ECONOMIC MEMO

DANMARKS NATIONALBANK

8 APRIL 2021 — NO. 4

How do non-pharmaceutical interventions affect the spread of COVID-19? A literature review

Johannes Poeschl
Economist
ECONOMICS AND MONETARY POLICY, RESEARCH UNIT
jpo@nationalbanken.dk

Rasmus Bisgaard Larsen
Economist
ECONOMICS AND MONETARY POLICY
rbl@nationalbanken.dk

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Abstract

This memo reviews the academic literature on the effectiveness of non-pharmaceutical interventions in mitigating the spread of COVID-19. The review only includes empirical papers.

The literature suggests that interventions are generally effective in mitigating COVID-19 spread. Mask mandates and bans of mass gatherings are associated with reductions in infections. School closures can also be effective. The evidence on workplace closures and business restrictions is more mixed.

The effectiveness of interventions depends on their timing and the characteristics of the country or region in which the intervention is used.

Introduction

The COVID-19 pandemic has led to a burst of research activity in all economic fields that is remarkable in terms of both its productivity and its creativity.

In this economic memo, we provide a short summary of the literature. A comprehensive literature review, however, would be a daunting task. In our choice of literature, we therefore make two important restrictions: first, we focus on papers that investigate the effectiveness of non-pharmaceutical interventions (NPIs) on health outcomes – often the number of COVID-19 infections or deaths. Therefore, we ignore a vast literature that has investigated the effects of COVID-19 on economic and financial outcomes.

Second, we only include empirical papers in our review. There have been many efforts to study various aspects of the pandemic using epidemiological models. This is ultimately the way to conduct a counterfactual policy analysis, as models can account for the behavioural responses of people to policies. Yet, in the current situation of an evolving pandemic, models suffer from substantial parameter uncertainty.

We restrict ourselves in this way, because we want to survey the literature on a very fundamental and important question: which non-pharmaceutical interventions have worked, and why?

We make no attempt to assess the optimal use of NPIs when it comes to their effect on COVID-19 spread, other health outcomes, the economy etc. Our summary of studies that identify the effectiveness of different NPIs in mitigating COVID-19 spread should be seen as a foundation for such an assessment.

Summary of reviewed literature

Table 1

Intervention	Papers finding strong association	Papers finding no or uncertain association
Banning mass gatherings	6	2
School closures	5	4
Precautionary measures at nursing homes	2	0
Reduced workplace presence	3	0
Restaurant and bar closures	1	0
Mobility restrictions	11	3
Face mask requirements	6	0

Note: This table summarises the effects of non-pharmaceutical interventions on health outcomes found in the references surveyed in this paper.
Source: The references contained in the table.

Table 1 summarises the findings in literature by listing the number of papers that find a strong association between a type of intervention and health outcomes as well as the number of papers that find no or an uncertain association. The individual papers are listed in tables 2 and 3. Many studies point towards lockdowns in general being effective in mitigating the spread of COVID-19. The main channel seems to be through a reduction in household mobility. Among the least controversial measures are bans of mass gatherings and mask usage. There is also substantial evidence that school closures are effective. The evidence on workplace closures and business restrictions is more dispersed and more mixed.

Evidence on general effectiveness of non-pharmaceutical interventions

We start with a brief discussion of the literature on the effectiveness of lockdowns in general and the channels through which they work. We also point to the literature on the behavioural responses of households to NPIs that complicate the analysis of the causal effects of lockdowns.

Mobility restrictions and general effects of lockdowns – microeconomic evidence from US counties

As Chernozhukov, Kasahara, & Schrimpf (2020) discuss in detail, many measures work by reducing household mobility, and they can be seen as alternative policies designed to restrict household mobility. Moreover, while the measures might directly affect household mobility, they also do so indirectly by changing the behaviour of households. It is therefore of general interest to measure to what extent policies affect mobility, and to what extent mobility itself affects COVID-19 outcomes. *Several of the reviewed papers exploit the staggered introduction of mobility restrictions across regions in the United States to estimate the effectiveness of restrictions. The main finding is that mobility restrictions were successful in reducing the spread of COVID-19. The literature also suggests that mobility restrictions were more effective in more densely populated areas, and if adopted early.*

California was one of earliest adopters of stay-at-home orders in the United States. The state's governor issued a state-wide stay-at-home order on 19 March 2020, i.e. at a time when the daily increase in COVID-19 cases was relatively low compared to states with similar urbanicity. Friedson, McNichols, Sabia, & Dave (2021) study the effects of this stay-at-home order using synthetic control methods that compare the development in COVID-19 cases in California to a 'synthetic California'. The authors estimate that the order cumulatively reduced the number of COVID-19 cases by 161 to 195 per 100,000 population one month following the order compared to the 'synthetic California'.

The same authors explore the impact of stay-at-home orders across the United States (Dave D. M., Friedson, Matsuzawa, & Sabia, 2021). Using state-level data on daily COVID-19 cases, they exploit the fact that states enacted stay-at-home orders at different times over Spring 2020 to estimate the effect of stay-at-home orders on the development in COVID-19 cases in a difference-in-difference framework. The authors estimate that cases decrease by 53.5% cumulatively over three weeks following the issue of a stay-at-home order. The estimated effects vary across states, however, since early-adopting and more densely populated states experienced larger decreases in cases following stay-at-home orders.

