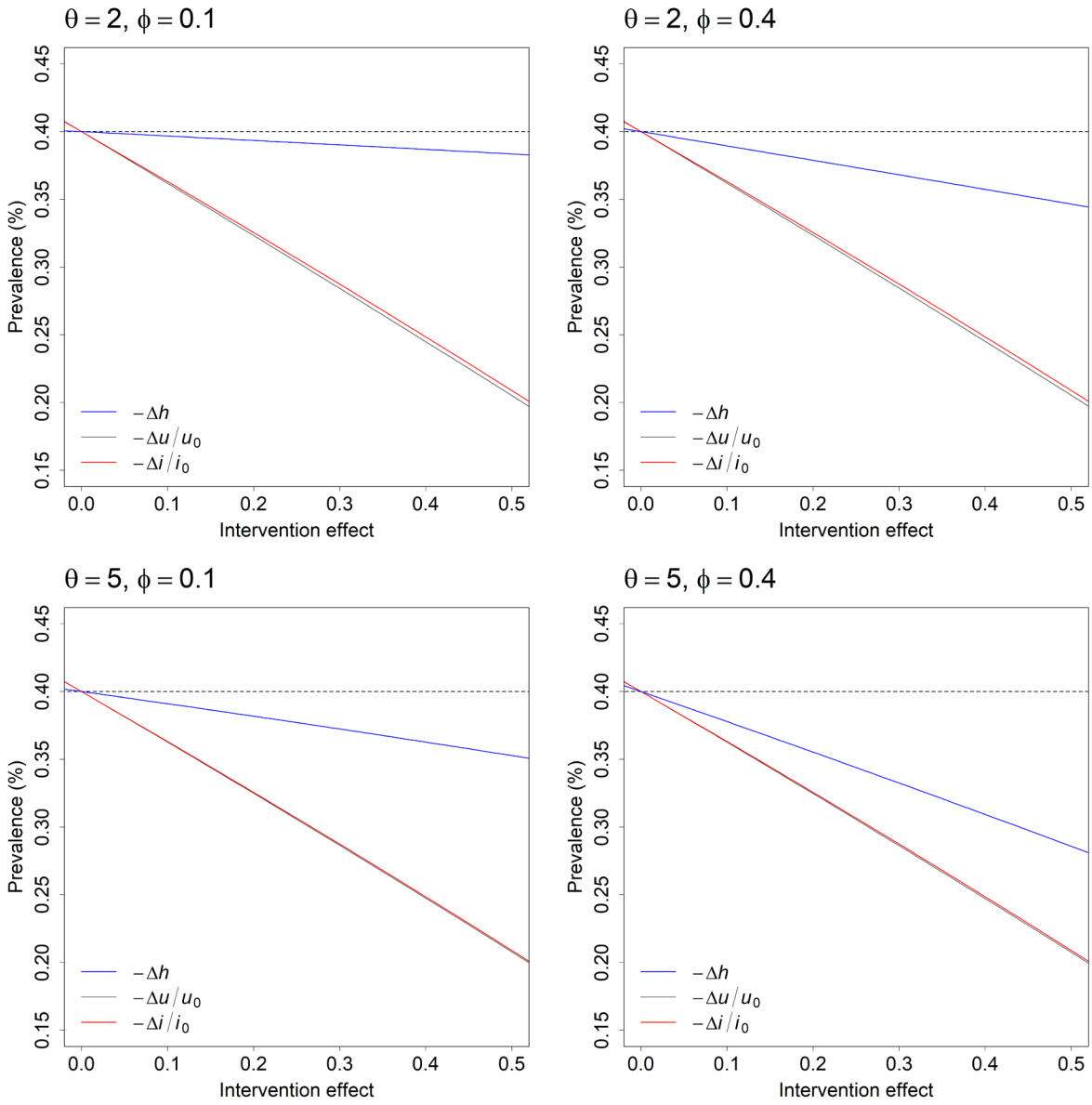

Fig. S2. Post-intervention equilibrium prevalence of mental disorders for universal (grey), selective (blue), and indicated (red) preventive interventions with varying individual-level effects (cf. Fig. 3). Pre-intervention values for u and i (u_0 and i_0, respectively) were derived from mental disorder prevalence estimates for Nigeria (Demyttenaere et al., 2004).

