In search of an effective NPI blend for COVID-19 control in rural environments: lessons learned from the early epidemic control measures in Yakima County, Washington

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What do we already know?

Multiple Non-Pharmaceutical Interventions (NPIs) have been deployed at local, state, and national levels with the aim of reducing transmission of COVID-19. Some of these NPIs include extensive shutdowns of non-essential businesses, school closures, and face mask usage mandates, among others. While some of these NPIs are easy to adopt by the community, others are harsher and have a negative impact in some communities in terms of, for example, increased unemployment. With evidence that the full combination of both strict and mild NPIs is effective, but with little data on the actual efficacy of each individual NPI, it is hard for authorities to design a combination of easier-to-adopt NPIs that are able to control disease spread.

What does this report add?

We use an agent-based model to estimate the effect that different groups of NPIs had in controlling the epidemic in Yakima County. The NPIs that we consider in this analysis are: (1) distancing and behavioral changes introduced after the Stay Home, Stay Healthy mandate in the State of Washington; (2) farmworker protection requirements introduced between April and May; and (3) face mask utilization, which significantly increased after local and State mandates in June. We further analyze COVID-19 epidemic outcomes by the end of September, with hypothetical scenarios in which farmworker protection rules and/or face mask mandates were not enacted, and compare them with the status quo. Both the estimates and the projected outcomes in the absence of some NPIs provide an assessment of the impact of NPIs in a rural county characterized by a heavy agricultural economy.

What are the implications for public health practice?

Our findings reinforce the importance of behavioral changes (e.g., increased hygiene practices, reduced social interactions, social distancing) and face mask usage as effective NPIs that contribute to tangible decreases in COVID-19 transmission rates. They also emphasize the importance of rapid response by local authorities to enact strict mandates in specific high-risk communities or industries. In the case of areas with a large influx of migrant populations, local authorities need to work with representatives of the agricultural community to devise practices and accommodations necessary to minimize the risk of transmission in temporary (and usually crowded) housing facilities. Finally, the combination of NPIs used for controlling the epidemic in Yakima County between March and September outlines successful strategies that could be taken in this or comparable rural areas when facing new outbreaks.

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Executive summary

Enactment and deployment of Non-Pharmaceutical Interventions (NPIs) should consider both the positive effect that the NPIs have in effectively controlling the disease as well as the potentially negative impact that such interventions have in the community. The goal is to deploy a combination of NPIs that maximize epidemic control and minimize the negative impact in the community.

One of the challenges for attaining such a goal is the difficulty in estimating the effect that a particular NPI, or a combination of NPIs could have. In the case of COVID-19, quantifying the effect of an NPI is not easy due to data scarcity, diversity in target populations, and concurrent deployment of multiple NPIs.

The conditions in which NPIs were applied in Yakima County, however, allowed us to effectively address the challenge of quantifying the effect of NPIs, at least to a certain level. To do that, we took advantage of the fact that, in this county, the main NPIs were not implemented concurrently but rather sequentially with a few weeks of separation between the deployment of successive NPIs. The specific NPIs considered here are: (1) Reduced contacts in workplaces and community as a result of non-essential business closures; (2) behavioral changes adopted by the community; (3) regulations specific to the agriculture industry; and (4) face mask wearing and its associated increase in behavioral changes.

We found that, in Yakima County (a county that is heavily dependent on agriculture), the adoption of specific regulations aimed at high-risk environments in the agriculture businesses had a very significant impact in reducing the rate of transmission. In our modeling analysis, high grower compliance with these regulations are responsible for 50% to 60% reductions of COVID-19 transmission rate in farmworker housing facilities. Furthermore, we found that face masks and the attendant increase in other protective behaviors reduces transmission by at least 27%. Combined with behavioral changes adopted by the community, these NPIs have contributed to controlling the spread of COVID-19 even after the initial relaxation of business closures that started under the “Roadmap to Recovery for Yakima” plan initiated in late August.

Continued use of these interventions, including tailoring industry-specific regulations to meet the needs of specific worksites and situations, is then recommended until disease spread is contained or successful treatments or vaccines become widely available. In particular, continued use of face masks, industry-based rules, and policy enforcement, combined with cautious reopenings with an eye toward industry-specific closures or regulations, should be maintained for COVID-19 epidemic control.

Key inputs, assumptions, and limitations of our modeling approach

We used Covasim, an agent-based model of COVID-19 transmission and interventions developed by the Institute for Disease Modeling, to estimate the efficacy and historical impact of face masks in Yakima County, Washington. This study attempts to disentangle the impact of face coverings from other factors that influence transmission of COVID-19 such as reductions in mobility associated shelter-in-place and work-from-home orders, and other non-pharmaceutical interventions such as personal hygiene and physical distancing. This analysis is challenging because of many unknowns surrounding mask usage and efficacy. While there is growing anecdotal and observational evidence that masks slow the spread of COVID-19, no gold-standard randomized controlled trials have assessed the efficacy of homemade masks when used by the general public. A further challenge is that detailed data on mask usage does not exist at this time. Mask usage by the general public has changed dramatically over time from near-zero in early March to levels estimated to be near 95% in Yakima county. Furthermore, we expect that mask usage is heterogeneous, varying by the type of mask, as well as by age and risk/ethnicity of individuals. Lastly, increased mask usage likely occurs with an attendant increase in other personal protective behaviors, thus mask wearing is really a combination of all these factors.

Considering these crucial limitations, an analysis such as this would not be possible without significant assumptions. We explain these assumptions in detail in the following sections, but briefly:

1. We assume that COVID-19 transmission occurs at some rate between contacts. Masks and other non-pharmaceutical interventions modify the transmission rate per contact, but transmission is also affected by reductions in contacts due to behavior change and stay-at-home orders. As part of assessing the efficacy and potential impact of masks, we assume that changes in physical contacts can be estimated by cell phone mobility data provided by SafeGraph.
2. The transmission rate per contact is driven by a number of factors including personal hygiene, physical distancing, environment (outdoor/indoor/ventilation), eye protection, and masks.
3. We cannot differentiate the physical act of wearing a face mask or covering from other policy or behavioral changes associated with masks. Throughout this analysis, the term “masks” should be interpreted in the broad sense.