A state-wide stay-at-home order was issued in Texas on 2 April 2020. Leading up to this order, individual counties in Texas independently issued stay-at-home orders at different points in time. Dave D., Friedson, Matsuzawa, Sabia, & Safford (2020) exploit this staggered enactment of orders across Texan counties to investigate the effects on local COVID-19 cases in an event-study framework. They estimate that stay-at-home orders reduced the daily case growth rate by 21-26 percentage points for two and a half weeks following the order in early-adopting counties. Late-adopting counties also experienced a decrease in the daily case growth rate after a stay-at-home order, but the estimated effect is smaller and takes longer to materialise. Moreover, the authors estimate that most of the effects of stay-at-home orders are driven by urbanised counties with high population densities even after controlling for local age composition, the severity of local outbreaks, and the political leanings of residents.

Amuedo-Dorantes, Kaushal, & Muchow (2020) focus on two types of mobility restrictions in the United States: non-essential business closure and stay-at-home policies. They use county-level data on COVID-19 cases during February to April 2020 to estimate the effects of the adoption speed of mobility restrictions on infections and deaths in a difference-in-difference setup. The authors estimate that an early issuance of either business closure or stay-at-home-orders subsequently reduced the local COVID-19 mortality rate. The effects take around four weeks to materialise, however, which is consistent with the common period of initial infection to recovery.

Effects of mobility on spread of COVID-19

Three of the reviewed papers analyse the impact of mobility on COVID-19 spread in the United States without tying mobility to any specific government policy. *These papers find that reduced mobility is associated with fewer COVID-19 cases. One of the papers estimates that visits to workplaces and restaurants predict the largest increases in COVID-19 case growth rates, while another paper emphasises that the mitigating effect from reduced mobility on COVID-19 spread is driven by a reduced probability of a large outbreak.*

Glaeser, Gorback, & Redding (2020) use weekly zip code-level data on COVID-19 cases from six major US cities covering the period of April to June 2020 together with mobile phone and underground turnstile data to analyse how the mobility of residents affects the spread of COVID-19. In order to account for endogeneity of mobility, they instrument for local mobility by residential teleworkability and the share of residents working in essential industries. The estimates from both across-city regressions and weekly panel data regressions for New York City show that zip codes with larger decreases in mobility also had fewer COVID-19 cases. One caveat is that these estimates cannot be interpreted as the effects from reduced travel alone since they capture the combined effect from exposure to COVID-19 during travel as well as the exposure at destination.

Wilson (2020) and Kapoor et al. (2020) also study the effect of mobility, using exogenous variation in mobility due to bad weather. Wilson (2020) analyses outcomes at US county level, using local projections to predict the effect of bad weather on COVID-19 cases. His data combines Google mobility data with weather data from 4,700 weather stations in the United States. He finds that higher mobility predicts large increases in COVID-19 infection rates. In particular, visits to workplaces and restaurants predict the largest increases in COVID-19 case growth rates. Kapoor et al. (2020) use rainfall as an instrument for mobility. Their data is county-level US data for March and April 2020. They find that a reduction in mobility due to rainfall in a county reduces COVID-19 cases and deaths for an extended period of time compared to counties that did not experience bad weather and thus no such reduction in mobility. They also show that the reduction in COVID-19 outcomes is driven by a reduced probability of a large outbreak.

Behavioural responses

A few papers take a closer look at behavioural changes induced by NPIs. *The main finding is that these changes in behaviour are at least as important, if not more so than the NPIs themselves. This has important implications for identifying the effects of a policy: the effects of a policy will be understated when comparing areas that impose the policy with areas that do not, as people in areas where the policy is not imposed also adjust their behaviour. Disentangling the behavioural effect from the effect of the NPI itself is a difficult exercise and not something which many of the reviewed studies explicitly do. However, several of the studies do mention the presence of behavioural effects.*

In an already highly cited study, Goolsbee & Syverson (2020) investigate the effect of lockdowns on mobility using mobile phone GPS data on visits to businesses. They find that most of the reduction in visits is explained by voluntary changes in behaviour as opposed to lockdowns. Most of the fall in visits cannot be attributed to lockdown measures as such, but instead reflects voluntary behavioural responses to observed higher death rates and local COVID-19 progression. This points towards some substitutability between lockdown policies and voluntary measures: in the absence of more severe measures, people voluntarily reduce mobility when they see bad COVID-19 outcomes. This also implies that evaluating the effectiveness of measures requires an understanding of how people's mobility choices respond to lockdown measures.

The Wisconsin Supreme Court repealed the state's stay-at-home order on 13 May 2020. Dave D. M., Friedson, Matsuzawa, McNichols, & Sabia (2020) investigate how the lifting of the order affected the subsequent development in COVID-19 cases and deaths using synthetic control methods. Relative to the 'synthetic Wisconsin', they find no discernible indications of the lifting of the order causing a subsequent increase in cases or deaths. The authors attribute this lack of effect to residents having internalised the risk of infection. Indeed, they estimate that the repeal of the order only caused a moderate and short-lived decrease in social distancing in Wisconsin. Hence, the effect from lifting a stay-at-home order is not necessarily symmetric to that of enacting the order.