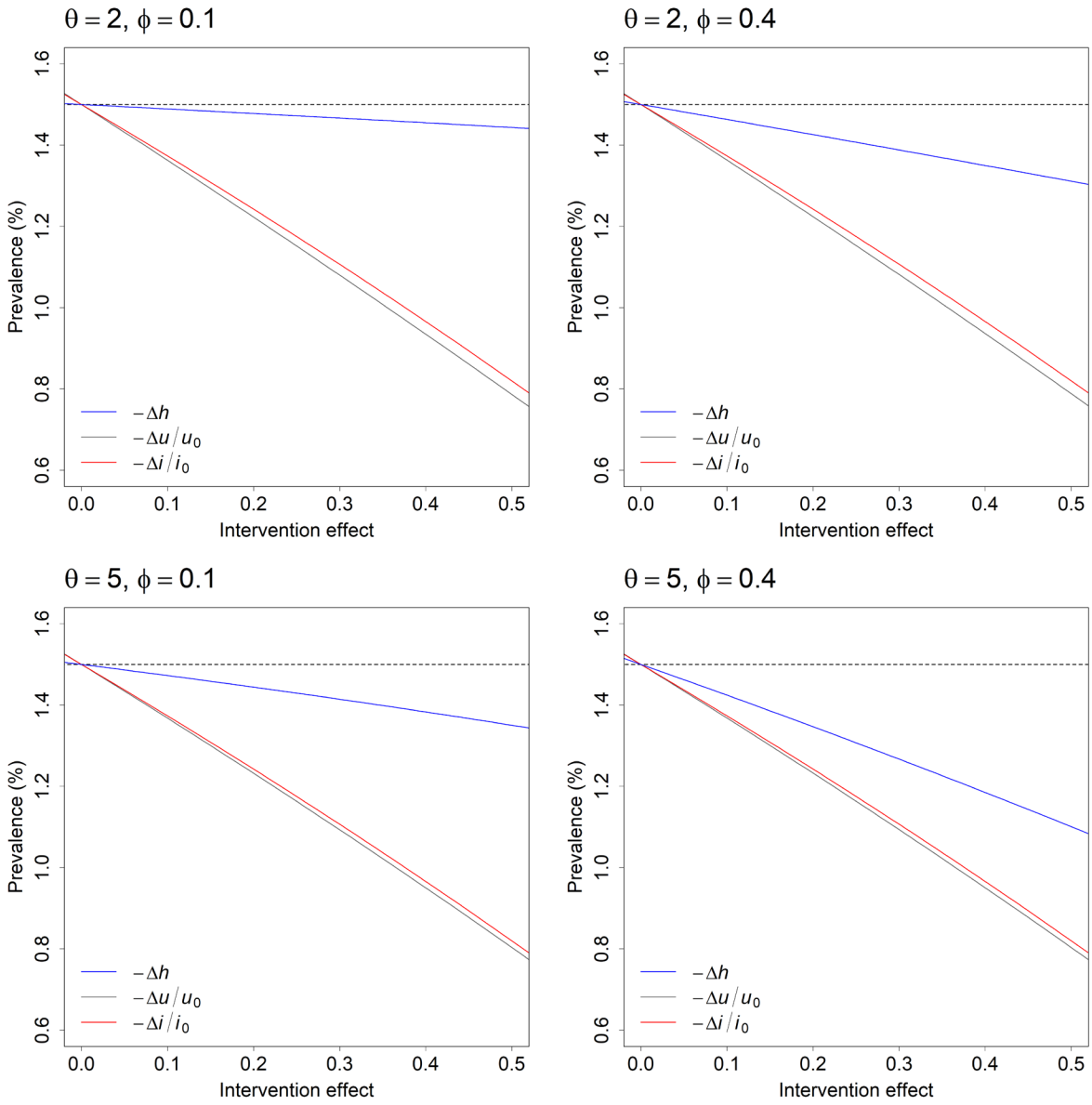

Fig. S3. Post-intervention equilibrium prevalence of mental disorders for universal (grey), selective (blue), and indicated (red) preventive interventions with varying individual-level effects (cf. Fig. 3). Pre-intervention values for u and i (u_0 and i_0, respectively) were derived from mental disorder prevalence estimates for Japan (Demyttenaere et al., 2004).

