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Supplementary Information for

Network Interventions for Managing the COVID-19 Pandemic and Sustaining Economy

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Figures S1 to S22

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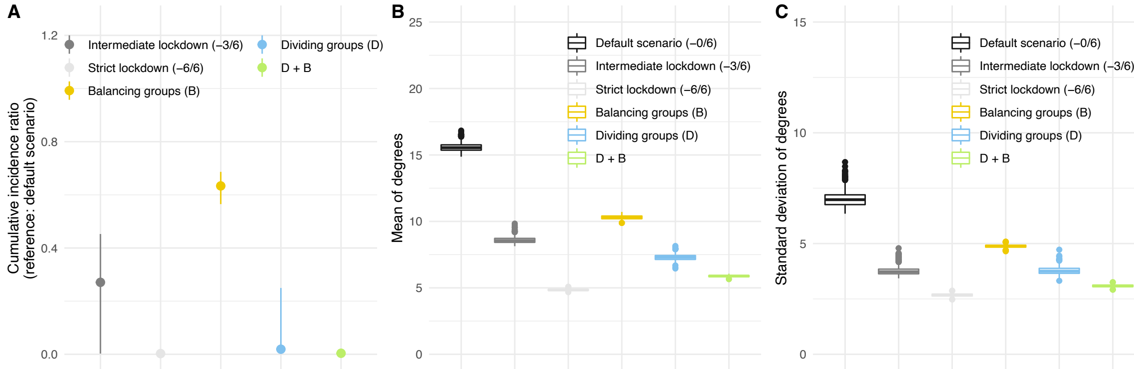

Figure S1. A. Cumulative incidence ratio (CIR) with the reference of the default scenario. The CIR represents the relative cumulative risk of infection over the simulation period (300 days) in each scenario as compared to the default "natural course" scenario. Smaller values represent lower risks. The dots and bars represent medians and 95% quantile ranges (QRs) among the 1,000 iterations. Please refer to the dynamics of Fig. 2B. **B and C. Boxplots for the means and standard deviations of degrees in each scenario.** The middle lines represent medians. The boxes represent interquartile ranges (IQRs), while the whiskers represent 1.5 x IQRs.

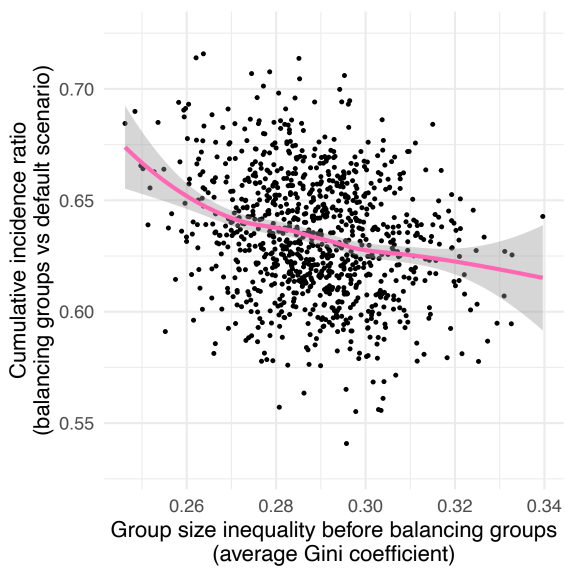

Figure S2. Association of the level of group size inequality before balancing groups and cumulative incidence ratio of "balancing groups" strategy (reference category: default setting). Inequality was calculated by averaging the Gini coefficients of group sizes in each of the 8 sectors. Networks with a higher initial group size inequality within sectors can benefit at a greater degree (i.e. have a lower cumulative incidence ratio) from balancing the group sizes. The smoothing curve (pink) was obtained using a local regression model (loess in R). 18 outliers were omitted from the graph as they represented iterations where the cumulative incidence ratio was 0 (i.e. the infection did not spread in those iterations).

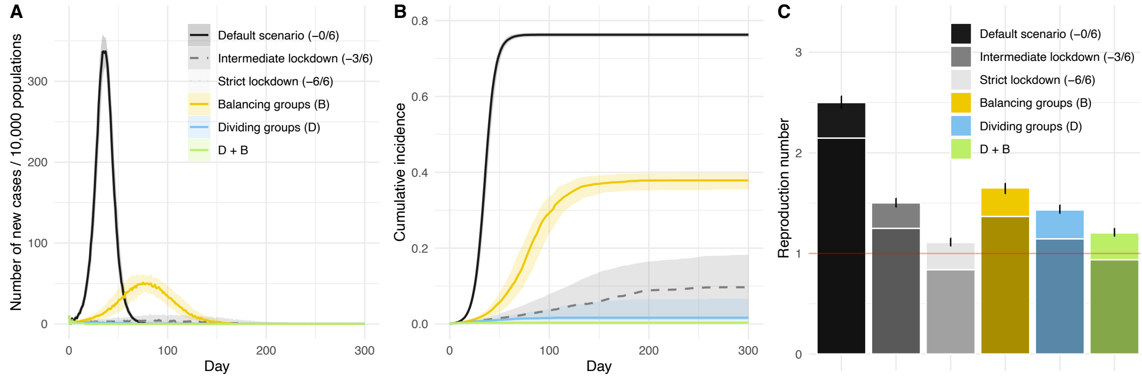

Figure S3. Robustness check: The group sizes are modified from "3,000, 1,000, 25, 25, 10, 25, 500, 500" to "3,000, 2,000, 50, 50, 20, 50, 700, 1,250" (larger numbers of groups in each sector compared to the original setting). The number of families does not change. Transmissibility was recalculated due to the change in network structure (0.06030), such that the median R_0 of the default scenario remains equal to 2.5. The explanation for each panel is the same as Figs. 2A, B, and D. The curves for the strict lockdown scenario and others in panel A are invisible because they are located near or on the x-axis (this also occurs in panel B). Since the role of the 3,000 families in the spread of transmission increases, the effect of dividing groups (not including families) is reduced, which results in a higher R_{eff} for the dividing groups and D + B strategies.

