The importance of sustained compliance with physical distancing during COVID-19 vaccination rollout: Supplementary materials

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1 Distribution of infections by vaccination status

Below we plotted the proportions of cumulative infections that originated in the vaccinated and non-vaccinated populations for scenarios where the original or a B.1.17-like variants circulate. We consider two different vaccination rates (slow and fast) and vaccination rollout combined with a compliance-targeting intervention: an intervention that targets compliance of non-vaccinated individuals, an intervention that targets compliance of vaccinated individuals and the combination of the two. We used the same values of parameters and initial conditions that were used in the main text (Table 2).

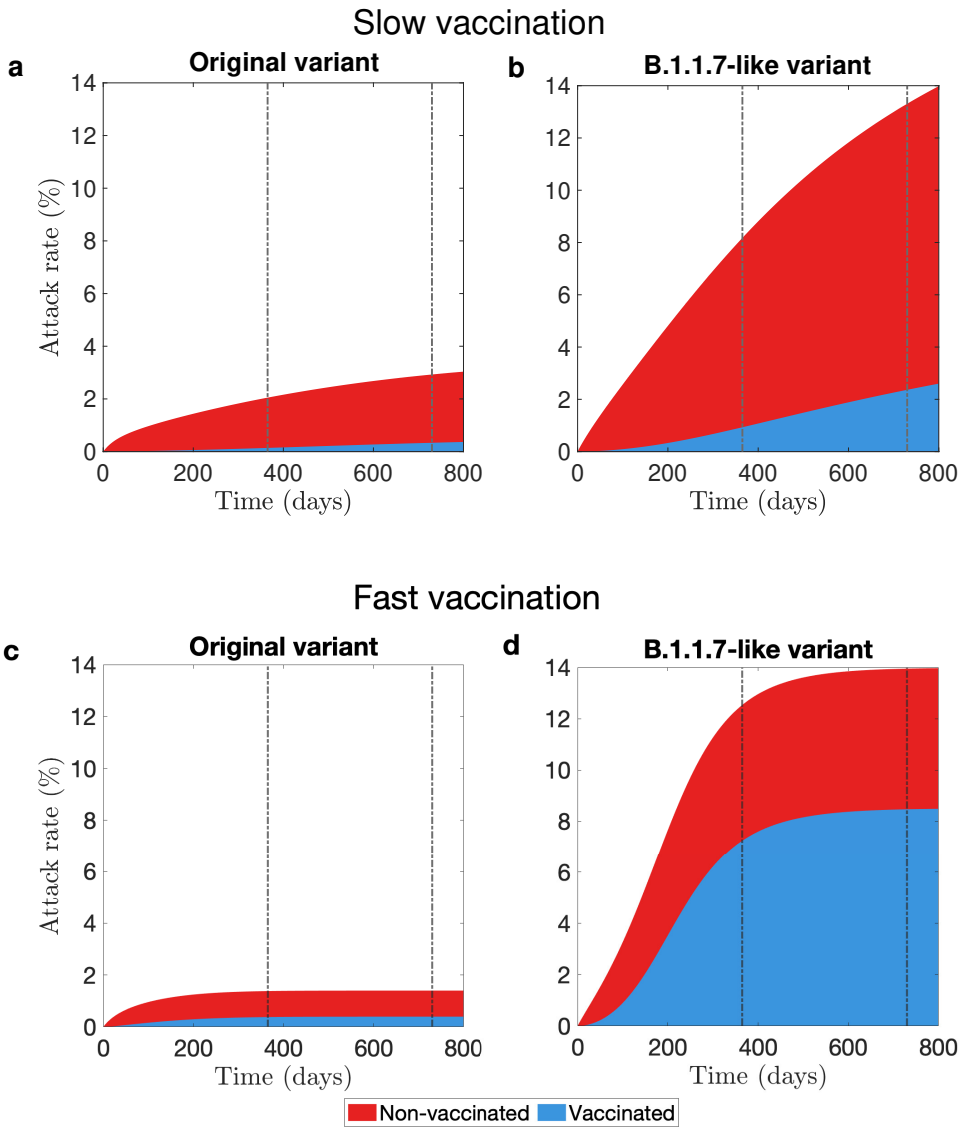

Figure 1: **Proportion of vaccinated and non-vaccinated individuals in attack rate during the vaccination rollout supplemented with intervention targeting compliance of non-vaccinated individuals. a** and **b** show attack rates versus time given the slow vaccine uptake rate. **c** and **d** show attack rates versus time given the fast vaccine uptake rate. **a** and **c** show these quantities for the original variant, **b** and **d** for a B.1.1.7-like variant. Vertical brown lines mark one and two years time points since the start of the vaccination campaign. Attack rate is the proportion of the population that has been infected until a given time.

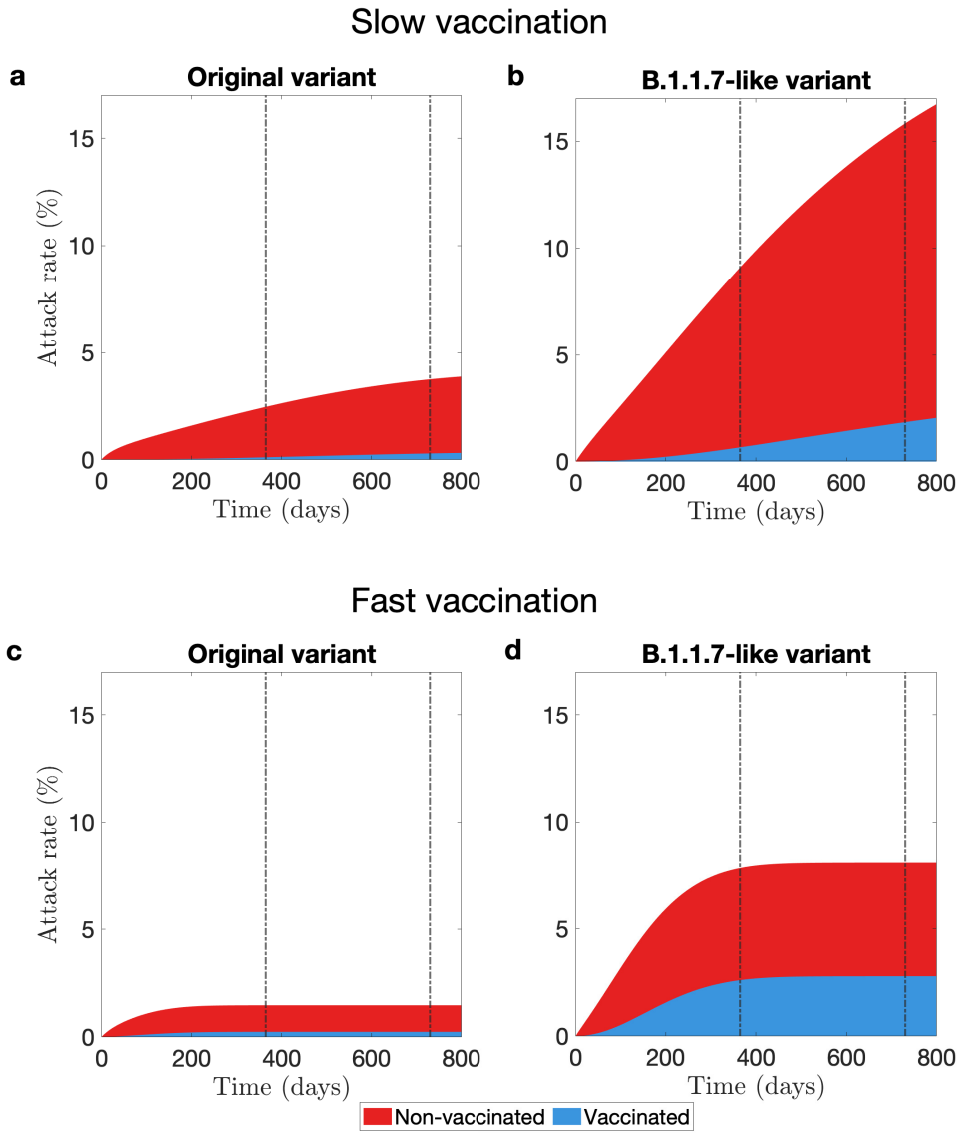

Figure 2: **Proportion of vaccinated and non-vaccinated individuals in attack rate during the vaccination rollout supplemented with intervention targeting compliance of vaccinated individuals.** **a** and **b** show attack rates versus time given the slow vaccine uptake rate. **c** and **d** show attack rates versus time given the fast vaccine uptake rate. **a** and **c** show these quantities for the original variant, **b** and **d** for a B.1.1.7-like variant. Vertical brown lines mark one and two years time points since the start of the vaccination campaign.