Beyond the core modeling assumptions described above, we note the following additional assumptions and limitations of this analysis:

- Yakima is a rural county with the majority of the economy relying on agriculture. The analyses and conclusions in this report would not necessarily extend to other settings such as urban or non-agricultural (e.g., mining) regions.
- Masks are not used at home; changes in mask usage over time affects only work and community contacts. Schools are closed during the period in which mask usage increased in this setting.
- Children under 6 years of age do not wear masks.
- Mask usage reduces transmission and acquisition probabilities-per-contact in equal magnitudes.
- In estimating mortality impacts, we have not considered hospital bed constraints.
- Importations to Yakima County from other counties, states, or countries are not considered.

Evolution of the COVID-19 epidemic in Yakima County

Yakima County is a rural county located in the south central region of Washington. It has a population of approximately 250,000 inhabitants, but every year receives seasonal (migrant) workers to help with its agriculture-based economy. This year, more than 15,000 seasonal workers were estimated to be in Yakima for the harvest season.

The evolution of the COVID-19 epidemic in Yakima is shown in Figure 1. The first cases of COVID-19 in Yakima were confirmed on March 8[2]. The number of cases kept increasing and, by mid-May, Yakima County had the highest rate of COVID-19 infections among counties on the West Coast (see https://www.spokanepublicradio.org/post/whats-driving-high-rate-covid-19-yakima-county). This led to local and state health authorities, along with agriculture industry representatives, to deploy increased protections that, by complementing those in place before May, could bring the epidemic under control. The case counts from June to August show a decreasing trend, showing that the full set of NPIs, combined with community adoption of better practices, were successful. This allowed health authorities to initiate gradual reopenings through the "Safe Start Yakima County" program starting in mid-August, enabling the operation of an increased number of businesses and commercial activity.

[2] Based on our modeling results, we estimate that there were between 177-256 infections on March 1 (see Appendix A)

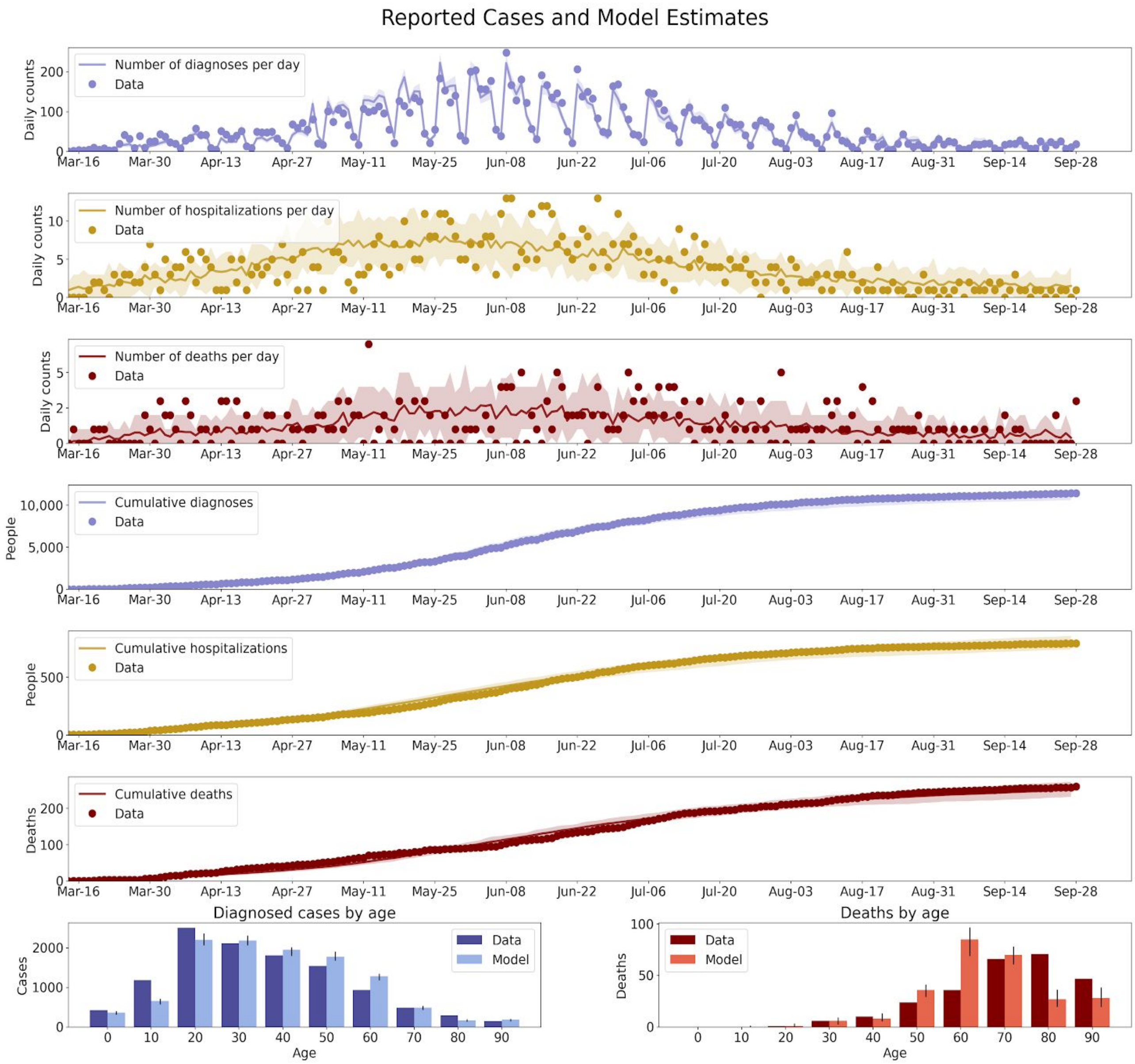

Figure 1. *Daily and cumulative counts of positive diagnoses, hospitalizations, and deaths show an increasing trend for the COVID-19 outbreak in Yakima County until June, at which point the number of daily cases start decreasing. Cumulative cases and deaths by age show higher incidence in adults, as well as higher mortality in older populations.*

Effect of Non-Pharmaceutical Interventions (NPI)

NPIs were introduced in Yakima County primarily through state and local mandates, along with their associated communication campaigns. These mandates are:

- **Stay Home—Stay Healthy (March 23):** State of Washington mandate prohibiting people to leave their place of residence for non-essential activities, prohibiting multi-person activities (e.g., social and spiritual gatherings, concerts, festivals), and ceasing operations of non-essential businesses.