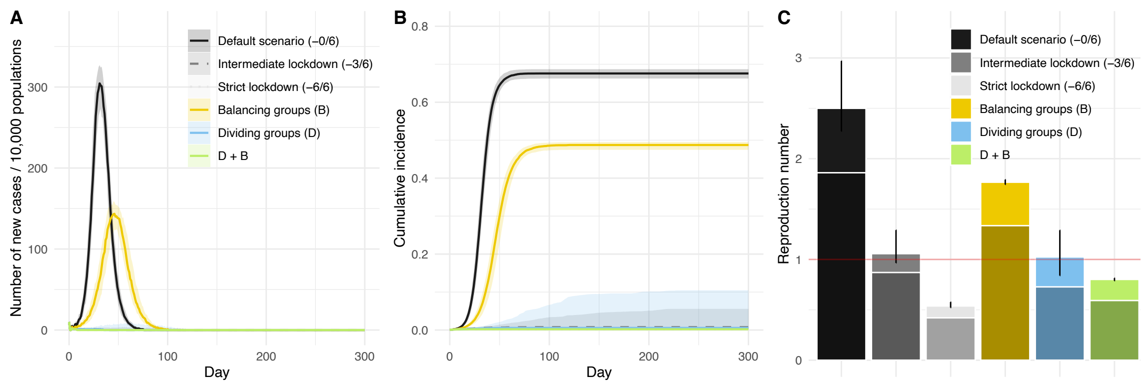

Figure S4. Robustness check: The group sizes are modified from "3,000, 1,000, 25, 25, 10, 25, 500, 500" to "3,000, 500, 10, 10, 5, 10, 250, 250" (smaller numbers of groups in each sector compared to the original setting). The number of families does not change. Transmissibility was recalculated due to the change in network structure (0.02576), such that the median R_0 of the default scenario remains equal to 2.5. The explanation for each panel is the same as Figs. 2A, B, and D. The curves for the strict lockdown scenario and others in panel A are invisible because they are located near or on the x-axis (this also occurs in panel B). Since the role of the 3,000 families in the spread of transmission decreases, the effect of dividing groups (not including families) is increased, which results in a lower R_{eff} for the dividing groups and D + B strategies.

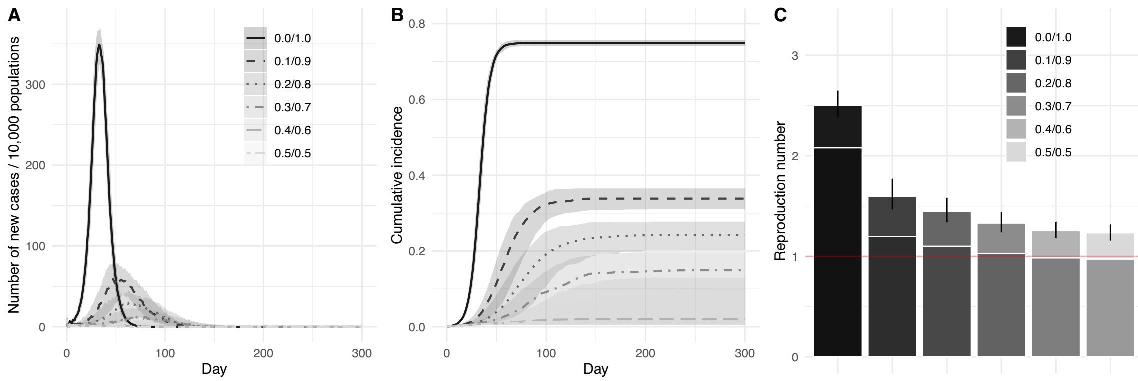

Figure S5. Robustness check. In the dividing groups strategy, the probability of assignment to two subgroups was modified from the original 0.5/0.5 to 0.0/1.0 (default setting), 0.1/0.9, 0.2/0.8, 0.3/0.7, and 0.4/0.6. The explanation for each panel is the same as Figs. 2A, B, and D. We confirmed that the effect of the split in the dividing strategy is maximized when the split is even (0.5 and 0.5), agreeing with mathematical predictions. On the other hand, even if the split is not even, we can still expect substantial effects by dividing groups (with diminishing returns).

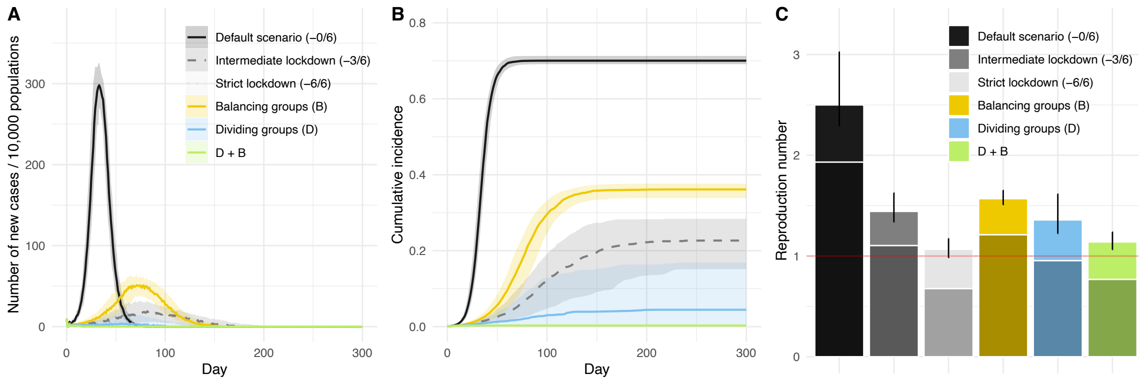

Figure S6. Robustness check: Geometric distributions with a parameter of 0.2 were used instead of a uniform distribution to draw probabilities for group assignment. Transmissibility was recalculated due to the change in network structure (0.03457), such that the median R_0 of the default scenario remains equal to 2.5. The explanation for each panel is the same as Figs. 2A, B, and D. The curves for the strict lockdown scenario and others in panel A are invisible because they are located near or on the x-axis (this also occurs in panel B). A geometric distribution with a smaller parameter (i.e. success probability) creates a larger proportion of groups with large group sizes. Since such large groups are balanced out with small groups (the degree of balancing is higher in this setting), the effect of balancing groups is amplified.