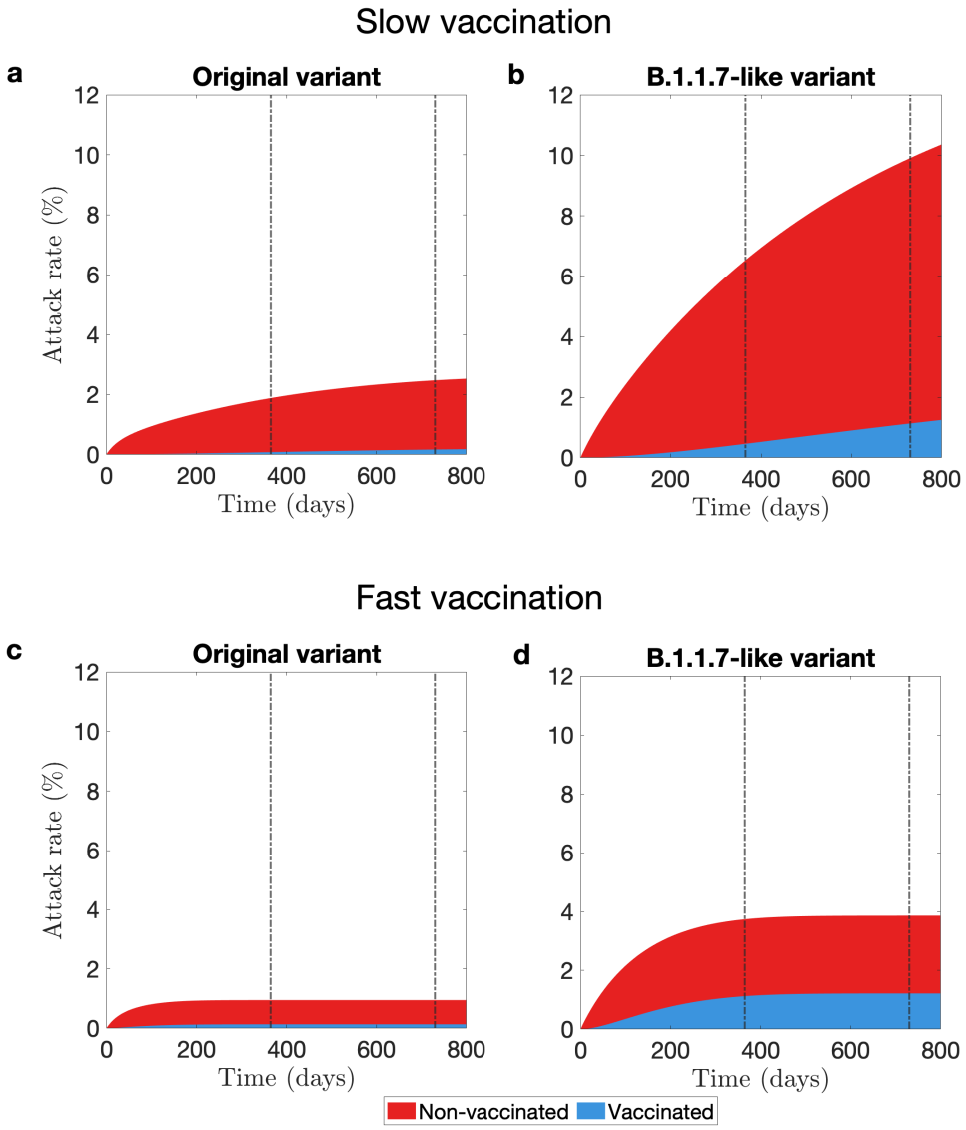

Figure 3: **Proportion of vaccinated and non-vaccinated individuals in attack rate during the vaccination rollout supplemented with intervention targeting compliance of both non-vaccinated vaccinated individuals.** **a** and **b** show attack rates versus time given the slow vaccine uptake rate. **c** and **d** show attack rates versus time given the fast vaccine uptake rate. **a** and **c** show these quantities for the original variant, **b** and **d** for a B.1.1.7-like variant. Vertical brown lines mark one and two years time points since the start of the vaccination campaign.

2 Scenarios for sensitivity analyses

Scenarios and parameter values considered in sensitivty analyses presented in the supplementary materials are summarized in Table 1.

Table 1: **List of scenarios for sensitivity analyses**

Parameter	Value (unit)	Meaning
Scenario		
Per capita compliance acquisition rate, δ		
Slow compliance acquisition	1.5×10^{-6} (1/individual)	Given a constant daily incidence of 5,387 cases, 20% of the population is compliant, see Section 3.2.2
Medium compliance acquisition	6.2×10^{-6} (1/individual)	Given a constant daily incidence of 5,387 cases. 50% of the population is compliant, see Section 3.2.2
Fast compliance acquisition[£]	4×10^{-5} (1/individual)	Given a constant daily incidence of 5,387 cases, 86% of the population is compliant, see Section 3.2.2
Compliance loss rate without vaccination, μ_0		
Slow compliance loss	1.67×10^{-2} (days)	Individuals stay compliant for 60 days
Medium compliance loss[£]	3.33×10^{-2} (days)	Individuals stay compliant for 30 days
Fast compliance loss	6.67×10^{-2} (days)	Individuals stay compliant for 15 days
Vaccination rate, υ		
Slow vaccination[£]	5.9×10^{-4} (1/day)	Slow vaccination uptake rate, based on the vaccination rate in the Netherlands on 07/01-07/02, 2021 [1]
Fast vaccination[£]	4.9×10^{-3} (1/day)	Fast vaccination uptake rate, based on the vaccination rate in the UK on 01/07-02/07, 2021 [1]
Average contact rate at the start of vaccination rollout, $c \cdot N^C(0) + r_1 \cdot c \cdot N(0)$		
Low contact rate	4 (individuals/day)	The effective reproduction number $R_e = 0.88$
Medium contact rate[£]	5 (individuals/day)	The effective reproduction number $R_e = 1.10$
High contact rate	6 (individuals/day)	The effective reproduction number $R_e = 1.32$
Reduction factor in vaccination rate of infectious individuals, k_1		
No vaccine uptake	0	
Low vaccine uptake	0.5	
High vaccine uptake[£]	1	

[£] Used in the main analyses.

3 Sensitivity analyses

In this section we investigate the sensitivity of the epidemic dynamics in a population with vaccination, but without any additional interventions targeting compliance to the assumptions about the initial conditions and the parameter values.

3.1 Initial conditions

3.1.1 Compliance distribution

In the main analysis, we calibrated the compliance distribution of the population at the start of the vaccination rollout using reported compliance with a specific measure (keeping 1.5m distance) in the Netherlands as a proxy to being compliant to all recommended measures, and subsequently substantially reducing contact rates. In what follows, we investigate effect of the initial compliance distribution on the outcomes of vaccination rollout. We differentiate between the scenarios where the original variant circulates and where B.1.1.7-like variant circulates. Additionally, we consider slow and fast vaccination rates. Here we consider three scenarios of initial compliance distribution: 20%, 65%, and 90% compliant.

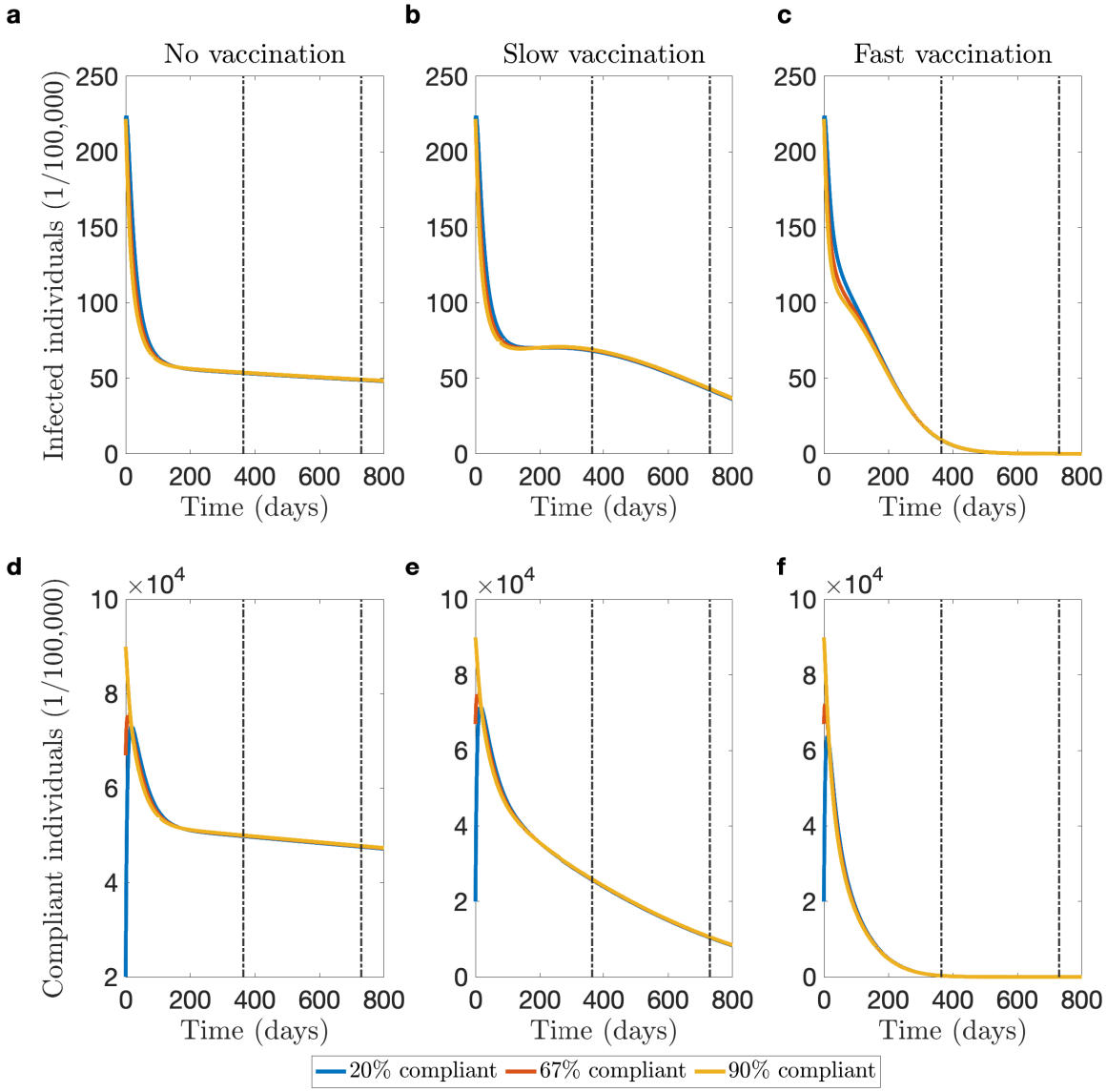

Figure 4: **Infection and compliance for different distributions of compliant individuals at the start of the vaccination rollout.** **a**, **b** and **c** show prevalence versus time, **d**, **e** and **f** show compliant population versus time. **a** and **d** show these quantities for no vaccination scenario, **b** and **e** show them for slow vaccination, and **c** and **f** for fast. The original variant is circulating. Vertical brown lines mark proportion of individuals who are vaccinated and were infected after the vaccination.

