



#virus

Data Science

Modeling Coronavirus Progress

The spread of the novel Coronavirus (2019-nCoV) that originated in Wuhan, China, late last year has governments working to implement containment measures. We introduce how epidemiologists model outbreaks and present thresholds for investors to gauge whether initial efforts are curtailing the spread or if more action is likely.

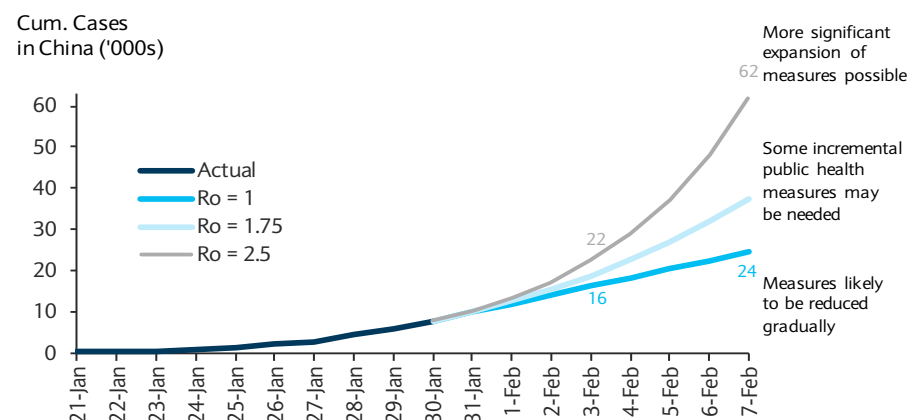
We fit a model to the early portion of the known case volume to make some framing estimates for the effectiveness of the quarantine and travel restrictions announced on 23 January. As the incubation period is estimated to be 5-7 days, we are entering the window when the effects should be reflected in the growth of new cases.

While noting the uncertainty inherent in such early analysis, we our work suggests:

1. Those measures appear to have had some impact on the rate of spread already.
2. If the number of cases in China is less than 17k on Monday, 3 February, and fewer than 25k by Friday, 7 February, current containment measures are likely sufficient and we would expect a gradual rollback as the number of new cases declines.
3. If that number is closer to 22k by 3 February, and tracking well above that by 7 February, it suggests that incremental public health measures may be implemented, with the implication of additional disruptions to travel and other activities.

Our modeling focuses on the reproduction number (R_0), the average number of new people infected per case. The R_0 of the Novel Coronavirus has been estimated at between 2 and 3 (higher than SARS, which had R_0 estimated at 2.0). R_0 over 1 implies approximately exponential growth of an epidemic in the early stages.

FIGURE 1
The Next Week Will Offer a View Into Whether More Public Health Measures Are Likely



Source: WHO, Barclays Research

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Special Report

Research

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Coronavirus Spread Follows Established Outbreak Models

The first reports of a new respiratory infection – variously named Wuhan Virus, novel coronavirus, or labelled 2019-nCoV – emerged late last year. Since then, the illness has spread quickly, with the WHO reporting 7818 confirmed cases globally (7736 in China), with a total of 12,167 suspected as of January 30th, 2020 (Figure 1). The WHO declared Novel Coronavirus a global public health emergency on the same day, underscoring its rapid spread so far (Figure 2).

Epidemics can be naively modelled as a four-state process, where a person goes from “susceptible”, to “exposed”, to “infectious”, to “recovered” (where they’re no longer infectious), and so is known as the SEIR model. This process follows specific dynamics, as defined by a set of differential equations, and so can give deterministic predictions of the future course of an outbreak in the large-number limit.