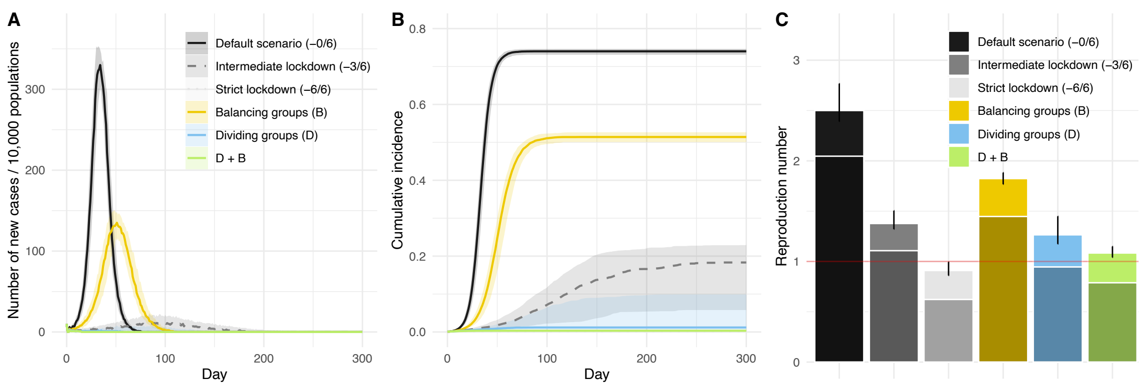

Figure S7. Robustness check: Geometric distributions with a parameter of 0.8 were used instead of a uniform distribution to draw probabilities for group assignment. Transmissibility was recalculated due to the change in network structure (0.04778), such that the median R_0 of the default scenario remains equal to 2.5. The explanation for each panel is the same as Figs. 2A, B, and D. The curves for the strict lockdown scenario and others in panel A are invisible because they are located near or on the x-axis (this also occurs in panel B). A geometric distribution with a larger parameter (i.e. success probability) creates a smaller proportion of groups with large group sizes. Since such large groups are balanced out with small groups (the degree of balancing is lower in this setting), the effect of balancing groups is attenuated.

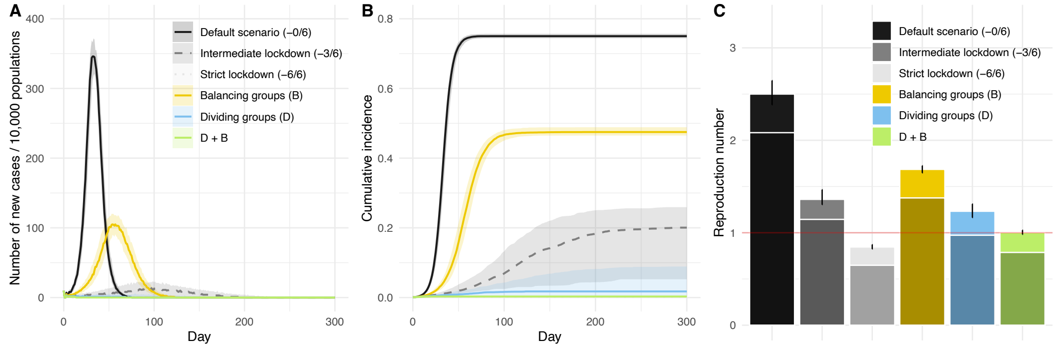

Figure S8. Rewiring probability in the small-world model of 0.0 (v.s. 0.2 in the original setting) in close ties. Transmissibility was recalculated due to the change in network structure (0.04461), such that the median R_0 of the default scenario remains equal to 2.5. The explanation for each panel is the same as Figs. 2A, B, and D. The curves for the strict lockdown scenario and others in panel A are invisible because they are located near or on the x-axis (this also occurs in panel B). The influence of the rewiring probability on the overall effect is minor due to the simulated networks being densely connected via weak ties, regardless of the presence of close ties.

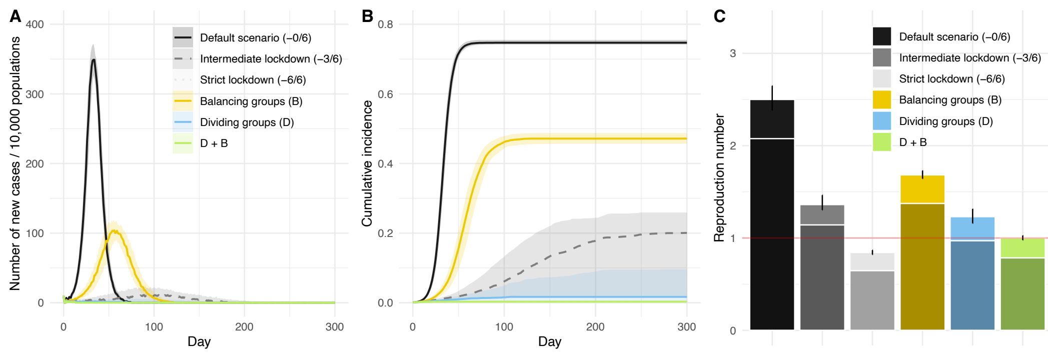

Figure S9. Rewiring probability in the small-world model of 0.5 (vs. 0.2 in the original setting) in close ties. Transmissibility was recalculated due to the change in network structure (0.04448), such that the median R_0 of the default scenario remains equal to 2.5. The explanation for each panel is the same as Figs. 2A, B, and D. The curves for the strict lockdown scenario and others in panel A are invisible because they are located near or on the x-axis (this also occurs in panel B). The influence of the rewiring probability on the overall effect is minor due to the simulated networks being densely connected via weak ties, regardless of the presence of close ties.