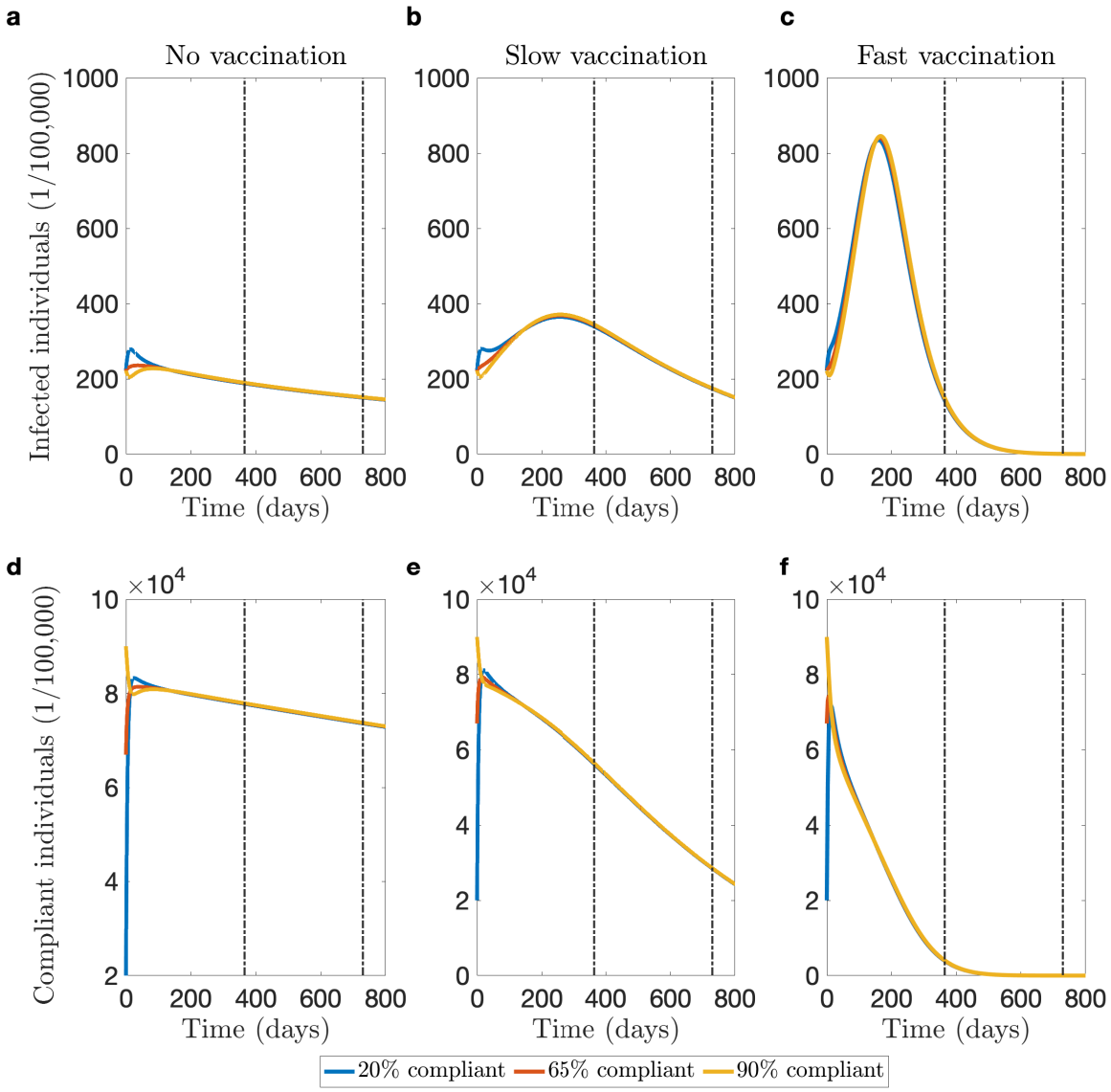

Figure 5: **Infection and compliance for different distributions of compliant individuals at the start of the vaccination rollout.** **a**, **b** and **c** show prevalence versus time, **d**, **e** and **f** show compliant population versus time. **a** and **d** show these quantities for no vaccination scenario, **b** and **e** show them for slow vaccination, and **c** and **f** for fast. A B.1.1.7-like variant is circulating. Vertical brown lines mark proportion of individuals who are vaccinated and were infected after the vaccination.

The model predicts that following an initial period, the outputs are not sensitive to the initial distribution of compliance (Figures 4 and 5).

3.1.2 Seroprevalence

We defined seroprevalence as the proportion of the population that has recovered from SARS-CoV-2 infection and is not actively infected at the start of the simulations. In the main analysis we calibrated the model such that seroprevalence in the population is 8%, which is higher than measured in the Netherlands in September/October 2020 [2]. Here we explore the impact of higher seroprevalence on epidemic and compliance dynamics by considering

higher seroprevalence values, 15% and 30%, as well as a lower value 5%. We observe that higher seroprevalence at the start of the vaccination rollout is associated with lower disease burden, where compliance needs to be maintained for a shorter period of time (Figure 6 and 7). Moreover, the vaccination rollout yields larger reductions of infections if initial seroprevalence is high.

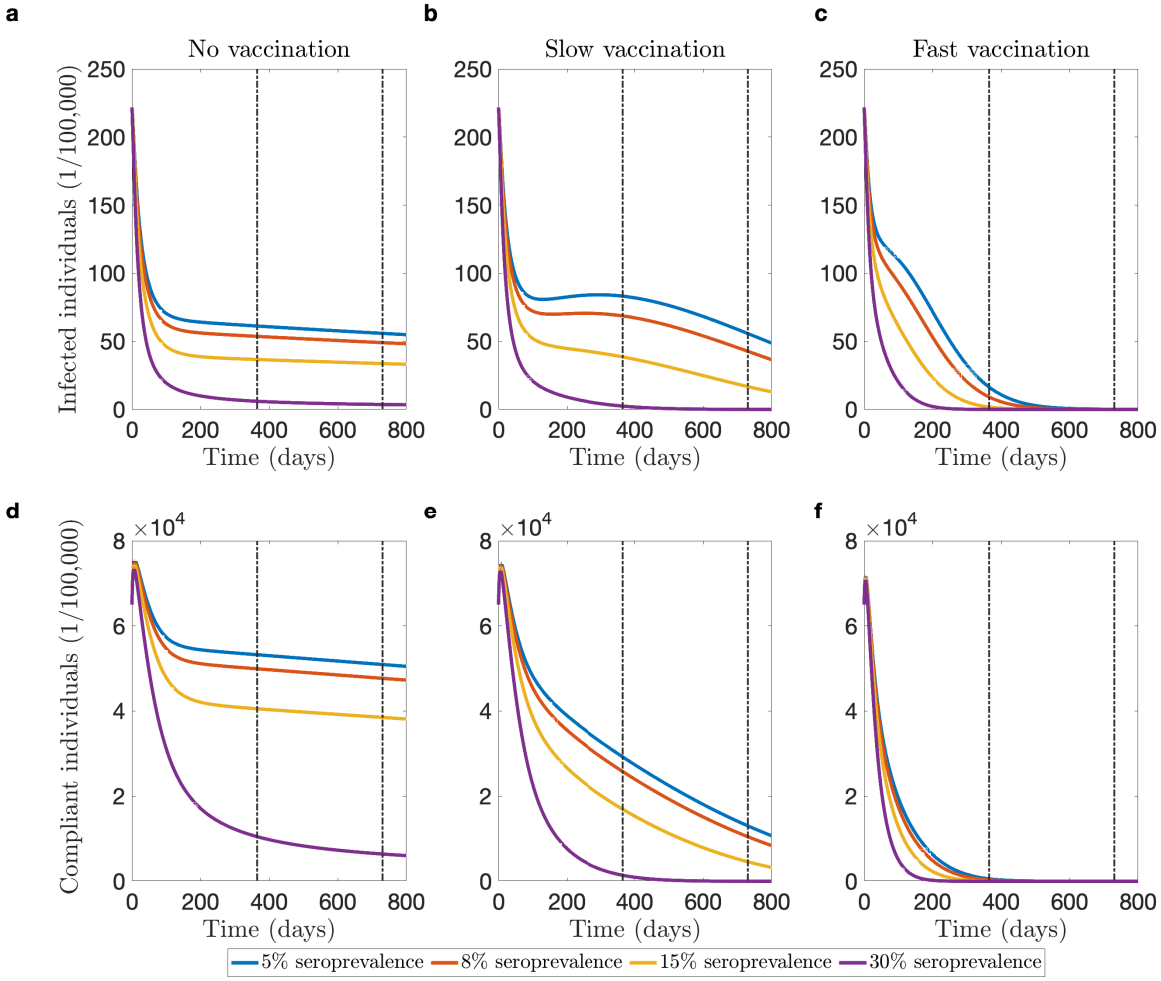

Figure 6: **Infection and compliance for different initial sizes of the recovered compartment (seroprevalence) at the start of the vaccination rollout.** **a**, **b** and **c** show prevalence versus time, **d**, **e** and **f** show compliant population versus time. **a** and **d** show these quantities for no vaccination scenario, **b** and **e** show them for slow vaccination, and **c** and **f** for fast. The original variant is circulating. Vertical brown lines mark proportion of individuals who are vaccinated and were infected after the vaccination.