- **State of Washington Farmworker Protection Requirements (April 23):** The Washington State Department of Health released new rules for farmworker housing on May 13. These new rules added more detail to those outlined in an earlier proclamation for high-risk employees, and many of them had already been put in practice weeks before their release by the Washington State Department of Health. In particular, we estimate that the new rules were put in practice by April 23. The new rules required housing operators to ensure specific conditions in sleeping quarters (e.g., spacing beds at least 6 feet apart), group shelter (e.g., maintaining the same occupants in each group shelter), cleaning (e.g, frequent cleaning and disinfection), and case management (e.g., providing transportation for medical evaluation or treatment), as described in the Guidance for Emergence Rule WAC-296-307-16102.

- **Yakima Health District Face Mask Directive (June 3):** Local directive requiring face coverings in indoor and confined outdoor public places. The directive was accompanied with a "Mask up to Open up" campaign, which included the free distribution of more than 300,000 face masks.

- **State of Washington Face Mask Orders (June 23):** New orders for Yakima County were imposed by Governor Inslee. These orders made the use of face masks in public places mandatory, reinforcing local Yakima Health District Directive on face mask usage from June 3.

- **Roadmap to Recovery for Yakima (August 27):** The Washington State Department of Health approved a modified phase 1 "Roadmap to Recovery" plan for Yakima County. Under this plan, indoor dining, religious services, in-store retail, professional services, and real estate services, among other services, were approved with reduced capacity (see press release for details).

The direct effect of these mandates on the epidemic dynamics is shown in Figure 2. The figure shows an estimated cumulative incidence of 15% by the end of September. It also shows distinct changes in transmission trends after the introduction of each mandate or intervention: the effective reproductive number (R_{eff}) decreases to around 1.3 after the Stay Home—Stay Healthy (SHSH) introduction, further decreases to levels close to 1.0 after the deployment of State of Washington orders for farmworker housing and finally decreases to around 0.8 after face mask mandates are put in place.

Although the impact of the mandates has been positive, one important question remains: "What is the effect of each of these mandates or interventions?" Answering this question is important for effectively translating successful interventions into other settings, as well as for safely rolling back business and community restrictions when appropriate. It also helps in defining and prioritizing interventions and mandates in case the epidemic starts showing consistent increasing trends. A model-based estimation of the effect of mandates and interventions, which could help in answering the question above, is next.

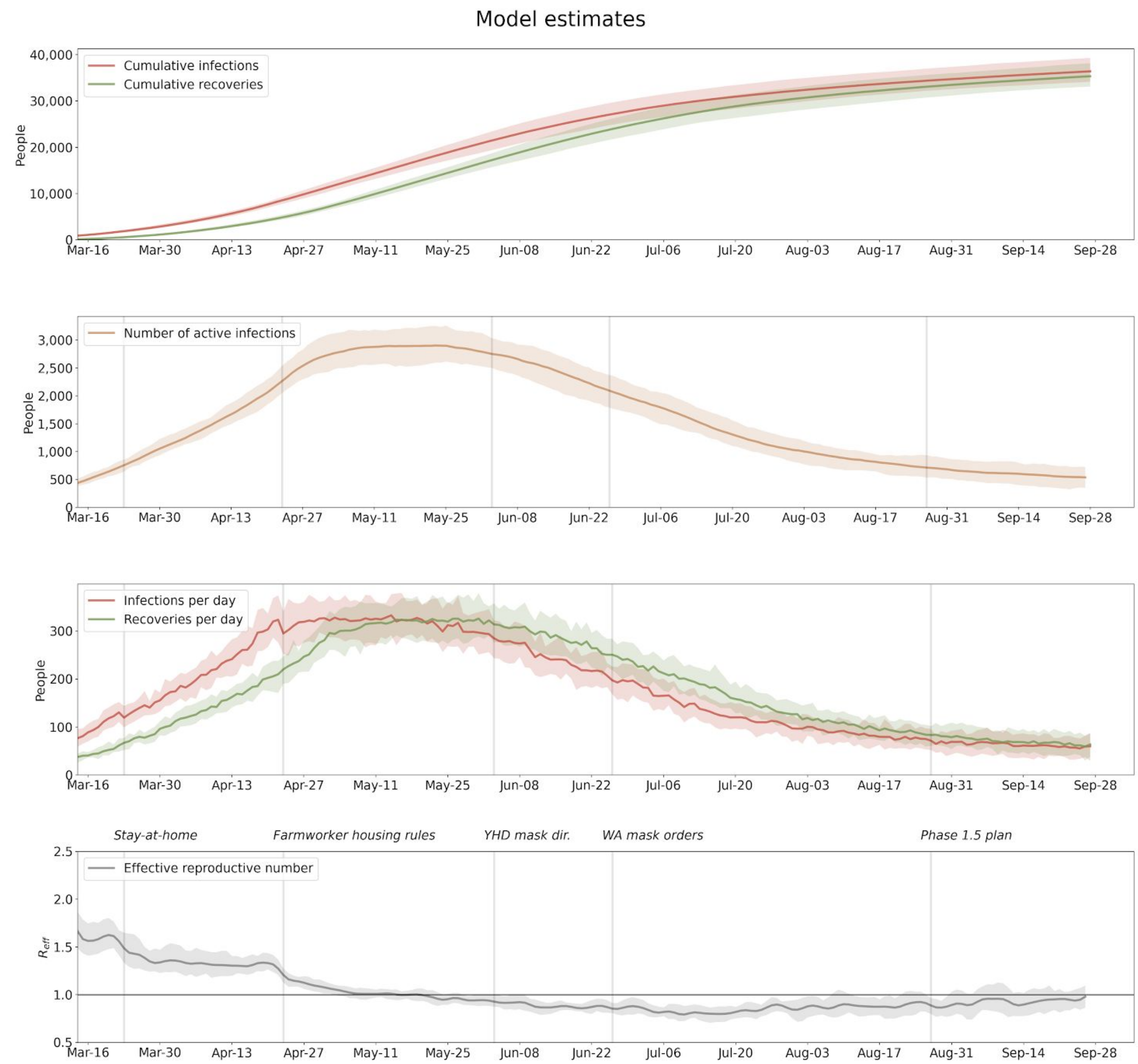

Figure 2. *Estimated number of infections and effective reproductive number (Reff) in Yakima County. The Reff estimate shows important drops after the introduction of mitigation orders, and a slight increase and stabilization around 1.0 after Safe Start reopenings for Yakima began in late August.*