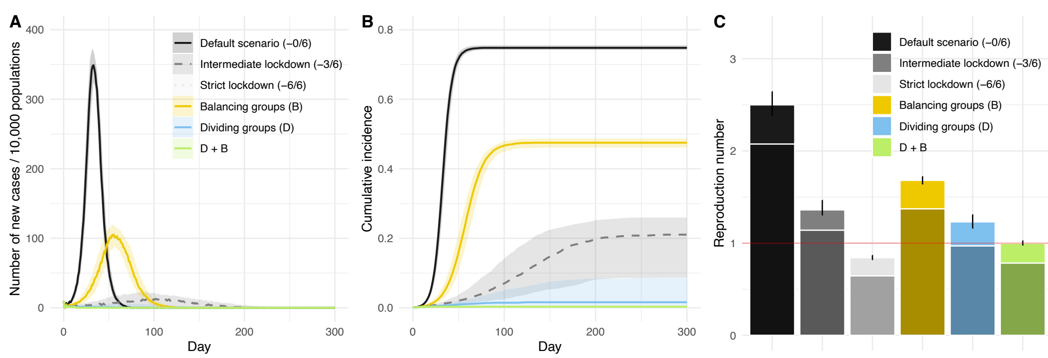

Figure S10. Rewiring probability in the small-world model of 1.0 (vs. 0.2 in the original setting) in close ties. Transmissibility was recalculated due to the change in network structure (0.04444), such that the median R_0 of the default scenario remains equal to 2.5. The explanation for each panel is the same as Figs. 2A, B, and D. The curves for the strict lockdown scenario and others in panel A are invisible because they are located near or on the x-axis (this also occurs in panel B). The influence of the rewiring probability on the overall effect is minor due to the simulated networks being densely connected via weak ties, regardless of the presence of close ties.

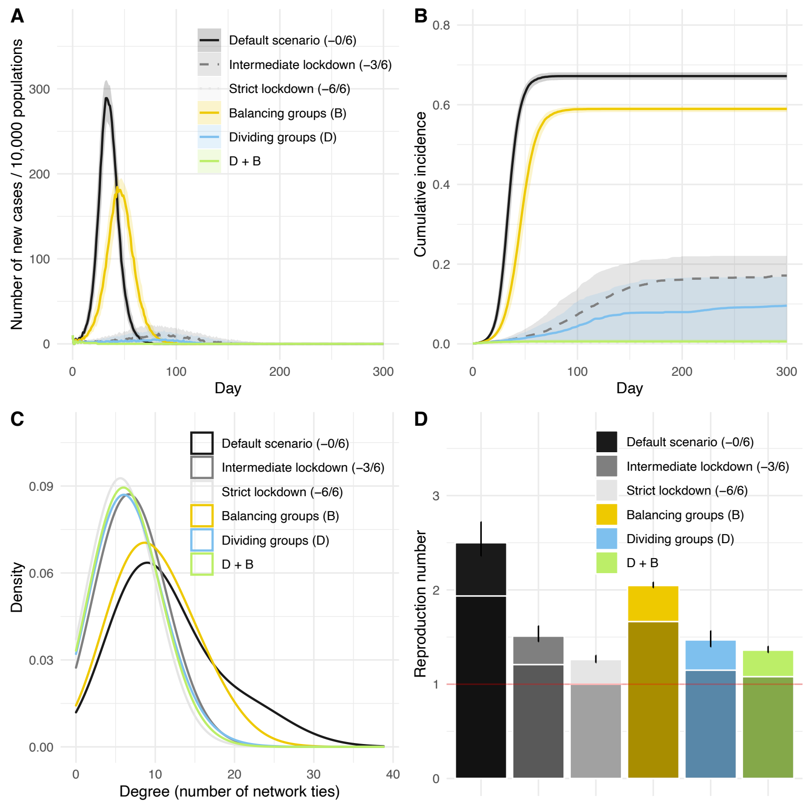

Figure S11. All close ties are removed after the social networks are constructed (retain family + weak ties only). Transmissibility was recalculated due to this re-scale (0.05575). The explanation for each panel is the same as Fig. 2. The curves for the strict lockdown scenario and others in panel A are invisible because they are located near or on the x-axis (this also occurs in panel B). The contribution of family ties in the reproduction number and other quantities increases.