A seemingly conflicting result as regards the mitigating effects of stay-at-home orders in the United States is presented by Lin & Meissner (2020). By exploiting the staggered enactment of stay-at-home orders across states in an event-study framework, they only find a statistically weak negative relationship between the issuance of a stay-at-home order and the subsequent daily case growth rate. The authors also compare county pairs that share a border but are situated in different states with different stay-at-home policies. Here, they find no relationship between the issuance of a stay-at-home order and the subsequent development in county-level COVID-19 cases compared to a bordering county in a state with no stay-at-home orders. The authors attribute this to a behavioural spillover effect to residents in the bordering county. Indeed, they use Google mobility data to show that mobility not only decreased in a county after a stay-at-home order was issued but also in the bordering county, where no such order was in place.

Microeconomic evidence from other countries
Three of the reviewed papers analyse mobility restrictions enacted in countries other than the United States. The findings from these papers are in line with those from the United States. *Evidence from Japan shows that voluntary mobility changes were important drivers of the total change in mobility. Estimates from Canada and China indicate that mobility restrictions mitigate the spread of COVID-19.*

Watanabe & Yabu (2020) use mobile phone GPS data for Japan. They provide evidence of the indirect impact of NPIs on mobility through behavioural responses similar to Goolsbee & Syverson (2020) by showing that about a quarter of the reduction in mobility in Tokyo around the declaration of the state of emergency in Japan in April 2020 is attributable to direct government measures, while the rest is attributable to voluntary changes in behaviour.

Karaivanov, Lu, Shigeoka, Chen, & Pamplona (2020) focus on the impact of mask mandates in Canada but also estimate the effects of other NPIs on COVID-19 case growth during the period of March to August 2020. The authors exploit variation in the timing of NPIs across Canada's ten provinces to estimate the impact of school closures and restrictions on businesses and gatherings. Restrictions on businesses and gatherings are associated with a reduction in the weekly case growth rate by 48 to 57% in the first few weeks after implementation or relaxation although these figures are not estimated with much statistical precision. The authors estimate a negative but not statistically strong association between school closures and subsequent case growth. However, this lack of statistical power may be driven by provincial school closures occurring over a very short time interval in March.

One of the papers presents an analysis of how mobility restrictions affected the spread of COVID-19 at its earliest stage in China (Fang, Wang, & Yang, 2020). The authors combine regional COVID-19 case data with population migration data from a major Chinese search engine, Baidu, to quantify the impact of mobility restrictions on the spread of COVID-19 from Wuhan in a difference-in-difference framework. Unsurprisingly, the estimates show that the Wuhan lockdown substantially reduced travel within, to and out of Wuhan. The authors also show that Chinese cities outside the Hubei province with large inflows of people from Wuhan experienced an increase in COVID-19 cases around 12-14 days after the inflow. In destination cities with social distancing policies such as building checkpoints or public transit shutdowns, the impact of inflows from Wuhan on cases was reduced.

Macroeconomic evidence on effectiveness of lockdowns from cross-country data
A few studies have compared the effects of policies using cross-country comparisons. These come with caveats that we discuss below. *To the extent that the studies can address any comparability issues across countries, their main finding is that lockdowns are effective, that they reduce mobility, and that their effects are decreasing over time.*

Bharati, Fakir, & others (2020) study the effects of NPIs through reductions in mobility using cross-country regressions. They use Google mobility data and measure NPIs using the OxCGRT stringency index. To avoid the problem that the stringency of a government's response may be related to the severity of the COVID outbreak, they instrument the stringency of a country with the stringency of a set of comparable countries. They find that higher stringency reduces COVID-19 outcomes.

Goldstein, Levy Yeyati, & Sartorio (2021) also use country-level data from Google's mobility indices, the OxCGRT stringency index and COVID-19 outcomes. Complementing the results in Bharati, Fakir, & others (2020), they find that lockdowns are associated with reductions in mobility and lower COVID infection and death rates. However, this association decreases over time: in particular, they find that an increase in the OxCGRT stringency index is associated with smaller declines in the COVID death rate if the stringency index has been high for around 120 days. They interpret the declining effect of lockdowns as lockdown fatigue.

Chen, Raitzer, Hasan, Lavado, & Velarde (2020) use a large panel dataset that combines data on reproduction rates, Google mobility information and NPIs. They run cross-country regressions to investigate the impact of various NPIs on the reproduction rate of COVID-19. They find that a 1 per cent reduction in mobility is associated with a reduction in the reproduction rate of around 2 per cent. Moreover, they find that of all the measures considered, bans on gatherings are associated with the largest reductions in the reproduction rate. Other measures associated with large declines in the reproduction rate are, in that order, school closures, mask use, mass testing and workplace closures.