Reduced activity in community, workplaces, and community

Initial reductions in disease transmission observed right after the introduction of Stay Home, Stay Healthy (SHSH) are explained by both decreases in activity in schools, workplaces, and community, as well as by behavioral changes adopted by Yakima residents. Decreases in activity are important as they effectively reduce the number of contacts among residents.

We can estimate business, community, and schools activity changes using cell phone activity data. Figure 3 shows such changes using SafeGraph weekly patterns data for Yakima County. The figure shows how, immediately after the introduction of SHSH, there is a significant decrease in activity in schools (due to school closures), as well as in businesses (due to non-essential business closures). The drop in activity in schools is significant as most students moved to a distance-learning model. The drop in activity in non-essential business is, however, limited to about 60% of the levels observed on February 29 (i.e. a 40% reduction). The reason for this relatively mild drop is possibly explained by the fact that the economy in the county is primarily based on agriculture, which is deemed as an essential industry. It is worth noting how business activity starts showing an increasing trend in May, not long after SHSH. This increase coincides with expected increase in agriculture activity in the region due to the start of the harvest season.

Business and schools activity estimates are used to inform our model of changes in the number of contacts that a person has in workplace, community, and school layers. In particular, relative changes in employee activity shown in Figure 3 translates into relative changes in the number of contacts that an individual has in the workplace layer (model). For example, a value of 0.5 relative visits per week for employees corresponds to a 0.5 reduction of the average number of contacts that a person has in the model. Similarly, changes relative visits of customers and schools translate into changes in the number of contacts in the community and schools layer, respectively.

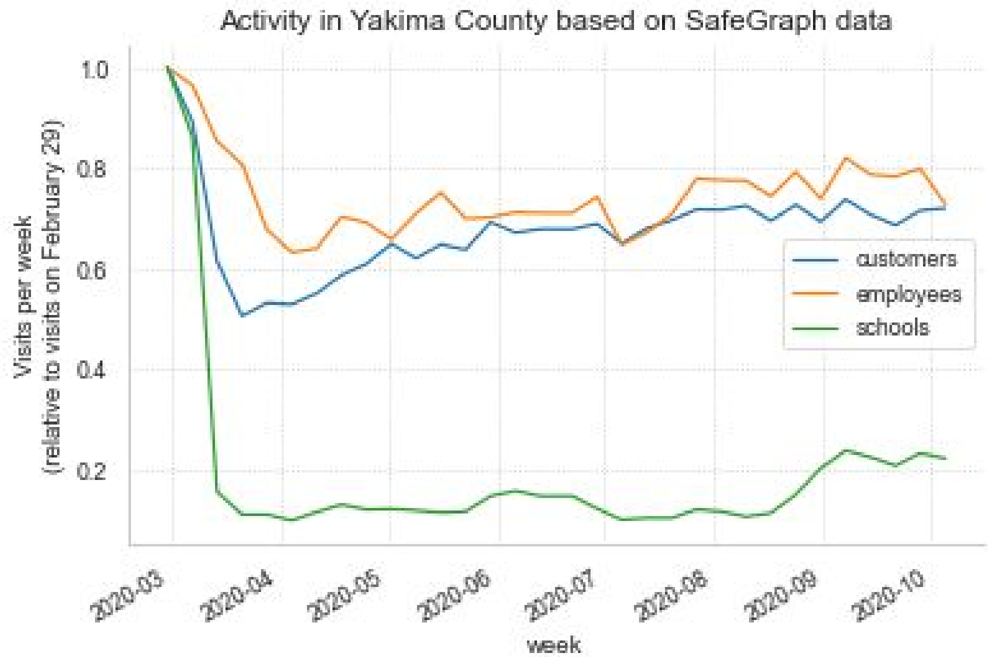

Figure 3. *Number of visits in schools and businesses relative visits on February 29, 2020. The number of visits is based on SafeGraph data. We assume that visits to businesses lasting less than 4 hours are considered to be customer visits whereas visits lasting more than 4 hours are considered visits by employees. Overall activity decreases after Stay Home—Stay Healthy orders on March 23, and starts an increasing trend after the beginning of April.*

Behavioral changes in community, workplaces, and schools

Behavioral changes early in the epidemic included a combination of increased hygiene practices, reduced social interactions, and increased social distancing, as well as case management NPIs such as isolating and quarantining diagnosed cases.

We can estimate the combined effect of these behavioral changes by quantifying how much the transmission rate[3] decreases when we introduce these changes in our model. In our model, this change is done using a factor or "transmission multiplier" that modifies the transmission rate. If the transmission multiplier is 1, then transmission rate is not affected by the behavioral change; similarly, if the transmission multiplier is 0.5, then the transmission rate is reduced by 50%. The transmission multipliers are found through calibration (see Appendix A), and are shown in Figure 4 for the community, workplace, and schools layer. For community and workplaces, there is not a significant attenuation in transmission that can be attributed to behavioral changes before March 22. After SHSH on March 23, however, transmission is estimated to consistently decrease to values between 0.75 and

[3] The transmission rate is the probability of transmission per contact per day. The estimated transmission rate for this study is in Appendix A.

0.82 (the estimate for the period after September 1 shows high uncertainty, but is also likely to fall close to this interval). Similarly, there is an estimated attenuation in transmission in schools of between 0.85 and 0.9. Due to schools being mostly closed since March 23, the uncertainty of this interval estimate is also high.