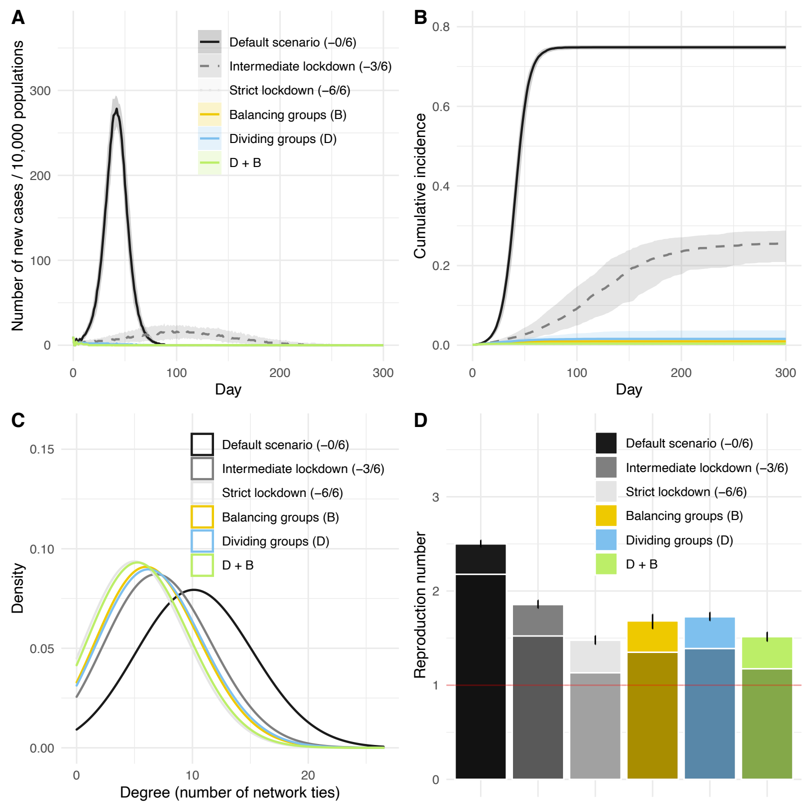

Figure S12. All weak ties are removed after the social networks are constructed (retain family + close ties only). Transmissibility was recalculated due to this re-scale (0.06991). The explanation for each panel is the same as Fig. 2. The curves for the strict lockdown scenario and others in panel A are invisible because they are located near or on the x-axis (this also occurs in panel B). The contribution of family ties in the reproduction number and other quantities increases. Furthermore, the effect of the balancing strategy is amplified because, in close ties, we assumed that new close ties are not constructed after balancing groups.

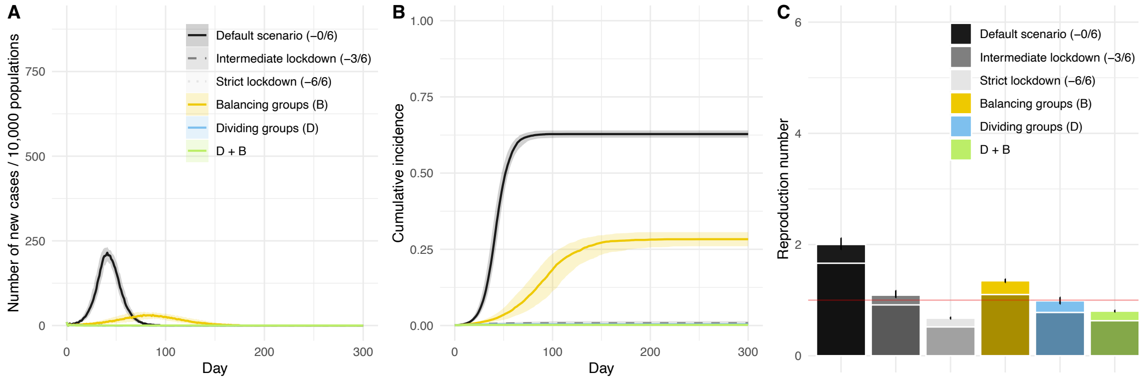

Figure S13. Robustness check: Transmissibility (β) was modified from 0.04458 to 0.03566 (i.e. R_0 was modified from 2.5 to 2.0). The explanation for each panel is the same as Figs. 2A, B, and D. The curves for the strict lockdown scenario and others in panel A are invisible because they are located near or on the x-axis (this also occurs in panel B).

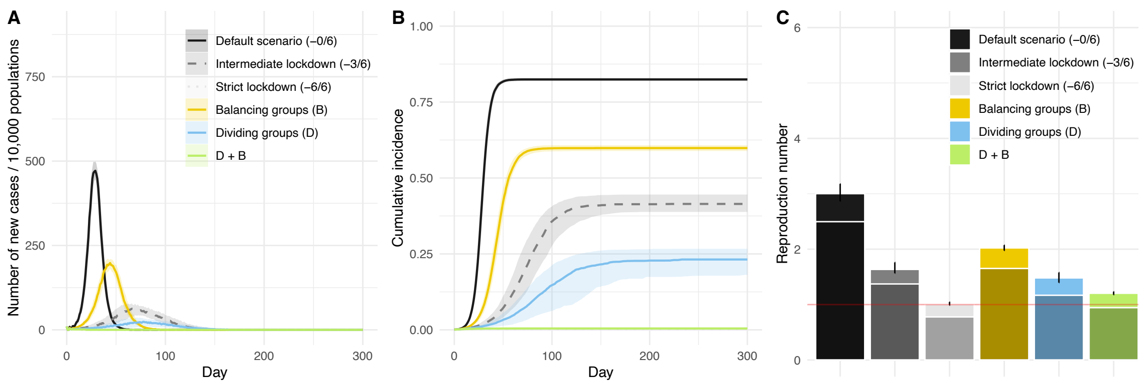

Figure S14. Robustness check: Transmissibility (β) was modified from 0.04458 to 0.05350 (i.e. R_0 was modified from 2.5 to 3.0). The explanation for each panel is the same as Figs. 2A, B, and D. The curves for the strict lockdown scenario and others in panel A are invisible because they are located near or on the x-axis (this also occurs in panel B).