A few papers have used Sweden, which pursued a different policy to most of the world, as a counterfactual for what happens if no lockdown is imposed. This exercise comes with the caveat that Swedes responded to the adverse COVID-19 situation by reducing their mobility voluntarily. Cho (2020), Born, Dietrich, & Müller (2020) and Conyon, He, & Thomsen (2020) investigate the Swedish case. The first two papers use a synthetic control method to analyse how not imposing a lockdown affected COVID-19 infection rates in Sweden relative to a statistical twin of Sweden that is identical in pre-treatment observables, but would have imposed a lockdown. They argue that compared to the counterfactual Sweden that would have imposed NPIs, the actual Sweden saw a cumulative infection rate that was around 75 per cent higher over the next two months.

Evidence on specific non-pharmaceutical interventions

A fundamental challenge in identifying the effectiveness of single interventions is that governments often impose many interventions at the same time. Most of the studies presented here address this challenge by exploiting differences in interventions across countries or administrative units within a country, which should in principle allow them to identify the marginal effects of single interventions.

Banning mass gatherings

Many countries have banned mass gatherings to battle community spread, resulting in cancellations of sports events, music festivals etc. Several of the papers in the reviewed literature attempt to quantify how such gatherings can spread COVID-19. Common to these studies is that they are not based on person-level data tracing individual cases to specific mass gatherings. Instead, regional data on COVID-19 cases and deaths is used to estimate the effect of mass gatherings on infection spread. *The literature mostly finds that mass gatherings accelerate the spread of COVID-19. One of the papers compares different NPIs enacted in Germany during Spring 2020 and estimates that a ban on mass gatherings was the most effective mitigator of COVID-19 case growth across German states. Not only can a mass gathering lead to more COVID-19 cases in the local area, but some papers also show that cases can spill over to other areas if the gathering attracts participants from other regions of a country. However, precautionary behaviour by local residents near a gathering might mitigate local COVID-19 spread. This might explain why two of the reviewed papers studying specific mass gatherings find no association between the gatherings and subsequent COVID-19 spread.*

Only one of the reviewed papers provides a direct answer to the question of whether a general ban on mass gatherings reduces the community spread of COVID-19 or not. Weber (2020) compares the effectiveness of different NPIs on COVID-19 case growth in Germany by comparing German states that enacted different NPIs at different times during Spring 2020. He finds that the cancellation of mass events was one of the most effective policies among the set of NPIs introduced in Germany during Spring 2020. These results come with the caveat that the introduction of NPIs was not randomly timed across German states, that Germany is divided into a small number of states, and that there is only limited time variation in when these measures were enacted.

A number of studies present empirical investigations of specific mass gatherings. While these studies cannot quantify how the banning of mass gatherings in general impacts the spread of disease, they help us understand how mass gatherings can foster community spread. Additionally, many of these studies employ anonymised mobile phone data to measure foot traffic at mass gatherings, which can inform the mechanisms through which disease transmission works.

Some authors have highlighted the role of sports events in transmitting disease among spectators. Ahammer, Martin, & Lackner (2020) analyse how indoor NBA and NHL games affected subsequent COVID-19 infections and deaths in the counties where the events took place. They find that an additional NBA or NHL game taking place is associated with a subsequent 13% increase in the cumulative number of COVID-19 infections and an 11% increase in the cumulative number of COVID-19 deaths. These results are based on data from late March and early April 2020.

Olczak, Reade, & Yeo (2020) use regional data from the UK to examine how outdoor football matches impacted local COVID-19 infections and deaths. Their data covers late March and early April. They conclude that an additional football match is associated with an increase in the cumulative number of COVID-19 cases by six cases, and the cumulative number of COVID-19 deaths by two deaths.

Dave, McNichols, & Sabia (2020) study the impact of the Sturgis Motorcycle Rally on infection spread using synthetic control methods. The rally was a 500,000-person gathering with no mask-wearing or crowd-gathering limits held in Meade County, South Dakota, on 7-16 August 2020. The authors estimate that COVID-19 cases in Meade County increased cumulatively by 6.3-6.9 per 1,000 individuals in the following month relative to the synthetic Meade County. Moreover, they find that other counties across the United States which contributed to most of the inflow of participants to the rally also experienced a subsequent increase in COVID-19 cases relative to counties that did not. Hence, this case study underscores the fact that a mass gathering can not only accelerate infection in the local area. Participants travelling to the gathering can also cause COVID-19 to spread to other areas.

Analyses of political events indicate that precautionary behaviour by non-participants around mass gatherings might lessen the spread of disease. Dave D. M. et al. (2020) find no indications that the political rally held by President Donald J. Trump on 20 June 2020 in Tulsa, Oklahoma, affected the spread of COVID-19 in Tulsa or in counties from which there were large inflows of rally participants.

Similarly, Dave D. M., Friedson, Matsuzawa, Sabia, & Safford (2020) show that Black Lives Matter protests in Summer 2020 in the United States were not associated with any subsequent increase in local COVID-19 cases or deaths. In both studies, the authors attribute the lack of spread of infection to the precautionary behaviour by non-participants since the stay-at-home behaviour of local residents actually increased around the events. Moreover, these events were typically associated with the temporary enactment of NPIs such as business closures or curfews, which curtail community spread.