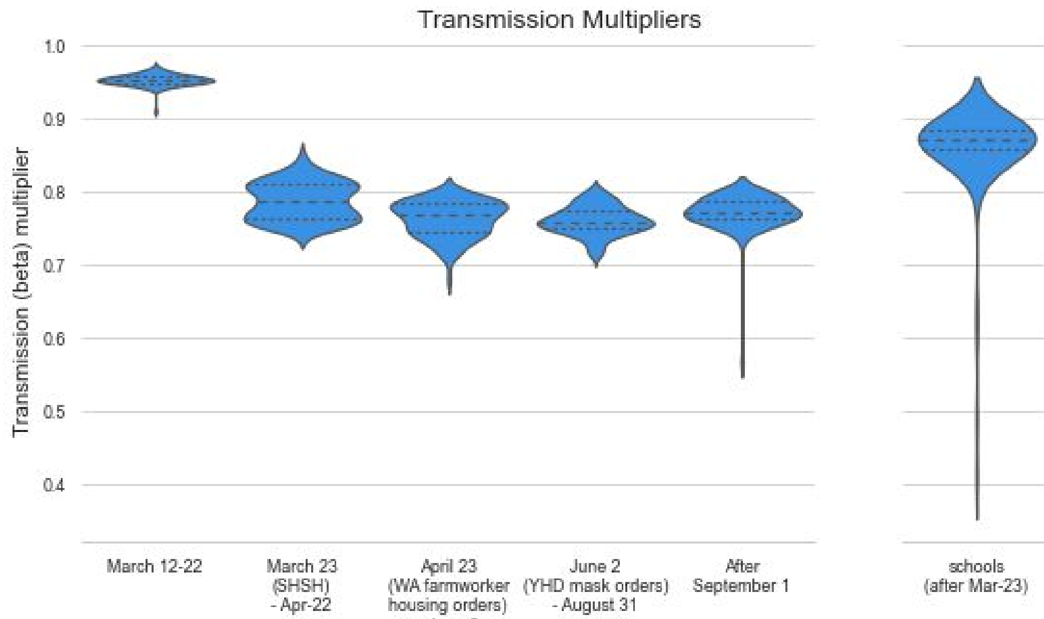

Figure 4. *Transmission multipliers in community, workplace, and schools layer, as estimated through model calibration. The violin plots represent the shape of the estimated density plot[4] of the parameters, with dashed and dotted lines showing the median and quartiles, respectively. Transmission multipliers quantify the effect of behavioral changes in these layers, as they directly translate into attenuations in transmission rates for each of the layers. For example, a transmission multiplier of 0.79 (such as the one shown here for SHSH) indicates that the transmission rate is reduced by 21%. In our model, the effect of NPIs in workplaces and the community is assumed to be equal, hence resulting in a single multiplier for both layers.*

Disease transmission rate decreased after implementing State of Washington orders for farmworker housing

Every year, Yakima County receives a large number of temporary (migrant) workers to help with activities of the crop year. In the region, the crop season (and hence the influx of temporary farmworkers) goes from approximately April to September, but temporary workers start arriving by late February. Temporary workers live in grower-provided housing, in which they share facilities in groups of about 55 people. This becomes very relevant for understanding disease transmission and mitigation in

[4] Density plots in this report represent the probability of a parameter taking a specific value given the data. They are estimated using Kernel Density Estimates (KDEs) based upon the top 100 candidate solutions rendered by the calibration process (see Appendix A).

Yakima County, as this type of facility provides room for significantly higher interactions among workers living in the same location. Although the number of temporary workers is not precisely known, we estimated it to be around 15,000 workers based on the number of H2-A visa applications in the State of Washington. This number is significant given that the population of Yakima is estimated to be around 250,000.

As the epidemic progressed in March and early April, the need for interventions particularly targeting farmworker housing became evident. This led to new farmworker housing mandates that, although made official in May, were already being put in place by many growers in the region by late April. The impact of this intervention is possibly one of the main reasons behind the drop in the effective reproductive number after April 23 (see Figure 2 above). The specific attenuation in transmission rates due to this intervention is shown by the estimated transmission multipliers in Figure 4. Note that, based on our model, a reduction in transmission in farmworker housing on the order of 0.4 to 0.5 was likely. After September 1, and possibly due to the decrease in temporary workers as well as by limited data, the uncertainty of this estimate increases. Model-based estimates support a significant reduction in transmission due to growers' adoption of the new farmworker housing regulations.

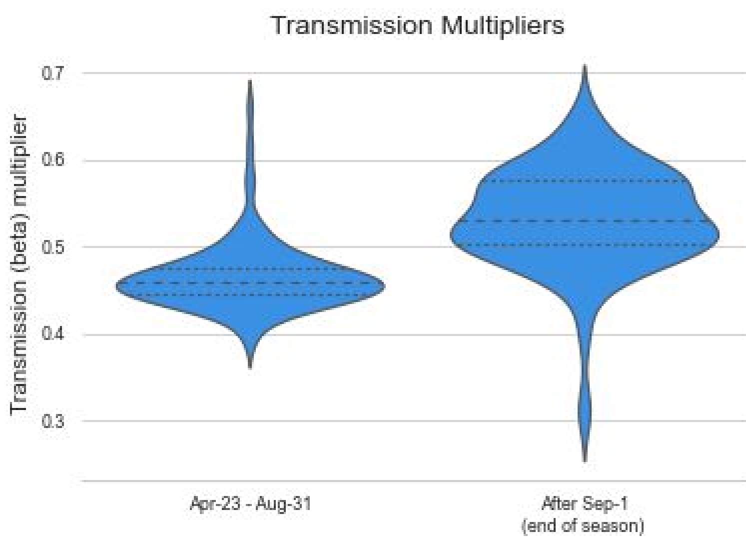

Figure 5. *Transmission multipliers in farmworker housing facilities. The violin plots represent the shape of the estimated posteriors, with dashed and dotted lines showing the median and quartiles, respectively.*

Adoption and effectiveness of face masks further reduced disease transmission

The impact of face masks on disease transmission depends on how many people are wearing masks (adoption or coverage), as well as on the benefit that mask usage provides in reducing COVID-19 transmission and acquisition (efficacy). Different combinations of mask coverage and efficacy may provide similar effects. We therefore anchor the analysis on an approximate mask coverage trend, and use epidemiological data to estimate mask efficacy. The reason for this choice is that there is survey data that gives us an approximation of the adoption, but due to the different types of face masks and usage practices, data on their efficacy is more scarce.