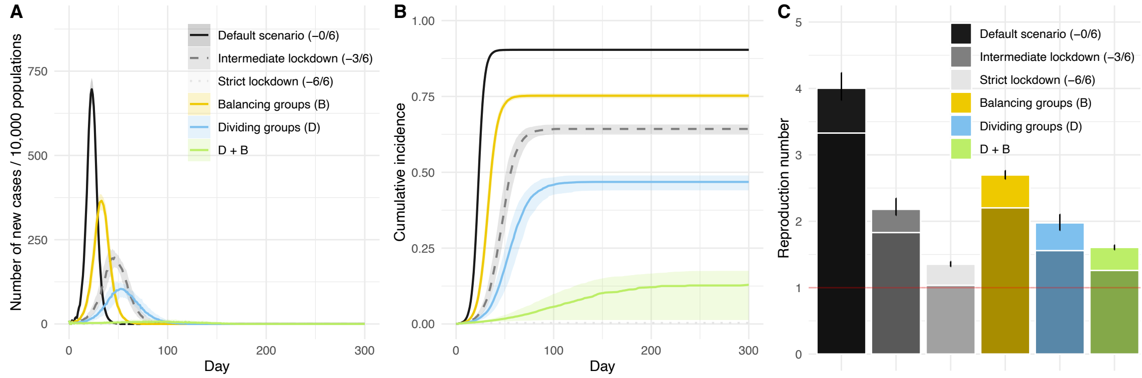

Figure S15. Robustness check. Transmissibility (*β*) was modified from 0.04458 to 0.07133 (i.e. R_0 from 2.5 to 4.0). The curves for the strict lockdown scenario and others in panel A are invisible because they are located near or on the x-axis (this also occurs in panel B).

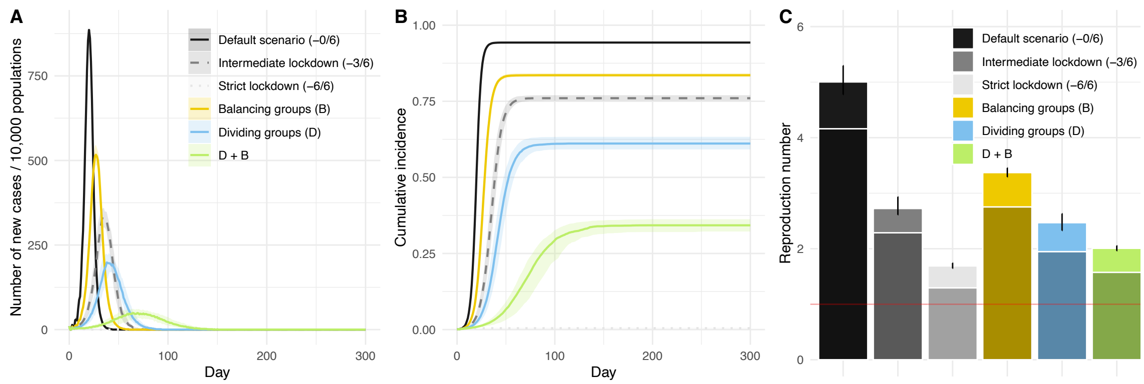

Figure S16. Robustness check. Transmissibility (*β*) was modified from 0.04458 to 0.08916 (i.e. R_0 from 2.5 to 5.0). The curves for the strict lockdown scenario and others in panel A are invisible because they are located near or on the x-axis (this also occurs in panel B).

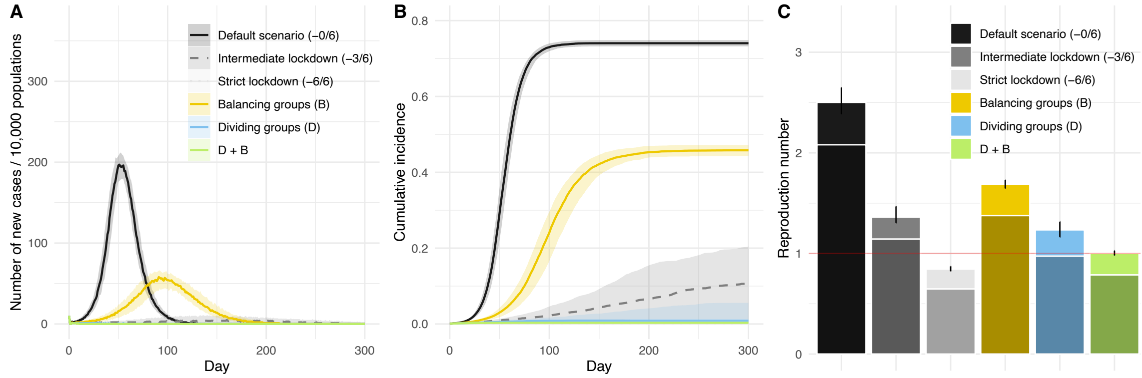

Figure S17. Robustness check: Infectiousness period (τ) was modified from 3 days to 7 days. Transmissibility was recalculated due to the change in network structure (0.01911), such that the median R_0 of the default scenario remains equal to 2.5. The explanation for each panel is the same as Figs. 2A, B, and D. The curves for the strict lockdown scenario and others in panel A are invisible because they are located near or on the x-axis (this also occurs in panel B). The peak of cases comes more slowly because we used a lower transmissibility (which corresponds to R_0 of 2.5).