This interpretation is supported by Dave, McNichols, & Sabia (2021)'s analysis of the Capitol Riot on 6 January 2021 in Washington D.C. Local residents increased stay-at-home behaviour around and following the riot, and the authors estimate that there was no effect on COVID-19 cases in Washington D.C. By contrast, counties outside Washington D.C.

from which there were large inflows of protesters subsequently experienced an increase in COVID-19 cases.

Cotti, Engelhardt, Foster, Nesson, & Niekamp (2020) investigate if counties with a larger in-person vote share during the presidential primary election in Wisconsin on 7 April 2020 subsequently experienced a differential development in COVID-19 cases. They estimate that a 10% increase in the number of in-person voters was associated with an 18.4% increase in the local COVID-19 positive rate two to three weeks later. This finding contrasts with the findings of other reviewed studies of political events. However, this may be because this study analyses an event that took place relatively early during the pandemic. This lower salience of COVID-19 risk might explain why Cotti, Engelhardt, Foster, Nesson, & Niekamp (2020) find an association between mass gatherings and subsequent COVID-19 cases, while other authors do not.

School closures (and openings)

Several of the reviewed papers study the effects of school closures in the United States by using regional data on COVID-19 cases to estimate the impact of school openings on local cases. As schools were closed more or less simultaneously across the US, evidence is better on the effects of openings than of closures. *The main finding is that school openings increase the spread of COVID-19, both in terms of the number of infections and in terms of the number of deaths. Among the studies that compare school openings to other NPIs, school openings are associated with relative large increases in infection and death rates.*

Goldhaber et al. (2021) study to what extent in-person or hybrid schooling contributed to the spread of COVID-19 in Michigan and Washington from September through November 2020. They use weekly COVID-19 cases at county level to estimate how switching teaching type affected local COVID-19 cases. After controlling for the level of pre-existing cases and the enactment of other NPIs, the authors do not find that in-person or hybrid teaching was associated with the spread of COVID-19 on average. However, when a county's level of pre-existing cases is moderate to high, the authors estimate that in-person or hybrid schooling was associated with subsequent increases in COVID-19 cases.

Chernozhukov, Kasahara, & Schrimpf (2021) study the impact of school closures on county-level infection and death growth rates in the United States.[1] They use detailed GPS foot traffic data at schools and variation in the timing of school reopenings in the US. They find that school reopenings are associated with a 7 percentage point increase in the COVID-19 case growth rate, while university reopenings are associated with a 1.4 percentage point increase in the COVID-19 case growth rate. Moreover, the increase due to university reopenings is concentrated among the relevant age groups, in particular young people aged 20-29.

Weber (2020) investigates the question of school closures using their staggered introduction across German states. Among the set of policies he considers (cancellation of mass events, school closures, curfews, business closures), school closures are associated with the largest reduction in cumulative infection rates.

Amodio, Battisti, Kourtellos, Maggio, & Maida (2021) use granular regional data from Sicily to study the impact of time variation in individual school openings on COVID-19 outcomes. They find that school openings are associated with a 1.5 to 3 percentage point increase in the COVID-19 infection rate two weeks after the school opening.

Only one of the reviewed studies uses individual-level data to analyse how in-person schooling affects the spread of COVID-19. Vlachos, Hertegård, & Svaleryd (2021) investigate if in-person schooling in Sweden increased the transmission of COVID-19 to parents and teachers. Lower-secondary schools (ages 14-16) continued in-person teaching in Sweden, while

[1] Chernozhukov, Kasahara, & Schrimpf (2020), using data until Summer 2020, find no clear effect of school closures. They argue that a lack of policy variation in school closures is the main reason for this.

upper-secondary schools (ages 17-19) were closed. This study compares outcomes during the period of March to June 2020 for teachers and parents of children in lower-secondary or upper-secondary school. After controlling for parental and teacher characteristics, the authors estimate that among parents with a child in the last grade of lower-secondary school there was a small increase in PCR-confirmed infections compared to parents with a child in the lowest grade of upper-secondary school. Among teachers in lower-secondary school, the PCR-confirmed infection rate doubled relative to upper-secondary school teachers. This increase in infection risk among lower-secondary school teachers also spilled over to their partners, who experienced an increase in infection rates. Although the estimates for teacher-level COVID-19 risk are significant, the authors conclude that the likely impact on the overall spread of COVID-19 from keeping lower-secondary schools open was minor.

Björk, Mattisson, & Ahlbom (2021) and Arnarson (2021) analyse the timing of school breaks across Europe. They emphasise that school breaks during a time with already high levels of community spread and no NPIs in place might have accelerated the transmission of COVID-19 across Europe during the early stage of the pandemic, where the perceived risk of infection was low. These authors exploit the fact that the timing of school breaks in February and March 2020 varies considerably both across and within European countries to estimate the impact of school break timing on COVID-19 spread. Björk, Mattisson, & Ahlbom (2021) find that regions with school breaks in week 9 later experienced an increase in weekly excess deaths per million of 16 during weeks 14 through 23 relative to regions with school breaks in week 6. Similarly, Arnarson (2021) finds that late school breaks were not only associated with more COVID-19 cases during March and April but also during the autumn. In summary, these two studies indicate that the late school breaks during the first quarter of 2020 might have accelerated the spread of COVID-19 since the breaks occurred at a time of widespread community transmission but no NPIs and a low perceived risk of infection.