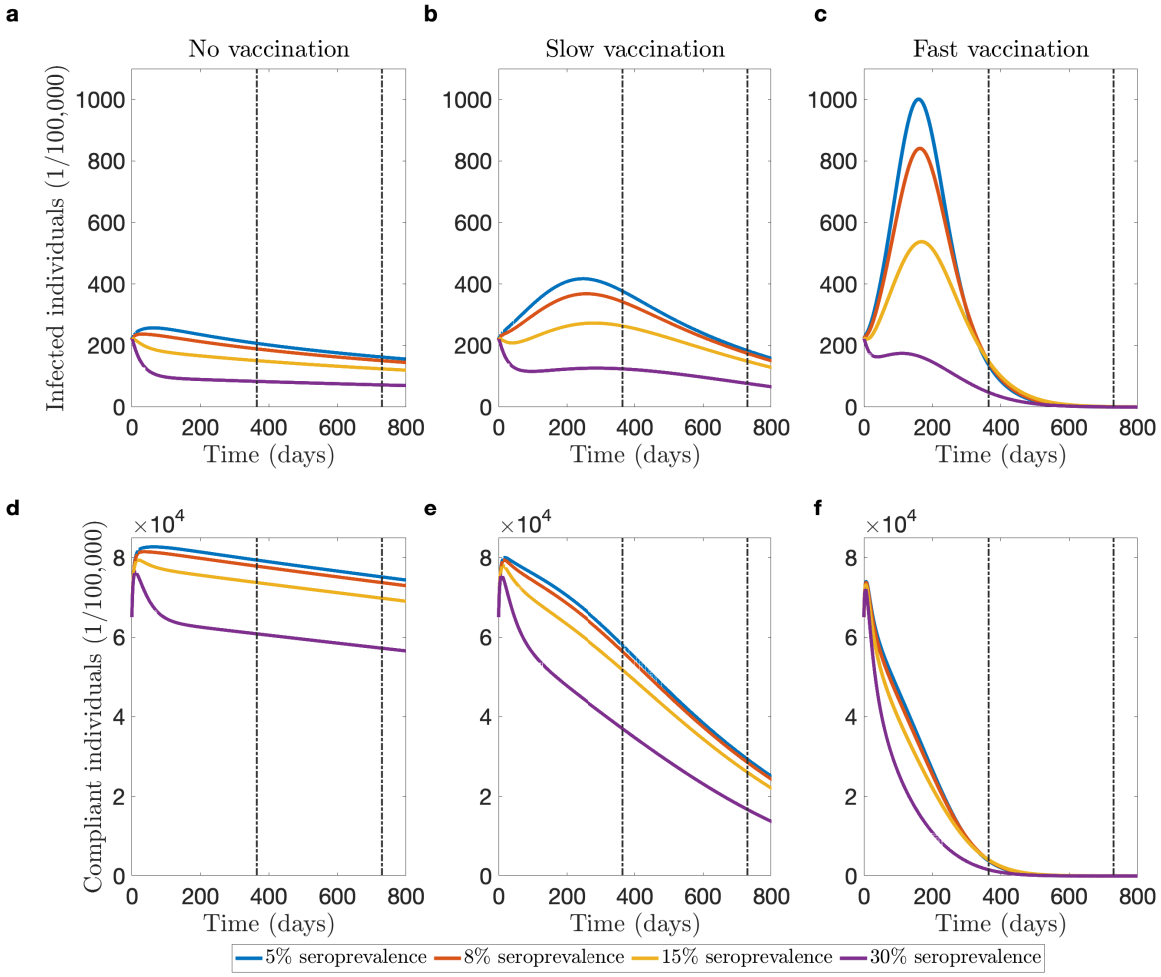

Figure 7: **Infection transmission and compliance for different initial size of the recovered compartment at the start of the vaccination rollout.** **a**, **b** and **c** show prevalence versus time, **d**, **e** and **f** show compliant population versus time. **a** and **d** show these quantities for no vaccination scenario, **b** and **e** show them for slow vaccination, and **c** and **f** for fast. A B.1.1.7-like original variant is circulating. Vertical brown lines mark proportion of individuals who are vaccinated and were infected after the vaccination.

3.1.3 Prevalence

In the main analysis we set prevalence to be equal to 37,706 individuals (0.22% when considering the population size of the Netherlands) which is equal the number of officially detected infections in the Netherlands during the week of November 11-17, 2020. However, since hallmark of SARS-CoV-2 spread is asymptomatic infections, the actual number of active infections during that week was likely to be higher. Using the estimate of infectious cases on November 11, 2020 as well as its upper and lower as provided by RIVM on Coronavirus Dashboard [3] we explored the impact of prevalence on epidemic and compliance dynamics by considering higher prevalence values, 0.48%, 0.66% and 0.85%, 82,000, 113,000 and 145,000 individuals respectively. To provide a frame of reference we also plotted the outputs for the value used in the main analysis.

We observe that for the original variant, variation of the prevalence within the interval that we considered has

little effect on the subsequent disease dynamics, qualitatively and quantitatively (Figure 8. On the other hand, for a B.1.1.7-like variant when vaccination rollout takes place there are some minor quantitative variation in the prevalence dynamics (Figures 9**e** and 9**f**), such that in the case where vaccination takes place, smaller initial prevalence corresponds to a higher secondary epidemic peak. However, difference in the initial prevalence does not affect qualitative dynamics of the prevalence, which appear to predominantly depend on the vaccination rate.

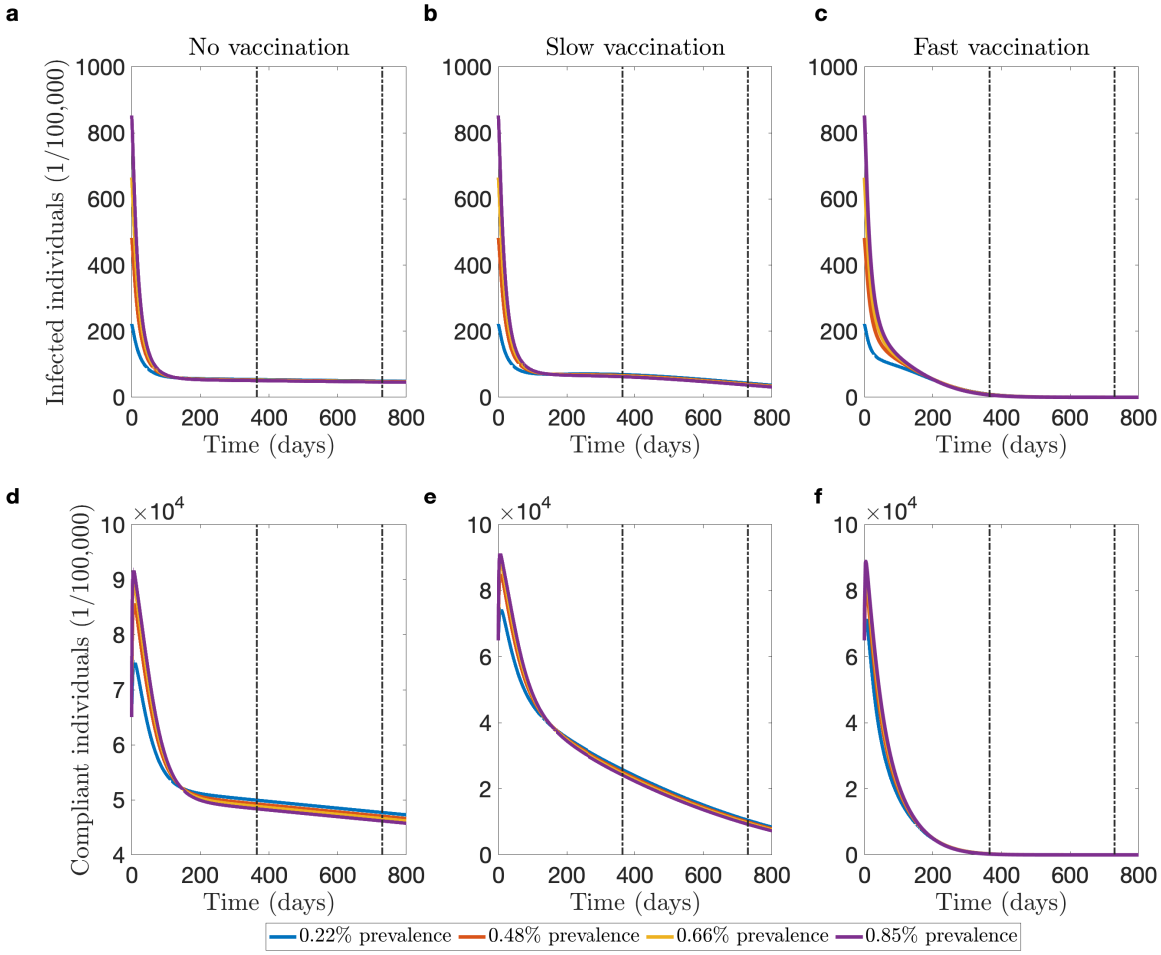

Figure 8: **Infection and compliance for different initial size of the exposed and infected compartment at the start of the vaccination rollout.** **a**, **b** and **c** show prevalence versus time, **d**, **e** and **f** show compliant population versus time. **a** and **d** show these quantities for no vaccination scenario, **b** and **e** show them for slow vaccination, and **c** and **f** for fast. The original variant is circulating. Vertical brown lines mark proportion of individuals who are vaccinated and were infected after the vaccination.

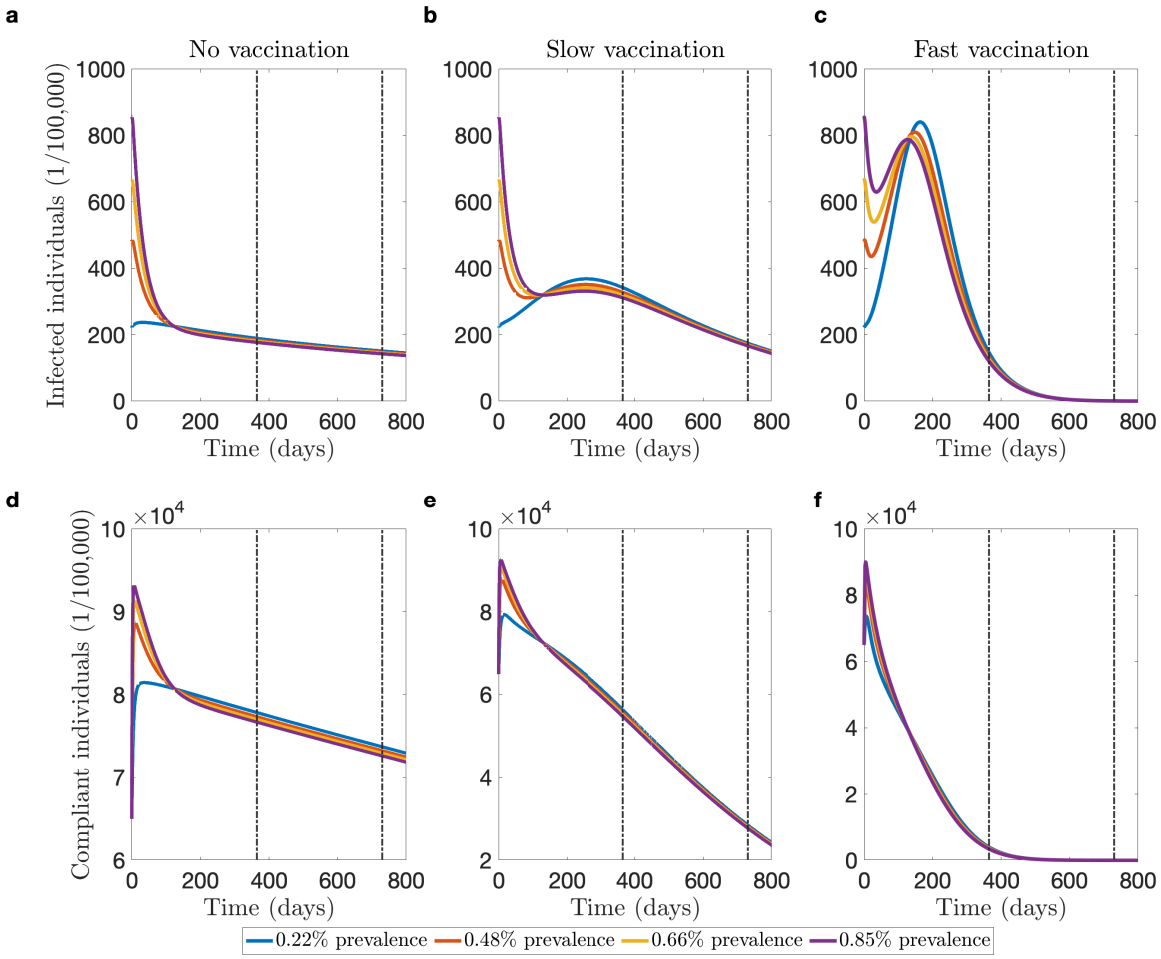

Figure 9: **Infection and compliance for different initial size of the exposed and infected compartment at the start of the vaccination rollout.** **a**, **b** and **c** show prevalence versus time, **d**, **e** and **f** show compliant population versus time. **a** and **d** show these quantities for no vaccination scenario, **b** and **e** show them for slow vaccination, and **c** and **f** for fast. A B.1.1.7-like variant is circulating. Vertical brown lines mark proportion of individuals who are vaccinated and were infected after the vaccination.