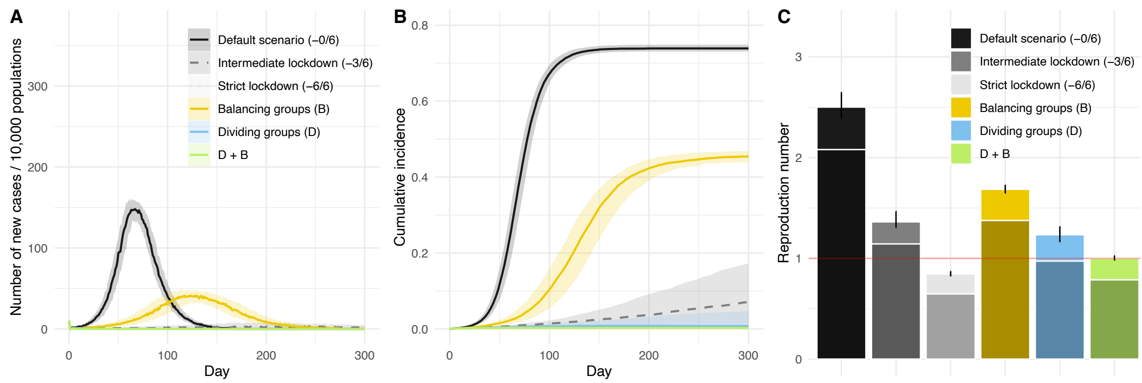

Figure S18. Robustness check: Infectiousness period (τ) was modified from 3 days to 10 days. Transmissibility was recalculated due to the change in network structure (0.01337), such that the median R_0 of the default scenario remains equal to 2.5. The explanation for each panel is the same as Figs. 2A, B, and D. The curves for the strict lockdown scenario and others in panel A are invisible because they are located near or on the x-axis (this also occurs in panel B). The peak of cases comes more slowly because we used a lower transmissibility (which corresponds to R_0 of 2.5).

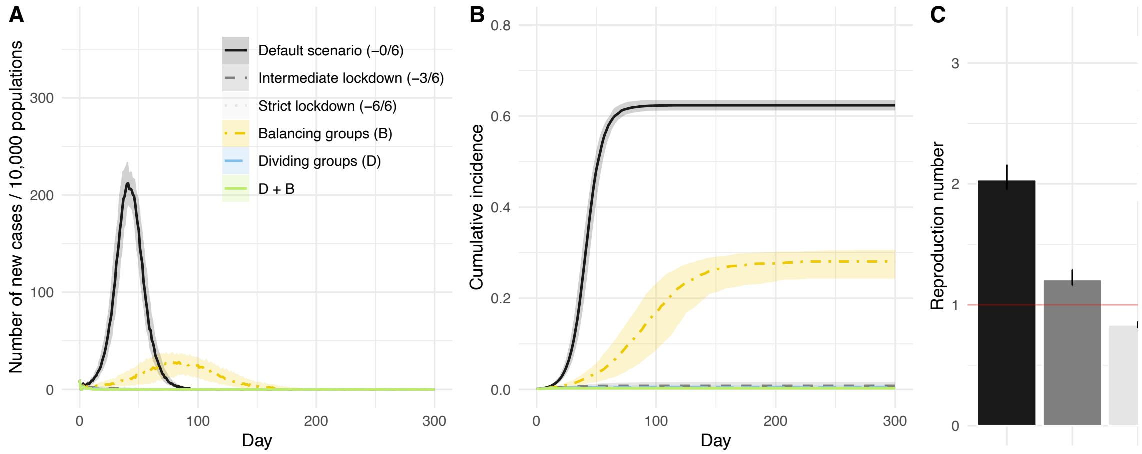

Figure S19. Individuals were required to stay home (keeping family ties but cutting close ties and weak ties) when they have symptoms. We assumed that the asymptomatic ratio is 0.45 and the pre-symptomatic period is the half of the infectious period. The explanation for each panel is the same as Figs. 2A, B, and D. The curves for the strict lockdown scenario and others in panel A are invisible because they are located near or on the x-axis (this also occurs in panel B). For panel C, we calculated the reproduction number using the equation below. *N'* is the "network N" (see Materials and Method, section c) based on the family ties only.

$$R_0 = 0.45 \times \beta \times N \times \tau + 0.55 \times (\beta \times N \times \tau \times 0.5 + \beta \times N' \times \tau \times 0.5)$$

Due to the complexity of the equation, the mean and the standard deviation portions of the reproduction number are not defined or displayed. Transmissibility was not rescaled here. The results show that isolating symptomatic individuals at home can reduce R_{eff} (2.035 [95%QR: 1.952 – 2.159] in the default scenario) as expected. The reproduction number of the D + B strategy with self-isolation is below 1 (0.948 [95%QR: 0.921 – 0.975]).

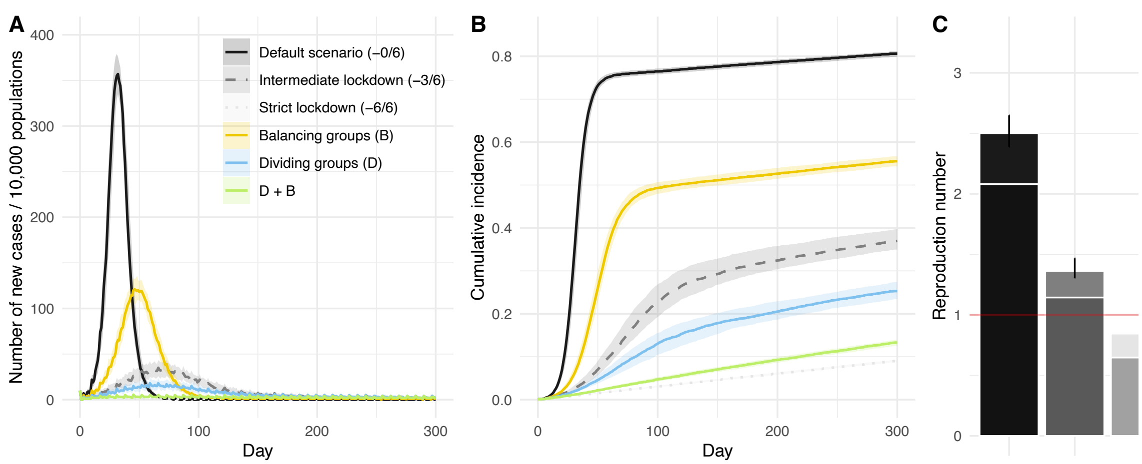

Figure S20. We introduced 10 new cases per week until Day 300 at random locations in the social networks. The explanation for each panel is the same as Figs. 2A, B, and D. The curves for the strict lockdown scenario and others in panel A are invisible because they are located near or on the x-axis (this also occurs in panel B). The results are mostly the same except that the cumulative incidence grows over the observation period due to the influx of new cases.