Precautionary measures at nursing homes

The elderly population is at a higher risk of developing severe complications from COVID-19, and the mortality rate increases with age. As a result, countries have taken precautionary measures to protect its elderly population in nursing homes, and the elderly are being prioritised in vaccine distribution plans. *None of the reviewed papers study specific NPIs related to nursing homes but one of the papers analyses disease transmission across nursing homes. The authors show how shared staff among nursing homes in the United States was strongly associated with more COVID-19 cases among residents.*

Chen, Chevalier, & Long (2021) combine nursing home-level COVID-19 case data with geolocation data from smart phones. The authors construct connectedness measures for individual nursing homes, which they relate to COVID-19 cases. They find that more connected nursing homes – those that share more staff with other homes – also had more COVID-19 cases among residents. Staff sharing is highly predictive for cases with around 49% of cases being attributable to shared staff. Moreover, the authors do an event study, which quantifies the extent to which new outbreaks in other nursing homes subsequently affect the risk of a connected nursing home experiencing its first outbreak. They estimate that a shared contact with a home experiencing its first COVID-19 case results in a 2.5 percentage point increase in the probability of the connected home experiencing its first outbreak two weeks later. This is a relatively large increase in risk as the baseline probability of a first case in any given week is 7%.

Reduced workplace presence

Policies aimed at limiting workplace presence have been used as a specific mobility-restricting tool for reducing the spread of COVID-19. These policies have typically been targeted at certain sectors based on the essentialness of the sectors. Moreover, sectors have been targeted based on their impact on COVID-19 spread since the nature of the work being done likely affects transmission risk. *Only one of the reviewed papers (Spiegel and Tookes, 2021) analyses how detailed and differentiated business lockdowns such as those imposed in Denmark affect COVID-19 spread. Instead, many other papers analyse the effects of general restrictions on workplace presence. Only one of the reviewed papers investigate the relationship between COVID-19 spread and workplace presence at the local level. This paper finds that reduced workplace presence in the United States was only associated with fewer COVID-19 deaths from mid-May 2020. Two other papers show that essential workers in the United States were more likely to test positive for COVID-19 or experience respiratory symptoms than non-essential workers. However, while these two papers find that workplace presence increases the risk of getting COVID-19 at the individual level, they cannot quantify its impact on community spread.*

McLaren & Wang (2020) analyse if workplace absence in the United States had an effect on COVID-19 deaths. They combine county-level mortality data from the start of the pandemic through August 2020 with data from Google on the share of workers who were physically present at their workplace. Since workplace presence is endogenous to local developments in COVID-19, they instrument for workplace presence with the share of workers in a county that could work from home prior to the pandemic. The authors' estimates indicate that counties with a higher degree of workplace absence did not experience a differential development in COVID-19 deaths up until mid-May. After mid-May, however, counties with less workplace absence experienced a sharp increase in COVID-19 deaths relative to those where a larger share of workers worked from home.

Two of the reviewed papers employ individual-level data to evaluate the impact of non-essential business closures. Song, McKenna, Chen, David, & Smith-McLallen (2021) use data from the largest health insurer in Pennsylvania in a difference-in-difference framework to estimate how being designated as an essential or non-essential worker affects the risk of contracting COVID-19. They analyse how infection rates developed among workers employed in essential industries relative to workers in non-essential industries after Pennsylvania issued a state-wide non-essential business closure order on 19 March 2020. Being an essential worker increased the probability of testing positive for COVID-19 by 0.75 percentage points, which is a large increase relative to an average positivity rate of 1.36%. The estimated increase in the probability of testing positive is larger among health care and social assistance workers, but also statistically significant in other industries. Moreover, the authors find evidence of within-household transmission as individuals cohabiting with an essential worker had a 0.09 percentage point higher probability of testing positive than individuals cohabiting with a non-essential worker.

Angelucci, Angrisani, Bennett, Kapteyn, & Schaner (2020) rely on data from a survey of around 7,000 US adults, who were surveyed every week from mid-March to late July 2020. In a difference-in-difference framework, the authors show that non-remote workers were more susceptible to experience self-reported symptoms of respiratory illness and at a perceived higher risk of contracting COVID-19 than remote workers after mid-March. In addition, the authors exploit the staggered lifting of non-essential business closures across states to compare workers in states that lifted closure orders early relative to workers in states that lifted them later. They find that the respiratory health of non-remote workers worsened more in states that reopened early.

Widespread face mask usage
Some papers have studied the effect of face masks on COVID-19 spread or on other outcomes related to COVID-19 spread. *The bottom line is that mask requirements are probably the least costly and most effective measures – all studies find that mask requirements reduce COVID-19 infection and death rates substantially. Moreover, mask usage is not associated with reductions in mobility.*

Chernozhukov, Kasahara, & Schrimpf (2020) estimate, using county-level data, that mandatory face mask policies reduce the growth rate of COVID-19 cases and deaths by 7 or 14 per cent, respectively, with an impact that decreases over time as a reduction in the number of cases reduces the voluntary reduction in mobility of households.