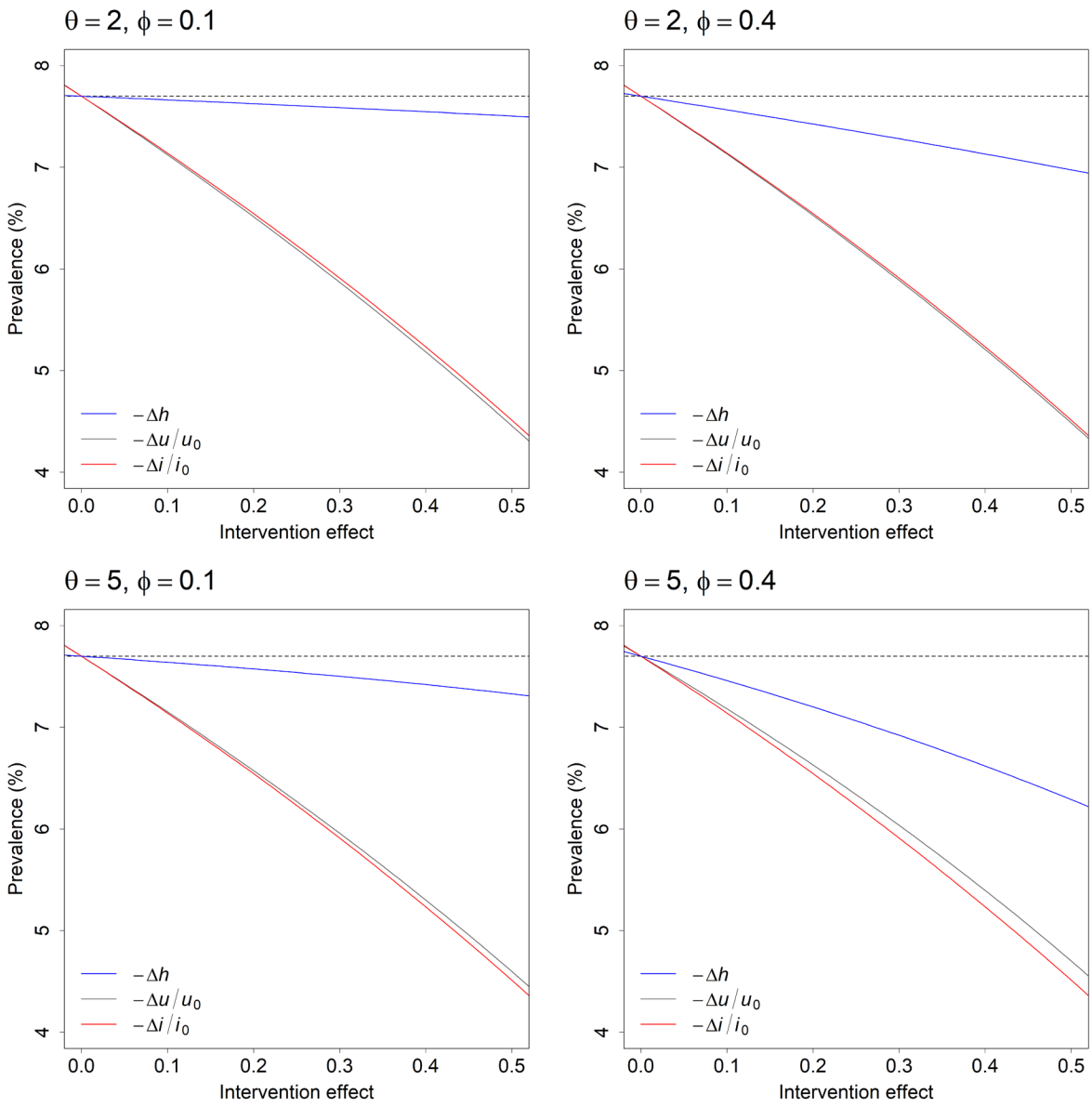

Fig. S4. Post-intervention equilibrium prevalence of mental disorders for universal (grey), selective (blue), and indicated (red) preventive interventions with varying individual-level effects (cf. Fig. 3). Pre-intervention values for u and i (i.e., u_0 and i_0) were derived from mental disorder prevalence estimates for the United States (Demyttenaere et al., 2004).

Supplementary appendix 5

Prevalence of full-threshold mental disorders over time for universal, selective, and indicated preventive interventions with identical population-level effects (at equilibrium)