3.2 Sensitivity analysis with respect to parameters

3.2.1 Infection transmission dynamics

In this section we investigate the effect of epidemiological parameters on the epidemic dynamics in the no vaccination scenario.

Next, we consider the effects of the recovery rate, γ or conversely the duration of being infected for infectious individuals, $1/\gamma$ for which we used the 5, 7, and 9 days (Figure 10). Fixing the values of the rest of the parameters to be the same as in the main text, when the infectious period is 5 days the contact rates are 8.8 and 2.8 individuals per day for non-compliant and compliant individuals, respectively. If the infectious period lasts 7 days, the contact rates are equal to 8.8 and 3 individuals per day, respectively. Finally, for the recovery rate which lasts 9 days, the rates are 8.6 and 2.9 individuals per day.

Overall, we observe that the epidemic burden increases as the infectious period increases, and that the dynamics are more sensitive to the value of infectious period when a more transmissible variant, B.1.1.7-like, circulates (Figure 10).

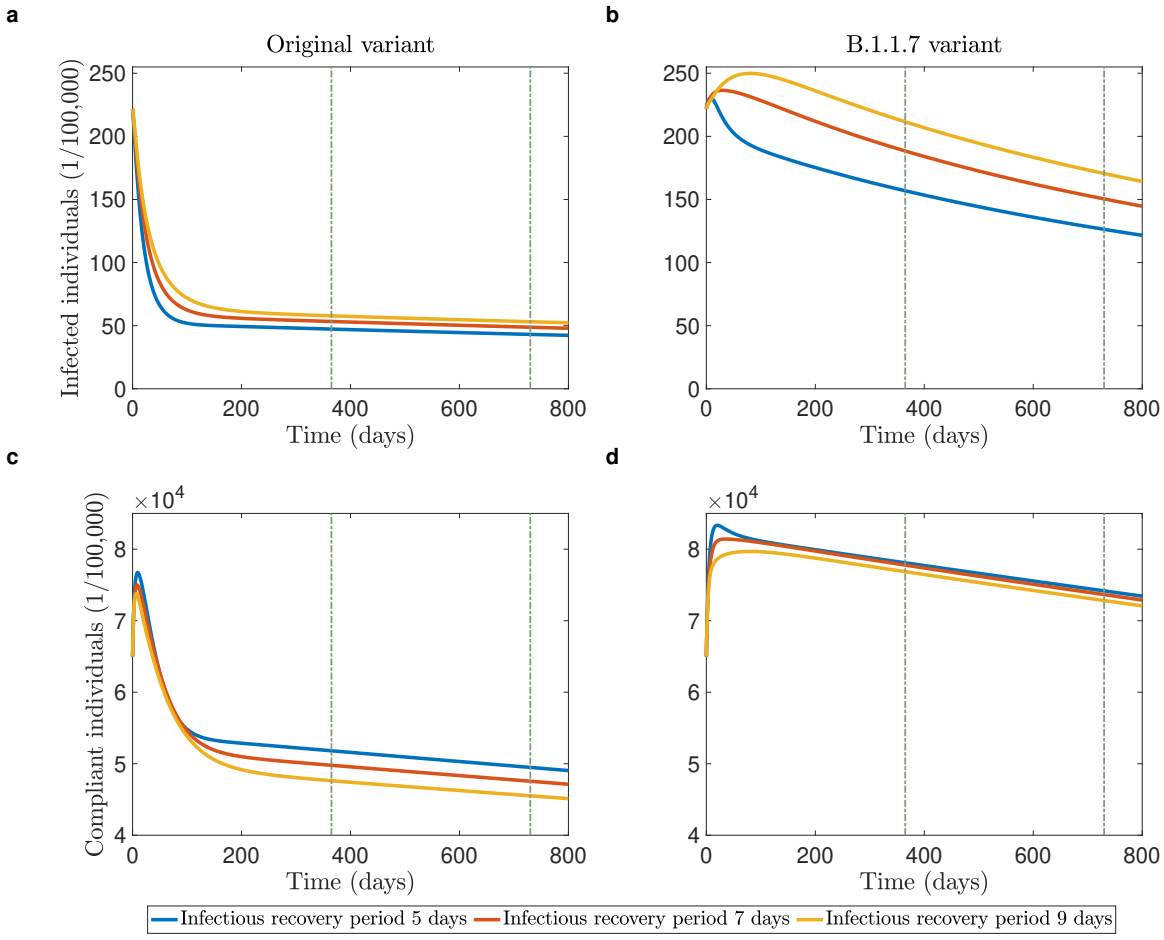

Figure 10: **Infection and compliance for different recovery rates of infectious individuals.** **a** and **b** show prevalence versus time. **c** and **d** show compliant population versus time. **a** and **c** show these quantities for the original variant, **b** and **d** for a B.1.1.7-like variant. Vertical brown lines mark one and two years time points since the start of the vaccination campaign.

3.2.2 Dynamics of compliance acquisition and loss

In the main text we set the per capita rate of moving to compliant mode, δ equal to 4×10^{-5} (1/individual). This value corresponds to 85% of population being compliant, given a constant daily incidence of infected cases 5,387 which is in agreement with the number of detected individuals on November 11-17, 2020 (Figure 11). The model predicts that if $\delta = 4 \times 10^{-5}$ nearly 87% of the population is compliant (fast compliance acquisition), if $\delta = 6.2 \times 10^{-6}$ 50% of the population is compliant (medium compliance acquisition), and if $\delta = 1.5 \times 10^{-5}$ 20% of the population is compliant slow compliance acquisition).

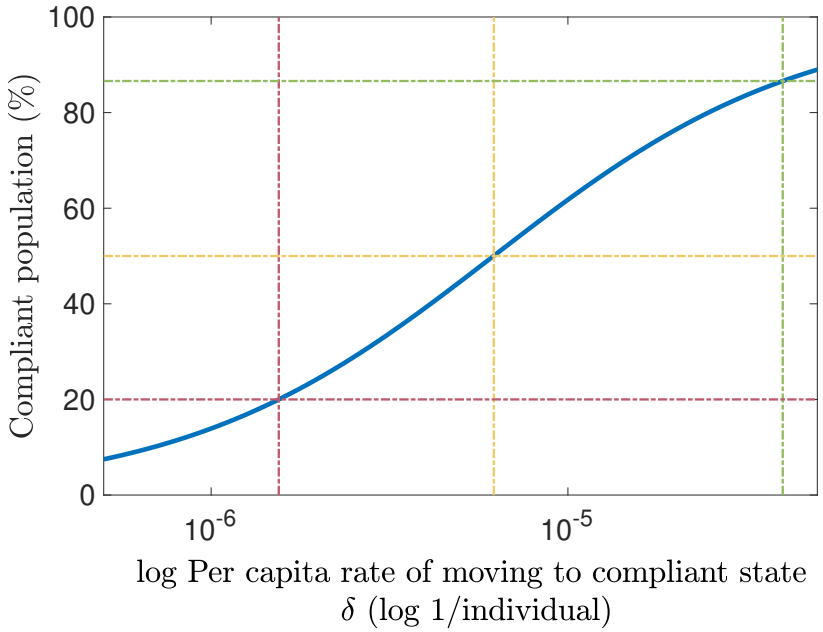

Figure 11: **Dependence of proportion of compliant population given a constant daily incidence of 5,387 cases on per capita rate of moving to compliant mode.** Intersection of dashed green lines marks the value of per capita compliance rate of moving to compliant mode, δ where nearly 87% of the population is compliant. Intersection of yellow dashed lines marks the value of δ where 50% of the population is compliant. Intersection of red dashed lines marks the value of δ where 20% of the population is compliant.