Karaivanov, Lu, Shigeoka, Chen, & Pamplona (2020) provide evidence of indoor mask mandates in Canada reducing the weekly growth rate of new COVID-19 infections. They exploit the staggered introduction of indoor mask mandates in Ontario and across Canadian provinces over the period from May to August 2020 to identify the effect of mask mandates on local infection rates. In the analysis of mask mandates in Ontario, the authors estimate that a mask mandate reduced the weekly growth in local new infections by 25-31% in the first few weeks after implementation. When analysing data across provinces, their estimates indicate that mask mandates decreased the province-level weekly growth rate of new infections by 36-46%.

Mitze, Kosfeld, Rode, & others (2020) use the staggered introduction of face masks in German regions to study the effectiveness of the introduction of face masks. In particular, they exploit the fact that face masks were introduced particularly early in the city of Jena. Relative to a synthetic 'twin Jena' constructed from other German regions that are identical in terms of observables and outcomes prior to the introduction of face masks, Jena saw a reduction in COVID-19 cases of around 40% after 20 days. When they extend the sample to include all German regions, they find that face masks are associated with much larger reductions in 20-day cumulative COVID-19 infection rates in urban areas compared to rural areas.

Welsch (2020) combines a survey on face mask usage conducted by the New York Times and the market research institute Dynata with county-level data for the United States on COVID-19 outcomes. To account for endogeneity in face mask usage, he instruments the attitude towards face masks in a county with the vote share for the Republican candidate in the 2016 US presidential election. He finds that a 1 percentage point increase in the fraction of a county's population that uses face masks reduces the cumulative COVID-19 death rate by 10.5%, or by an average of about six deaths in a typical county.

Face masks might have positive effects not only because they reduce the direct transmission of COVID-19, but also because they affect mobility by increasing the cost of going out. Kovacs, Dunaiski, & Tukiainen (2020) investigate whether face masks affect household mobility, using the staggered introduction of face masks across German states. They measure mobility using Google mobility data. They find a small, short-lived reduction in mobility the day after the introduction of face masks, but after two days, face mask policies are no longer associated with reduced mobility.

Restaurant and bar closures

Restaurant and bar closures have been a particularly controversial measure, yet there is little evidence on their effectiveness. *When compared to other business closures, it seems that restaurant and bar closures are more effective at reducing COVID-19 infection and death rates. However, there is less evidence on the effects of this policy than of other policies like face mask requirements, bans of mass gatherings and school closures.*

Using county-level data for the United States, Spiegel & Tookes (2020) investigate the effect of business closures. In their analysis, they compare various non-essential business closure policies, e.g. closures of schools, restaurants, bars, gyms, spas as well as other low-risk business closures (retail outlets, offices, manufacturing facilities). They find that counties that close restaurants or gyms see reduced COVID-19 fatality growth rates compared to similar counties that do not close restaurants. Closures of other non-essential businesses seem to not be associated with reduced death growth rates.

Using German state-level data, Weber (2020) finds that restaurant closures are associated with a roughly 2 percentage point reduction in the COVID-19 case growth rate, although the estimated coefficient of -0.019 is smaller than the one for other measures like the banning of mass gatherings (-0.067) and school closures (-0.082).

Results should be interpreted with care

This memo reviews observational studies of NPI effectiveness, which are based on data from different countries and which analyse different periods of the pandemic. Drawing sharp and general conclusions from the literature is difficult since regions differ in terms of their characteristics, which can impact local dynamics of the pandemic. Indeed, many of the reviewed studies emphasise that pre-existing infection dynamics and regional characteristics such as demographic composition impact the effectiveness of NPIs. As a result, a specific NPI might have a larger impact at a certain time or in a given region of a country. Therefore, estimates based on naïve comparisons across countries or even across regions within the same country should also be interpreted carefully, and the estimated effects from NPIs in other countries cannot necessarily be extrapolated to a Danish context.

Several of the reviewed studies stress how voluntary changes in behaviour shape the impact of NPIs on COVID-19 spread. Voluntary changes in behaviour may differ greatly between countries, which can affect the marginal impact of NPIs across countries. Moreover, behaviour can change during the period when NPIs are in force and thereby impact their efficacy. Accounting for such differences is important when interpreting the results in a Danish context.

While most of the studies use regional data to analyse NPI effectiveness, some also employ individual-level data. This form of disaggregated data is a powerful tool for understanding the social interactions through which COVID-19 is transmitted since the data can be used to estimate the impact of NPIs on individual-level infection risk. However, such estimates cannot easily be translated into an estimate of the impact on society-level COVID-19 transmission because they do not capture the general equilibrium effects of an NPI. As such, these estimates can be informative for mathematical modelling of pandemic dynamics, but counterfactual policy analysis of NPIs can only be done using epidemiological models.

A related issue is relevant when interpreting results from cross-regional analyses of individual countries. The effects of an NPI in one region of a country can spill over to other regions. Some of the reviewed studies indicate that this can occur because residents in the NPI-affected region tend to travel to other regions to circumvent the intervention but also due to a precautionary, behavioural response by residents in other regions . Such spillover effects can contaminate the estimates from a cross-regional analysis since regions in both the treatment and control groups are affected by an NPI enacted in the control group. Moreover, the estimated regional-level impact of an NPI does not translate into the same country-wide impact from the same NPI if enacted nationally.