Adoption of face coverings in Yakima County was assessed during "Operation Unmasked". The results are shown in Figure 6. They show an increase from 35% to 65% shortly after the introduction of local face mask mandates, and then to 95% after state orders for face mask wearing in Yakima County.

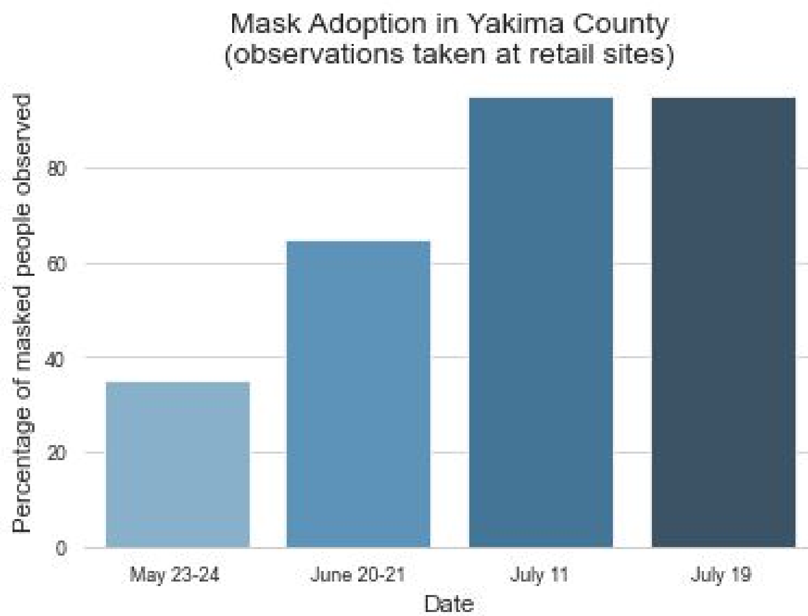

Figure 6. *Face mask wearing in Yakima County, as observed in multiple retail sites on different dates during Yakima's "Operation Unmasked". By the end of May, 35% of people were observed wearing masks in a sample of retail stores. Shortly after Yakima Health Department Directive mandating the use of face masks in public places, observed adoption increased to 65%. Later observation campaigns show an adoption of 95%.*

An explicit model of face mask (and related NPIs) interventions allows us to estimate the efficacy of face masks. In this model, an individual that wears a mask sees a reduction in both susceptibility and rate of transmission. The reduction is defined by the mask efficacy. Given the lack of data on the actual effect of face mask effects for susceptibility and transmission, we assume that a single efficacy parameter equally affects both susceptibility and transmission. Hence, we do not consider the potential asymmetrical efficacy of face masks. Furthermore, we assume that facemasks are not used in houses and that kids younger than 6 years old do not wear masks. We then apply the face mask intervention in the community and workplace layers of our model and estimate the mask efficacy parameter that better explains the data (note that we do not quantify the effect of face masks in healthcare settings, schools, households, or farmworker housing; the effect in those settings is rather embedded in the more generic "behavioral" interventions described above). Figure 7 shows a density plot of the estimated face mask efficacy. Our results indicate that, in Yakima County, the efficacy of wearing face masks has a median of

0.42, and could be between 0.27 and 0.69 based on the estimated 95% Confidence Interval (CI). This means that a person wearing a face mask in non-healthcare settings reduces their risk of transmission and susceptibility by 40% (CI: 31% - 67%). It is worth noting that the estimated efficacy is not meant to describe only the efficacy of physically wearing a mask, but rather the combined effect of wearing a mask and additional behaviors associated with wearing a mask (e.g., increased distancing, increased hand washing frequency).

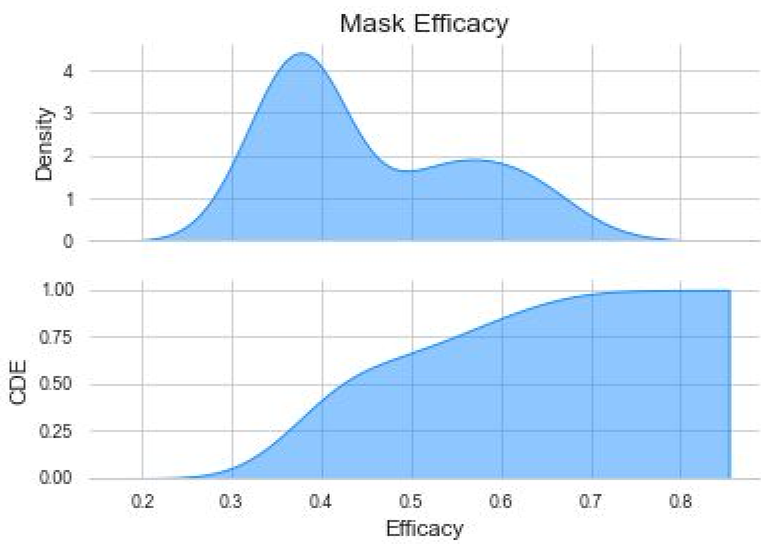

Figure 7. *Estimated density plot (top) and Cumulative Density Estimate (CDE) (bottom) of face mask efficacy[5]. These estimates assume face mask adoption in line with findings during "Operation Unmasked". These plots show that, very likely, wearing a face mask could reduce the risk of transmission and acquisition by a factor that could be between 0.3 and 0.7. Based on this estimate, face masks (and their associated behavioral changes) provide an important tool for reducing the risk of COVID-19 transmission and susceptibility.*

Estimated disease progression in the absence of NPIs

To assess the effect of the NPIs in the evolution of the COVID-19 epidemic in Yakima County, we simulated different scenarios in which: (a) all the NPIs described above are included; (b) face masks are not used; (c) farmworker housing rules are not implemented; and (d) neither face masks nor farmworker housing interventions are implemented. The results are shown in Figure 8, which shows the mean values for each of these scenarios when all other parameters are set as defined by the best 15 sets of parameters found through calibration. These results show that, in the absence of the face masks intervention, there would have been approximately 7,200 more infections by the end of September, as

[5] The density plot is a Kernel Density Estimate (KDE) based on the set of top solutions found in the calibration process. The CDE is the corresponding cumulative density function.

well as 133 more hospitalizations and 54 more deaths. Similarly, in the absence of the farmworker housing rules, there would have been 21,000 more infections, 496 more hospitalizations, and 157 more deaths in Yakima County by the end of September. This indicates that the definition and implementation of farmworker housing rules, which included the option of creating work group cohorts of up to 44 workers, had more impact than face masks for controlling the epidemic. The combination of both interventions had also significant impact: in the absence of both farmworker housing and facemask interventions, there would have been an additional 27,136 infections, 661 hospitalizations, and 212 deaths.