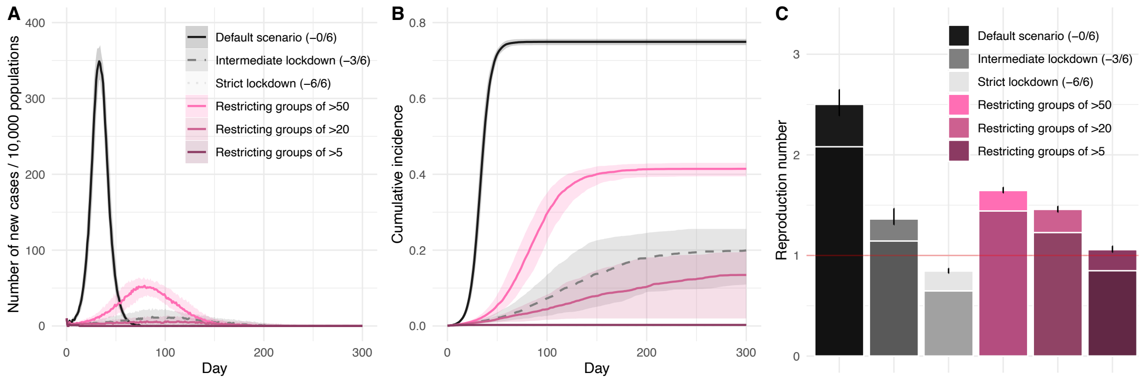

Figure S21. For the strict lockdown scenario (light grey), we make an exception in the 6 sectors, in which groups of 50 or less individuals (light pink), 20 or less individuals (pink), and 5 or less individuals (dark pink) are allowed to engage in their social and economic activities as normal. The explanation for each panel is the same as Figs. 2A, B, and D. The curves for the strict lockdown scenario and others in panel A are invisible because they are located near or on the x-axis (this also occurs in panel B). The effects of the lockdown strategies are attenuated accordingly.

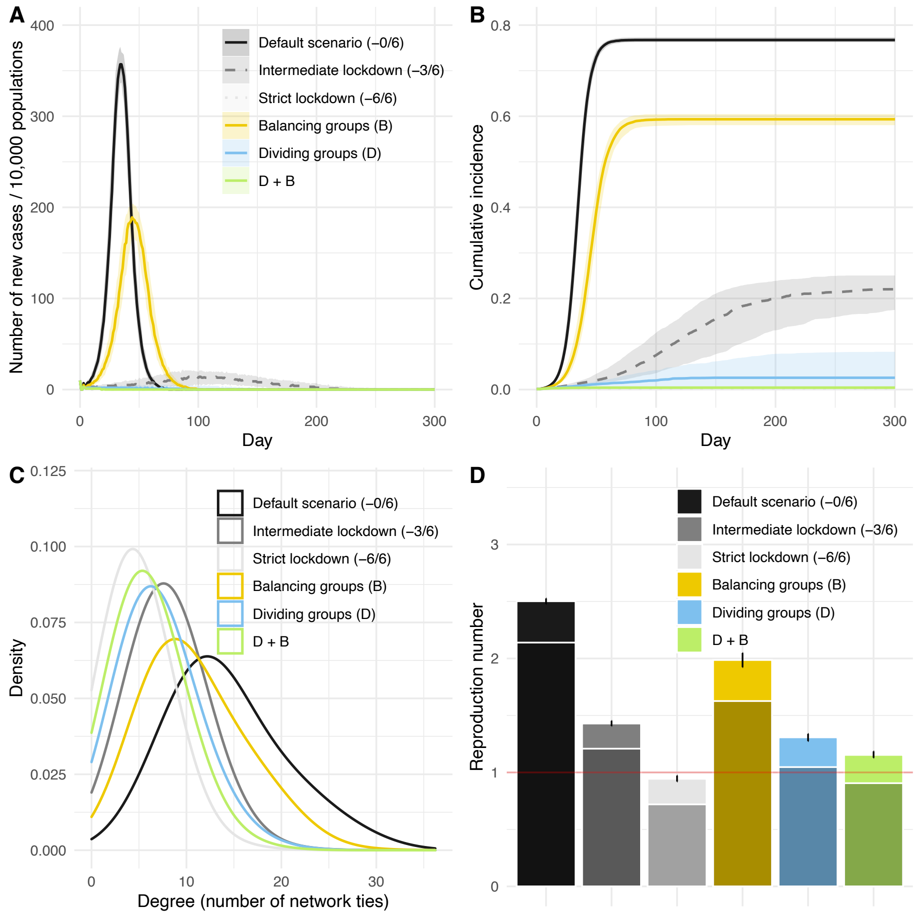

Figure S22. Robustness check: Non-random mixing for weak ties. We constructed weak ties using a non-random mixing schema, in which people preferentially sort into groups based on possession of a specific attribute and are therefore more likely to meet others who share the attribute. Transmissibility was recalculated due to the change in network structure (0.05040), such that the median R_0 of the default scenario remains equal to 2.5. The explanation for each panel is the same as Fig. 2. The curves for the strict lockdown scenario and others in panel A are invisible because they are located near or on the x-axis (this also occurs in panel B). Results show that the influence of homophily on the overall effect is minor, and the effects of the balancing and dividing strategies are somewhat attenuated because the contribution of the unchanged family ties increases due to the corresponding reduction in weak ties in the simulated social network structures.