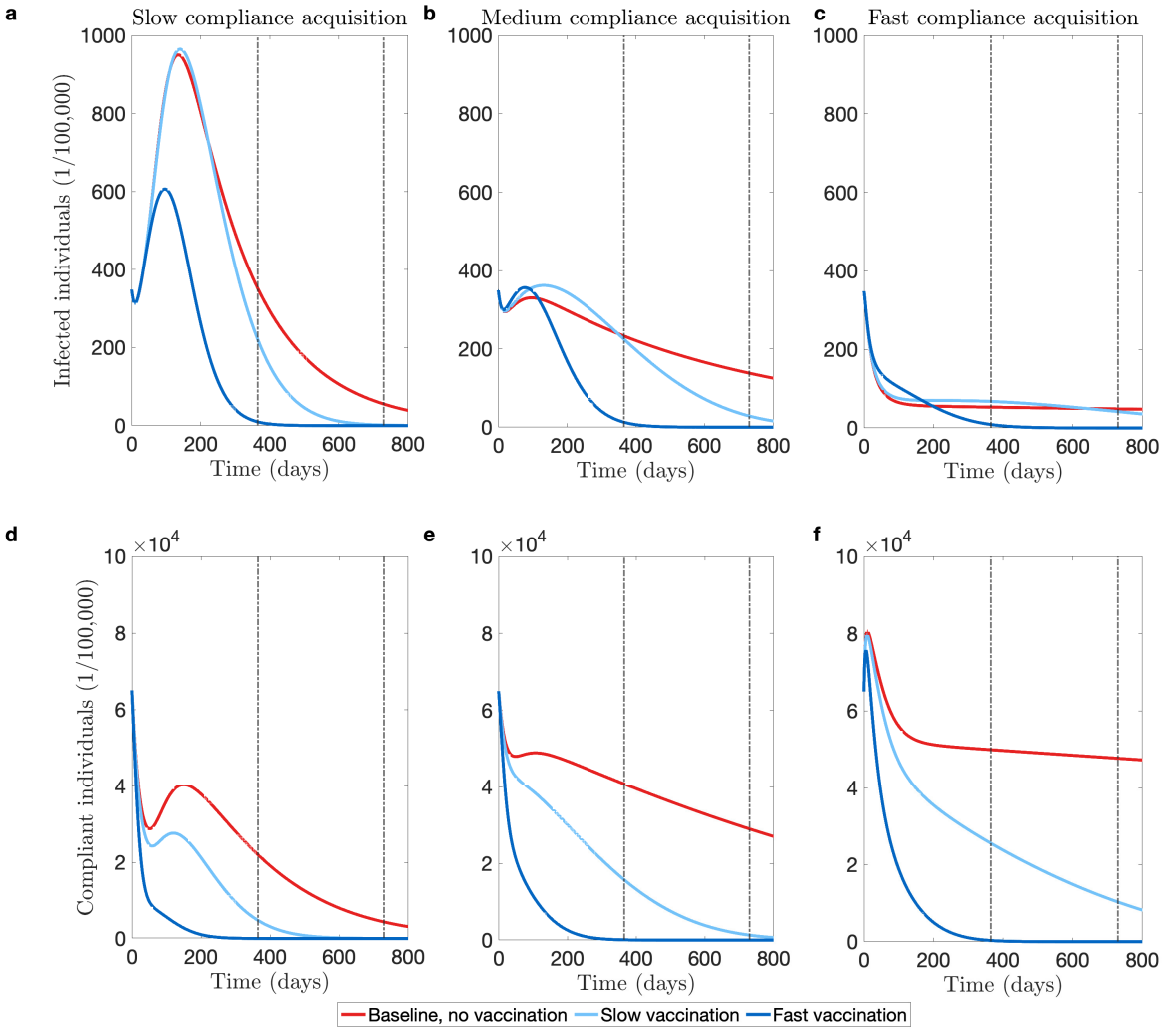

Figure 12: **Epidemic dynamics with and without vaccination for different per capita rates of becoming compliant**. **a** Prevalence of infected individuals versus time when rate of becoming compliant is slow; **b** The same output when rate of becoming compliant is slow; **c** The same output when rate of becoming compliant is fast; **d** Compliant population versus time when rate of becoming compliant is slow; **e** The same output when rate of becoming compliant is medium; **f** The same output when rate of becoming compliant is fast. The original variant is circulating. The remainder of parameters and initial conditions are set to the same values used in the main text. Vertical brown lines mark one and two years since the start of vaccination.

Recall that we differentiate between three rates of compliance acquisition rates: slow, medium, and fast (Table 1). In the main text we investigated the dynamics for the fast compliance acquisition rate. Here we investigate effect of the compliance acquisition rate on the epidemic dynamics without the vaccination, for the cases when either the original variant or B.1.1.7 are the variants circulating in the population (Figure 12). We observe that prevalence (as shown by the prevalence curves) is higher for lower compliance acquisition rates. If the compliance spread at the start of the simulations is the same order of magnitude as the incidence of infectious cases the epidemic will go through the population practically unimpeded. If the compliance spread is 100-fold faster than infection, then the prevalence peak is reduced, while if the difference between compliance spread rate and incidence of infectious cases is 1000-fold, the epidemic wave can be avoided altogether.

In the main text we set the compliance duration when there is no vaccination to be 30 days. This is an assumed value and here we test the effect of longer and shorter duration of compliance on epidemic dynamics without vaccination (Figure 13). We observe that sensitivity of the system to the duration of compliance depends on the variant that circulates. For the original variant, while the faster the compliance is lost the bigger is the epidemic burden, overall the qualitative and quantitative difference between the trajectories is not large. If more transmissible strain circulates then the difference of sizes of epidemic burdens is significant, moreover for very short duration of compliance a significant epidemic peak is possible.

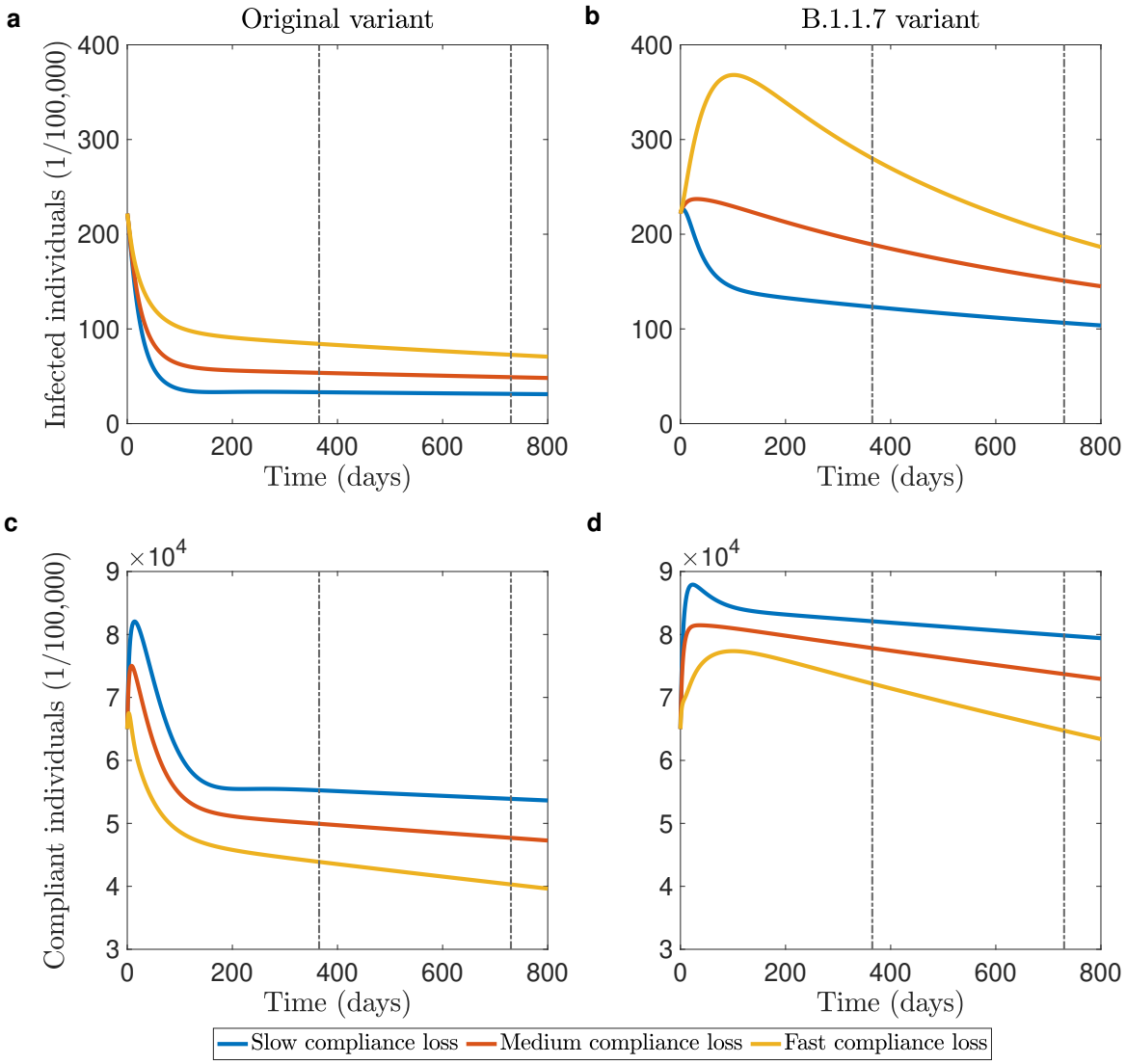

Figure 13: **Infection and compliance for different rates of compliance loss.** **a** and **b** show prevalence versus time. **c** and **d** show compliant population versus time. **a** and **c** show these quantities for the original variant, **b** and **d** for a B.1.1.7-like variant. Vertical brown lines mark one and two years time points since the start of the vaccination campaign.

In the main analysis we set up the contact rates for compliant and non-compliant individuals, such that given the

distribution of compliance, prevalence and seroprevalence is equal to 5 individuals per day. We explore effect of the average contact rate at the start of the simulations on the predicted dynamics of infection transmission without vaccination. As we varied the average contact rate, we re-calculated contact rates for non-compliant and compliant individuals and the effective reproductive number $R_e(0)$, keeping the rest of the parameters fixed. When the average contact rate is 4 individuals per day, the contact rates are equal to 7.0 and 2.4 individuals per day for non-compliant and compliant individuals, respectively with $R_e(0) = 0.88$. For the average contact rate equal to 5 the rates are 8.8 and 3.0 individuals per day with $R_e(0) = 1.1$. Finally if the contact rate is equal to 6, the contact rates are 10.5 and 4, with $R_e(0) = 1.3$. Generally, we observe that the higher is the average contact rate, the closer are contact rates of non-compliant and compliant individuals to each other.