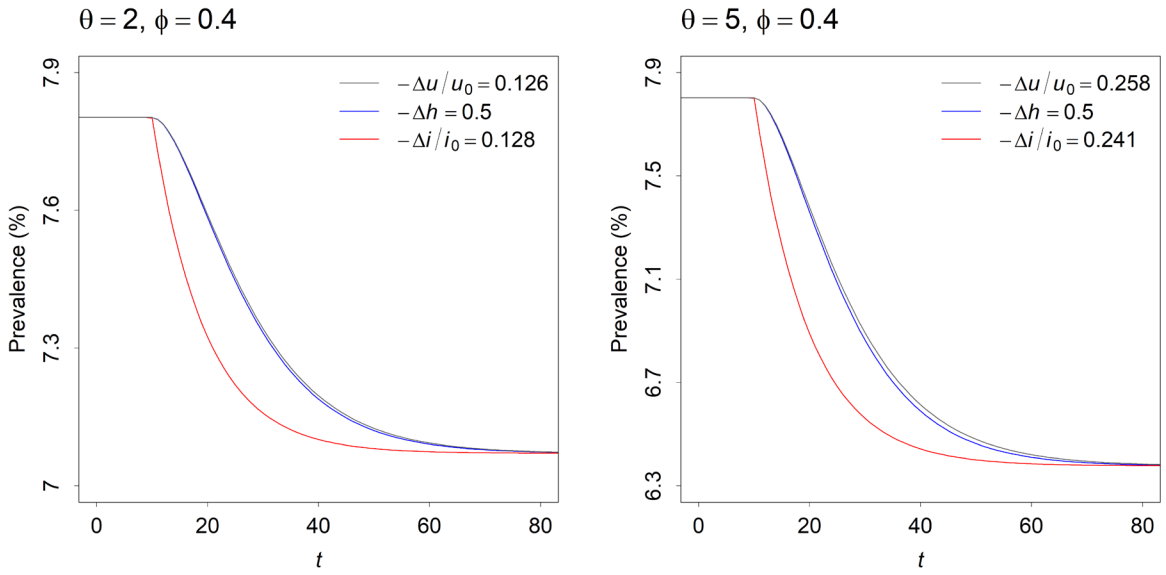

Fig. S5. Prevalence of youth mental disorders over time for hypothetical universal (grey), selective (blue), and indicated (red) preventive interventions (introduced at time t = 10) with identical population-level effects. In each plot, all three interventions yield the same post-intervention disorder prevalence at equilibrium; however, prevalence approaches the equilibrium value more rapidly for the indicated intervention than for the universal and selective interventions.