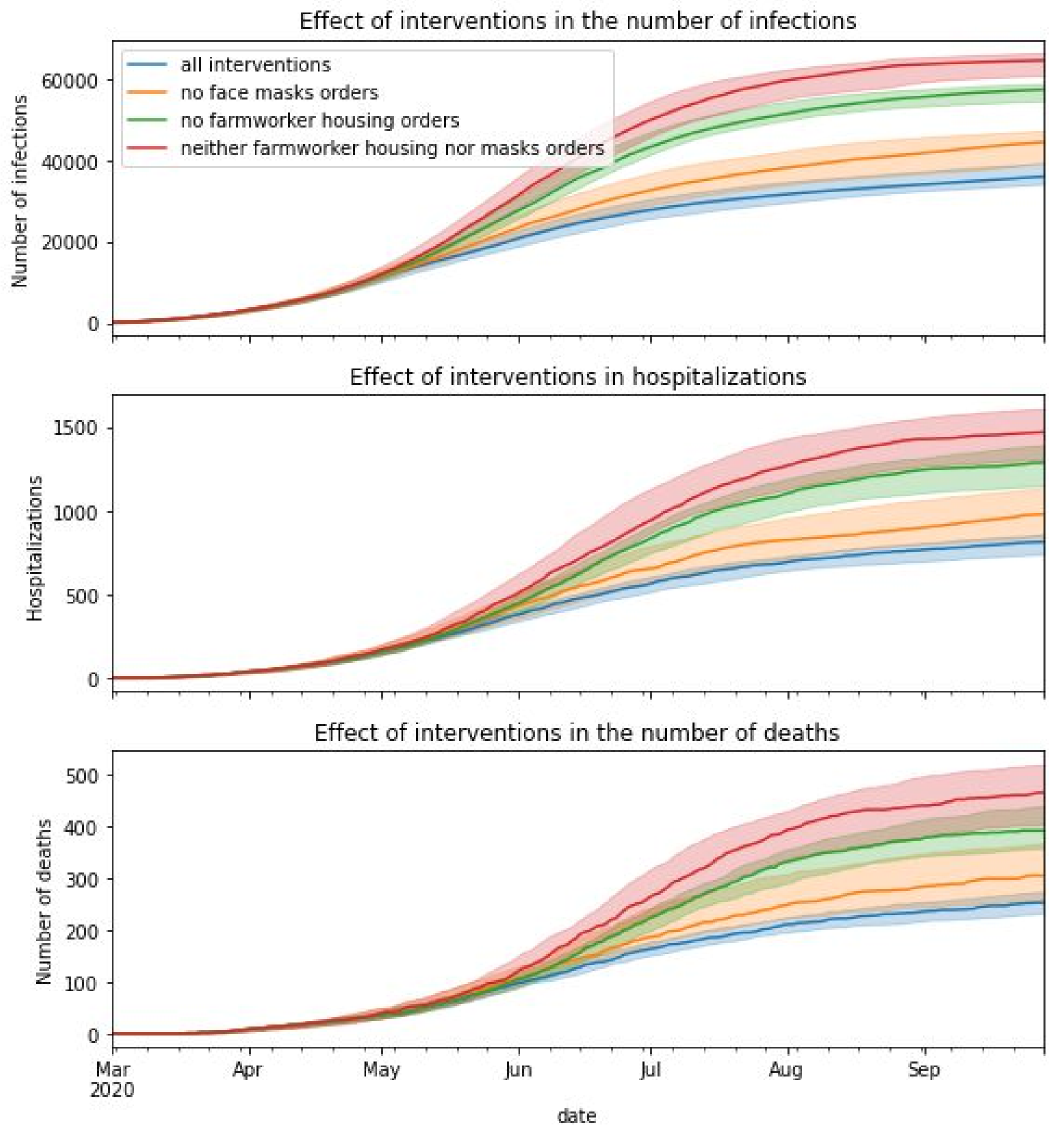

Figure 8. *Effect of farmworker housing and face mask order interventions in the control of the COVID-19 epidemic in Yakima County. The figure shows estimated infections, hospitalizations, and deaths in four different simulated scenarios: (1) all interventions applied (status quo); (2) no face masks orders enacted (which assumes that face masks were not used at all, or that wearing them is not effective); (3) no farmworker housing orders implemented; and (4) neither face masks nor farmworker housing orders implemented. The implementation of either face mask or farmworker housing order interventions*

reduces the number of infections, hospitalizations, and deaths. The use of both interventions (i.e., the all interventions applied scenario) has, as expected, more impact than each of the interventions on its own.

Discussion

The evolution of the COVID-19 epidemic in Yakima County shows the relative success of NPIs in controlling and mitigating widespread community transmission. After an early outbreak that seems to have peaked in May, the number of new transmissions started decreasing and the effective reproductive number remained at a value slightly less than 1 until the end of September.

The success in effectively controlling disease transmission to date makes Yakima County a valuable scenario that could help us understand and potentially quantify the effect of different NPIs. In particular, 4 types of NPIs can be analyzed in this scenario: (1) Large gathering prohibitions and non-essential business closures (2) behavioral changes in the community; (3) special directives for migrant/agricultural workers; and (4) face mask mandates.