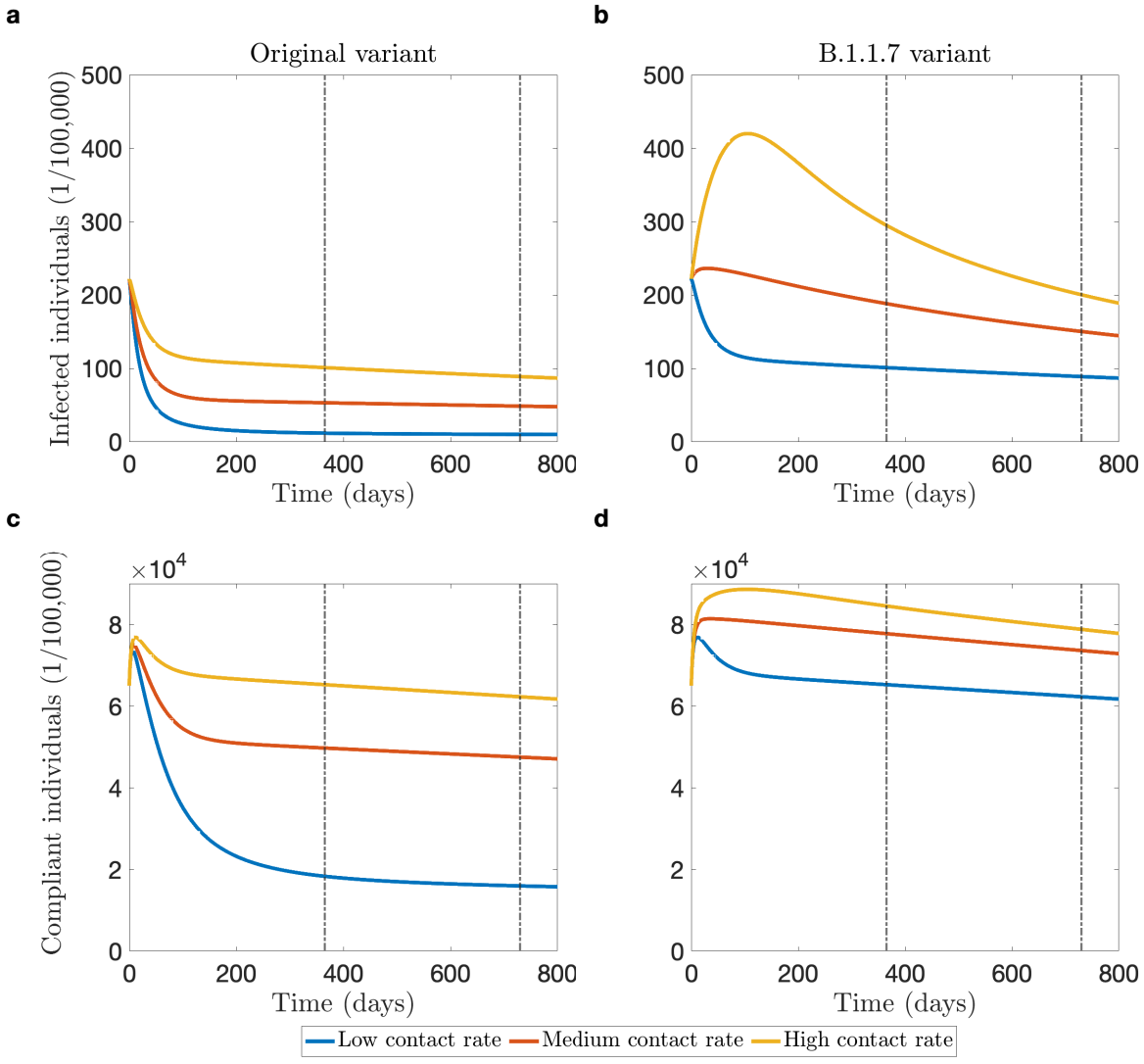

Figure 14: **Infection transmission and compliance adherence for different average contact rates at the start of vaccination rollout.** **a** and **b** show prevalence versus time. **c** and **d** show compliant population versus time. **a** and **c** show these quantities for the original variant, **b** and **d** for a B.1.1.7-like variant. Vertical brown lines mark one and two years time points since the start of the vaccination campaign. Vertical brown lines mark proportion of individuals who are vaccinated and were infected after the vaccination.

3.2.3 Vaccination

For most vaccines currently licensed for use in Europe data on their efficacy with respect to reducing susceptibility and or transmission potential is still forthcoming. In this work, we modeled vaccination as an event that works as conferring all-or-nothing protection, using efficacy of 60%. Here we investigate the effect of variation in this parameter on the interval 40-90% on the predicted epidemic dynamics, while keeping remaining parameters at the same values that were used in the main analysis (Figures 15 and 16). We observe that increasing efficacy causes for the prevalence to decrease. Finally, the simulations indicate that in order for the vaccination to produce improvements on no vaccination scenario despite waning compliance, the efficacy of the vaccine should be higher than at least 75%.

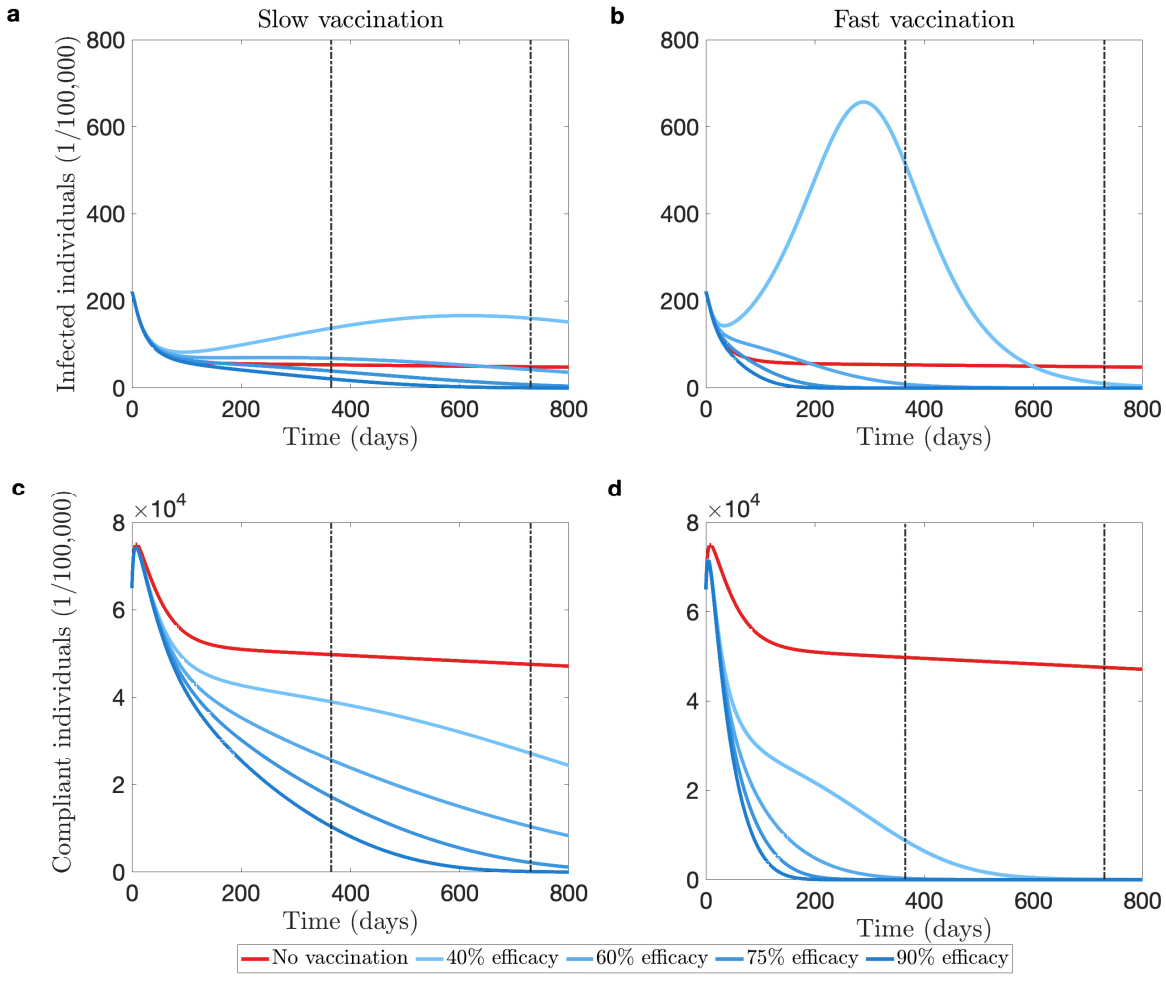

Figure 15: **Infection and compliance for different values of vaccine efficacy.** **a** and **b** show prevalence versus time. **c** and **d** show compliant population versus time. **a** and **c** show these quantities for the fast vaccination rate, **b** and **d** for the slow vaccination rate. We consider the scenario where the original variant circulates. Vertical brown lines mark one and two years time points since the start of the vaccination campaign.

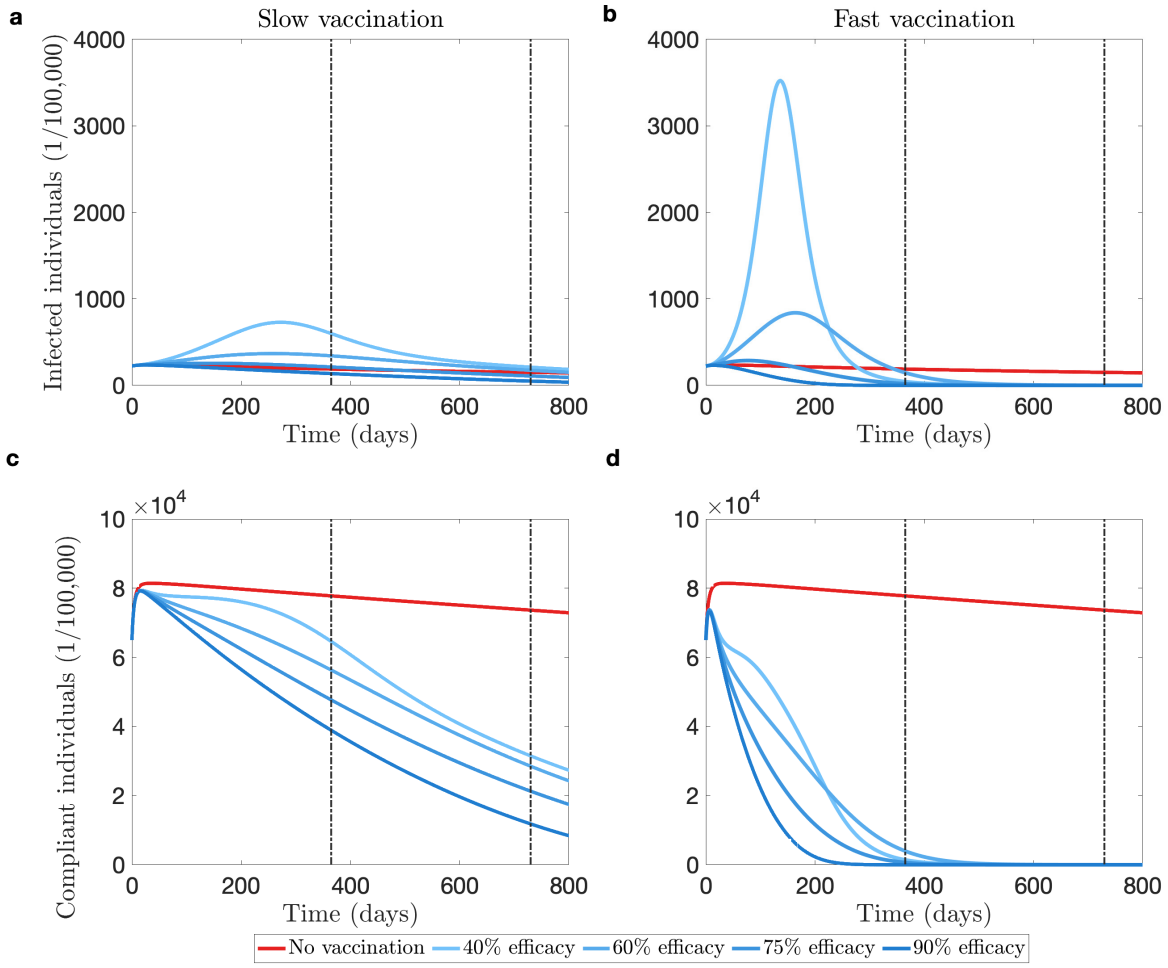

Figure 16: **Infection transmission and compliance adherence for different values of the vaccine efficacy in conferring sterilizing immunity.** **a** and **b** show prevalence versus time. **c** and **d** show compliant population versus time. **a** and **c** show these quantities for the fast vaccination rate, **b** and **d** for the slow vaccination rate. We consider the scenario where a B.1.17-like variant circulates. Vertical brown lines mark one and two years time points since the start of the vaccination campaign.