Different COVID-19 outcome variables are used in the various studies. Most of the studies measure the effect of NPIs on both confirmed cases and deaths. The data on confirmed cases is potentially contaminated by measurement error since it is affected by local testing strategies. Most studies attempt to control for this. Measuring the effect of NPIs on deaths is plagued by the typically short sample periods used in the reviewed studies since it typically takes around four weeks for an NPI to start impacting death rates.

Some studies analyse the enactment of NPIs, while others analyse the lifting of interventions. Some investigate the effects of both enactments and liftings but do not treat them differently. However, the effects of enactments and liftings are unlikely to be symmetric. First, the timings typically differ and happen in the context of different transmission dynamics, which affects the impact of an NPI. Second, during the period when an NPI is in effect, people may internalise the behaviour originally induced by the intervention. For example, some studies find a small impact on stay-at-home behaviour even after stay-at-home orders are lifted.

The earlier studies only analyse data from the first wave of the pandemic. This is important for three reasons when interpreting their results. First, the sample period is relatively short, which implies that some authors can only estimate the impact of NPIs within a short time horizon. Second, the behavioural response of people during the later stages of the pandemic may differ from their behaviour during the first wave. Salience of transmission risk, lockdown fatigue or circumvention of government policies will impact NPI effectiveness through the population's behaviour. Indeed, some of the reviewed literature emphasises that the behavioural responses to government interventions are important for their effectiveness. Third, the sample period predates the spread of new coronavirus strains and the distribution of vaccines. Both factors will alter the underlying dynamics of the pandemic and therefore also the impact of NPIs going forward.

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Summary of reviewed literature

Table 2

Intervention	Papers finding strong association	Papers finding uncertain or no association
Banning mass gatherings	• (Ahammer, Martin, & Lackner, 2020) • (Chen, Raitzer, Hasan, Lavado, & Velarde, 2020) • (Cotti, Engelhardt, Foster, Nesson, & Niekamp, 2020) • (Dave, McNichols, & Sabia, 2020) • (Dave, McNichols, & Sabia, 2021) • (Olczak, Reade, & Yeo, 2020)	• (Dave D. M., et al., 2020) • (Dave D. M., Friedson, Matsuzawa, Sabia, & Safford, 2020)
School closures	• (Amodio, Battisti, Kourtellos, Maggio, & Maida, 2021) • (Chernozhukov, Kasahara, & Schrimpf, 2021) • (Chen, Raitzer, Hasan, Lavado, & Velarde, 2020) • (Goldhaber, et al., 2021) • (Weber, 2020)	• (Chernozhukov, Kasahara, & Schrimpf, 2020) • (Karaivanov, Lu, Shigeoka, Chen, & Pamplona, 2020) • (Spiegel & Tookes, 2020) • (Vlachos, Hertegård, & Svaleryd, 2021)
Precautionary measures at nursing homes	• (Spiegel & Tookes, 2020) • (Chen, Chevalier, & Long, 2021)	
Reduced workplace presence	• (Chen, Raitzer, Hasan, Lavado, & Velarde, 2020) • (McLaren & Wang, 2020) • (Song, McKenna, Chen, David, & Smith-McLallen, 2021)	
Restaurant and bar closures	• (Spiegel & Tookes, 2020)	

Note: This table summarises the effects of non-pharmaceutical interventions on health outcomes found in the references surveyed in this paper.
Source: The references contained in the table.

Summary of reviewed literature

Table 3

Intervention	Papers finding strong association	Papers finding uncertain or no association
Mobility restrictions	• (Amuedo-Dorantes, Kaushal, & Muchow, 2020) • (Chernozhukov, Kasahara, & Schrimpf, 2020) • (Dave D. , Friedson, Matsuzawa, Sabia, & Safford, 2020) • (Dave D. M., Friedson, Matsuzawa, & Sabia, 2021) • (Fang, Wang, & Yang, 2020) • (Friedson, McNichols, Sabia, & Dave, 2021) • (Glaeser, Gorback, & Redding, 2020) • (Goldstein, Levy Yeyati, & Sartorio, 2021) • (Kapoor, et al., 2020) • (Karaivanov, Lu, Shigeoka, Chen, & Pamplona, 2020) • (Wilson, 2020)	• (Lin & Meissner, 2020) • (Karaivanov, Lu, Shigeoka, Chen, & Pamplona, 2020) • (Dave D. M., Friedson, Matsuzawa, McNichols, & Sabia, 2020)
Face mask requirements	• (Chen, Raitzer, Hasan, Lavado, & Velarde, 2020) • (Chernozhukov, Kasahara, & Schrimpf, 2020) • (Karaivanov, Lu, Shigeoka, Chen, & Pamplona, 2020) • (Mitze, Kosfeld, Rode, & others, 2020) • (Spiegel & Tookes, 2020) • (Welsch, 2020)	

Note: This table summarises the effects of non-pharmaceutical interventions on health outcomes found in the references surveyed in this paper.
Source: The references contained in the table.

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