Before analyzing the effect of the NPIs, it is important to consider the characteristics of the community. Yakima is a rural county, with the majority of the economy being based on agriculture. As such, it presents an environment typically characterized by lower population density than urban areas, and with potentially a larger number of outdoor jobs (i.e., large numbers of workers in well ventilated areas). These characteristics define an environment in which the transmission of COVID-19 should occur at a lower rate than in an urban or non-agricultural region. However, there are factors that could also increase the risk or rate of transmission: (a) the county receives a relatively large number of seasonal workers to help with the harvesting season, with a significant fraction of them living in congregate housing provided by the growers; and (b) with an economy based on agriculture, a large number of businesses are deemed as essential.

The effect of non-essential business closures, as well as other rules that were part of the SHSH directive, is perhaps the most obvious as it initially reduced the effective reproductive number from an estimated value of 1.8 to 1.3. Such dramatic reduction is expected given the stringent nature of this NPI. When other, less severe NPIs are properly implemented and adopted by the community, the need of SHSH-type shutdowns (and the impact in the community) could be reduced or even avoided, as evidenced by the epidemic control that has been observed after reopenings under the Yakima road to recovery plan that started in August.

One of these less severe NPIs are behavioral changes adopted by the community, such as increased hygiene practices, reduced social interactions, and increased social distancing. We estimate that these changes could reduce the rate of workplace and community transmission between 20% and 30% when implemented at the level done in Yakima County (we are aware that more data is needed to understand the level of adoption of these practices in this county).

The use of face masks comprise another important NPI whose adoption would further reduce the need for extensive business closures. We estimate that wearing face masks, along with its associated behavioral changes, could reduce transmission and acquisition of the virus by 31% to 67% in non-healthcare settings.

Finally, a particularly important NPI for Yakima, was the specific set of regulations for farmworker housing that were adopted by mid-May. Indeed, we estimate that this NPI could have reduced transmission in farmworker housing facilities by 50% to 60%. It was after the growers implemented these new regulations that we saw the effective reproductive number dropping to values close to 1. One of the reasons that explain the importance of this NPI in Yakima is the large number of seasonal workers (more than 15,000) that live in very crowded conditions. The new regulations were focused on reducing the risk of transmission within the congregate housing provided by growers, and minimizing interaction with the community at large (these rules included restrictions in the number of workers that would be allowed to go to cities/towns to buy groceries each day, for example). Seasonal and agricultural workers would also represent a significant portion of the workforce in the county, hence NPIs focused on this portion of the population would have an important effect in the overall disease transmission.

Conclusions

Assessing and quantifying the effect of NPIs is fundamental for enacting combinations of NPIs that, while effective for COVID-19 control, minimize the negative impact in the community. While it is difficult to properly measure the effect of individual NPIs in general, the evolution of the epidemic and the timing of NPIs in Yakima County give us the opportunity of addressing NPI efficacy quantification in a rural setting characterized by agriculture (it is expected for the effect of NPIs to vary depending on the specific conditions of the underlying community).

Our model-based analysis considered three broad groups of NPIs, namely: (1) distancing and behavioral changes; (2) farmworker protection rules; and (3) face mask utilization. We found that each of these NPIs effectively contributed to decreases in the transmission rate of COVID-19 in Yakima County, but none of them in isolation is responsible for full epidemic control.

Under the mild COVID-19 transmission conditions that were estimated for Yakima County prior to October, our results indicate that the combination of NPIs used allowed for epidemic control. This control allowed for some business reopenings while maintaining the effective reproductive below 1 by the end of September. Being able to maintain this epidemic control depends, however, on the amount of transmission occurring in the region, as well as on the acceptance and adoption of NPIs by its residents. Changes on either the epidemic dynamics or degree of acceptance could easily lead to increased community transmission and, consequently, to the need for implementing more stringent NPIs (such as full lockdowns) for epidemic control.

Appendix A: Calibration of model parameters

Calibration is the process of estimating the model parameters that better explain the data. The data, in our analysis, is daily counts of number of tests, positive diagnoses, hospitalizations, and deaths in Yakima County, obtained from the State of Washington Department of Health.

We calibrated our model using Optuna, which was configured to use the CMA-ES sampler (with restart) and 10,000 function evaluations. We had a total of 19 parameters. The estimated value and uncertainty found for these parameters are in Table 1. Estimated distributions of the parameters more relevant for the analysis in this document are included in the main text of this report.

Table 1. *Calibrated parameters.*

Feature	Parameter	Estimated value based on top 100 trajectories: Median (95% CI)
Initial conditions	Transmission rate (per contact/day)	0.0093 (0.0092, 0.0095)
	Seed infections on March 1	219 (177, 256)
Face masks	Efficacy	0.40 (0.31,0.67)
Transmission multipliers (the transmission rate is modified by this factor)	In workplaces and community: March 12-22	0.95 (0.94, 0.97)
	In workplaces and community: March 23 - April 22	0.79 (0.75, 0.83)
	In workplaces and community: April 23 - June 2	0.77 (0.72, 0.80)
	In workplaces and community: June 3 - August 31	0.76 (0.72, 0.80)
	In workplaces and community: after September 1	0.77 (0.75, 0.80)
	In farmworker housing: April 23 - August 31	0.46 (0.42, 0.58)
	In farmworker housing: after September 1	0.53 (0.41, 0.63)
	In schools: after March 23	0.87 (0.62, 0.90)
	In households	5.84 (5.45, 6.47)
	In farmworker housing facilities	0.46 (0.40, 0.56)
Testing	Odds Ratio (OR) of testing symptomatic person: March 1 - April 30	44 (40, 50)

	Odds Ratio (OR) of testing symptomatic person: May 1 - June 30	118 (109, 125)
	Odds Ratio (OR) of testing symptomatic person: after July 1	120 (95, 132)
Severity	Multiplier for conditional probability of symptoms becoming severe, given symptomatic, for people age 30-49	0.29 (0.21, 0.43)
	Multiplier for conditional probability of symptoms becoming severe, given symptomatic, for people age 50-69	0.42 (0.27, 0.52)
	Multiplier for conditional probability of symptoms becoming severe, given symptomatic, for people age 70+	0.56 (0.36, 0.79)