In the main analysis we assumed that individuals in all epidemiological stages are vaccinated at the same rate. Recall that in our model we do not distinguish between different classes of infectious (such as asymptomatically infected, or infectious individuals with mild or severe symptoms), however it is possible that individuals which manifest visible symptoms may not be eligible or may chose not to get vaccinated. Therefore, here we investigate the effect of varying the uptake rate for the individuals in the infectious compartment. We observe that the uptake rate of the infectious compartments does not play a significant role in the epidemic dynamics, regardless of the vaccination rate or virus variant that circulates (Figures 17 and 18). This can be explained by the relatively short duration of infectious period, which makes contribution of the infectious compartment to the total vaccination population small.

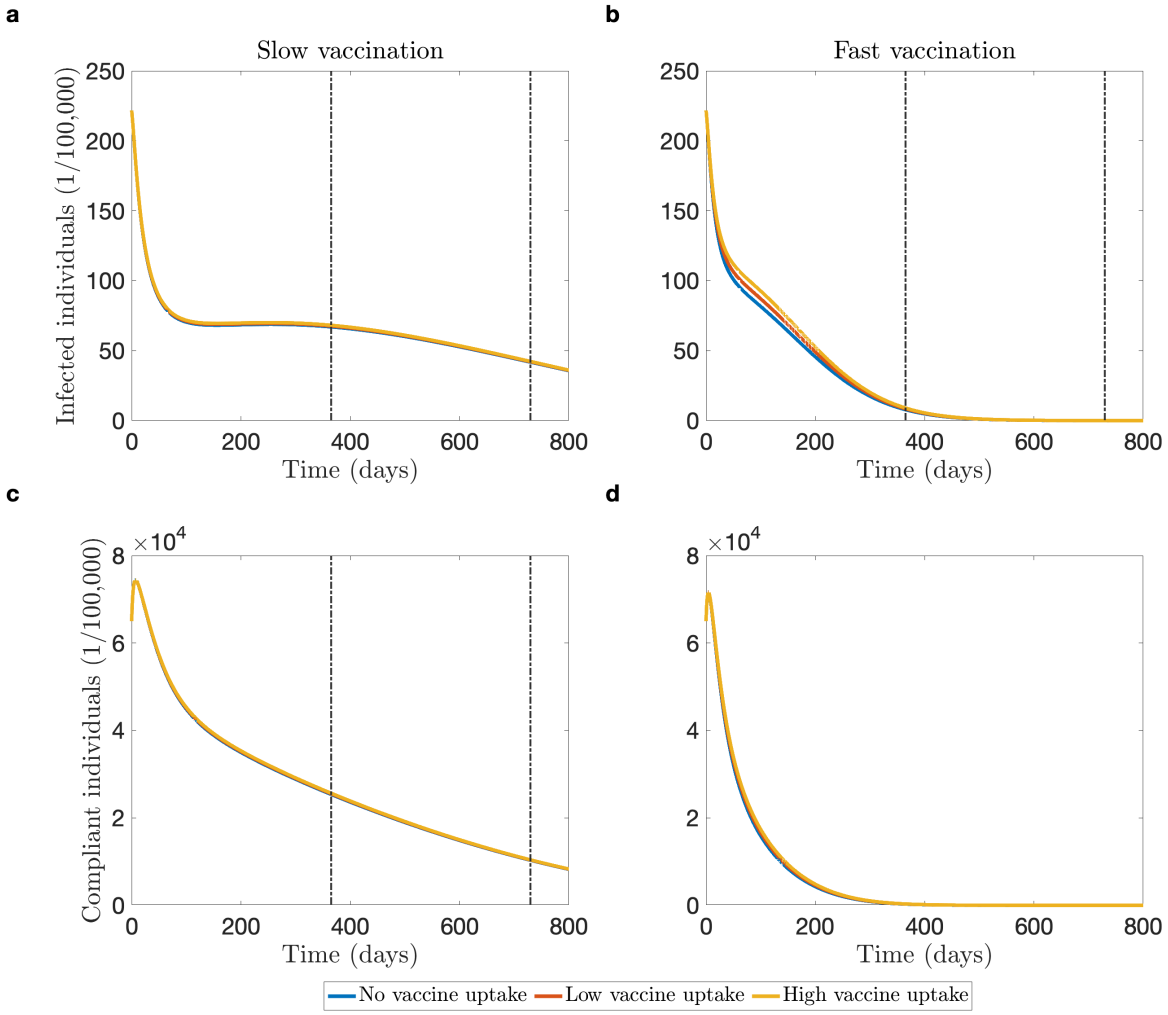

Figure 17: **Infection and compliance for different reduction factors of vaccine uptake by infectious individuals.** **a** and **b** show prevalence versus time. **c** and **d** show compliant population versus time. **a** and **c** show these quantities for the fast vaccination rate, **b** and **d** for the slow vaccination rate. We consider the scenario where the original variant circulates. Vertical brown lines mark one and two years time points since the start of the vaccination campaign.

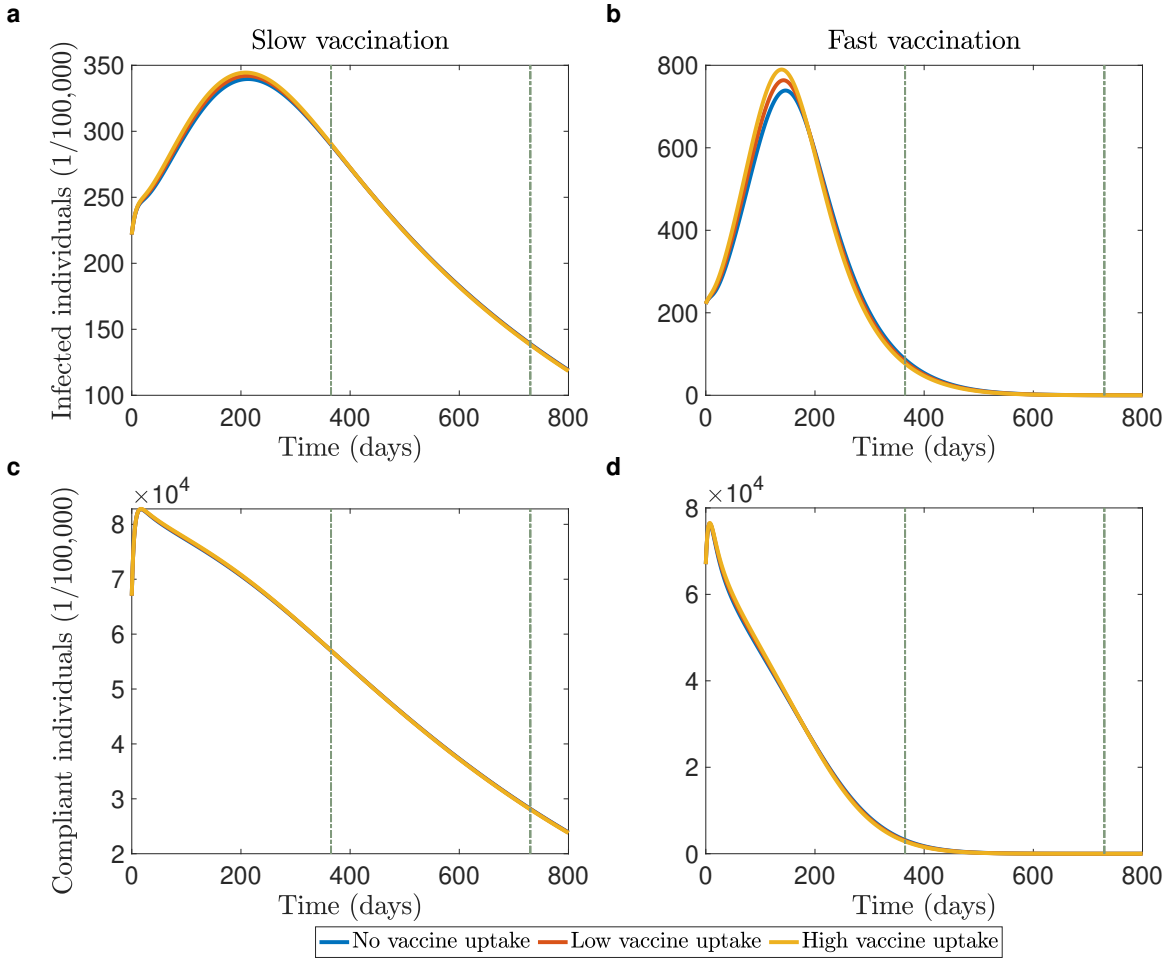

Figure 18: **Infection and compliance for different reduction factors of vaccine uptake by infectious individuals.** **a** and **b** show prevalence versus time. **c** and **d** show compliant population versus time. **a** and **c** show these quantities for the fast vaccination rate, **b** and **d** for the slow vaccination rate. We consider the scenario where the original variant circulates. Vertical brown lines mark one and two years time points since the start of the vaccination campaign.

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[1] Our World In Data. Coronavirus (COVID-19) Vaccinations, 2021. URL https://ourworldindata.org/covid-vaccinations. Accessed: March 4, 2021.

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[3] Number of infectious people: Coronavirus Dashboard:Government.nl, 2021. URL https://coronadashboard.government.nl/landelijk/besmettelijke-mensen. Accessed March 29, 2021.