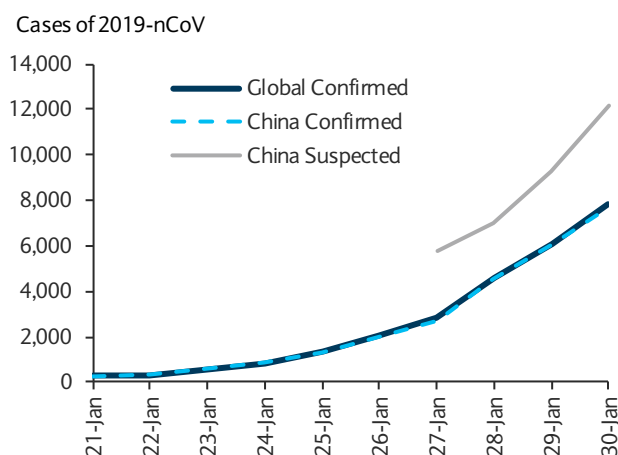
This model ignores some important effects. In particular, it assumes network structure is irrelevant, populations are homogeneous, and WHO reported cases are an instantaneous measurement of infected and recovered individuals.

The model also assumes model parameters are constant with time, which can be untrue when quarantines and other interventions are imposed. In the case of 2019-nCoV, there is likely to be a shift on parameters after quarantines and travel restrictions were implemented starting on 23 January.

Two critical parameters are the reproduction number (R_0), which measures the number of new infections per existing case, and the case fatality ratio (CFR), which measures the probability of an infection resulting in death.

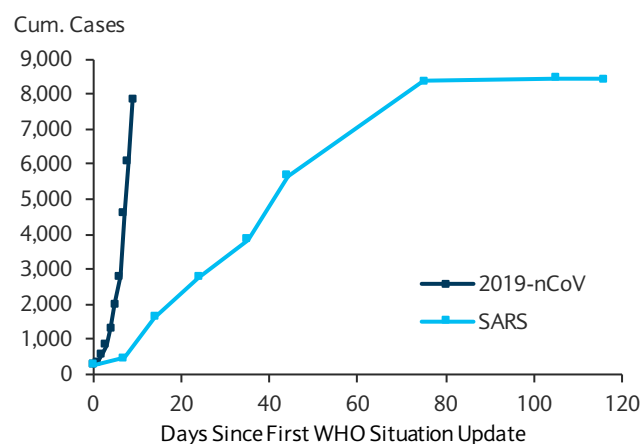
The R_0 of the Wuhan novel coronavirus has been estimated at around 2–3. An R_0 over 1 implies exponential growth of an epidemic in the early stage, which is consistent with the early data for the current outbreak. This also suggests 2019-nCoV is more contagious than SARS, which was estimated at 2.0; but much less so than measles (R_0 around 10).

FIGURE 1
Since the WHO situation report on 21 January, the number of cases has grown quickly



Source: World Health Organization

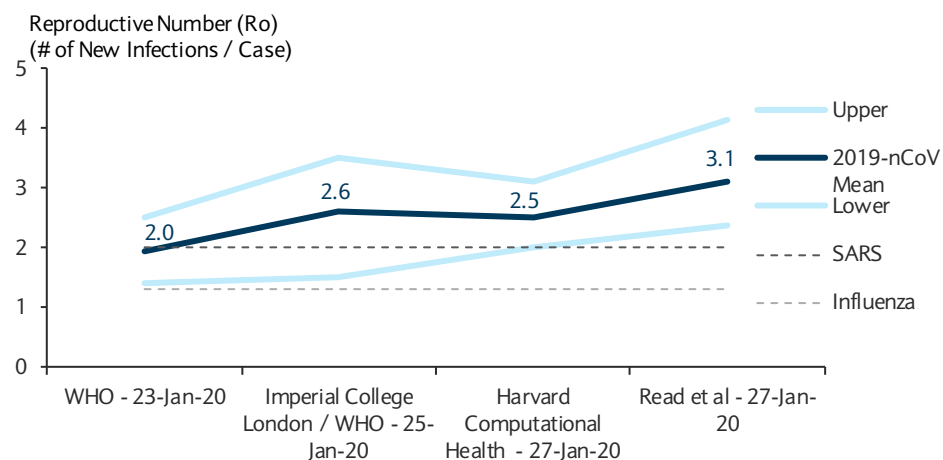
FIGURE 2
Novel coronavirus has spread more quickly than SARS



Source: World Health Organization

FIGURE 3

2019-nCoV appears more contagious than SARS ($R_0 \sim 2$), but less than measles ($R_0 > 10$)

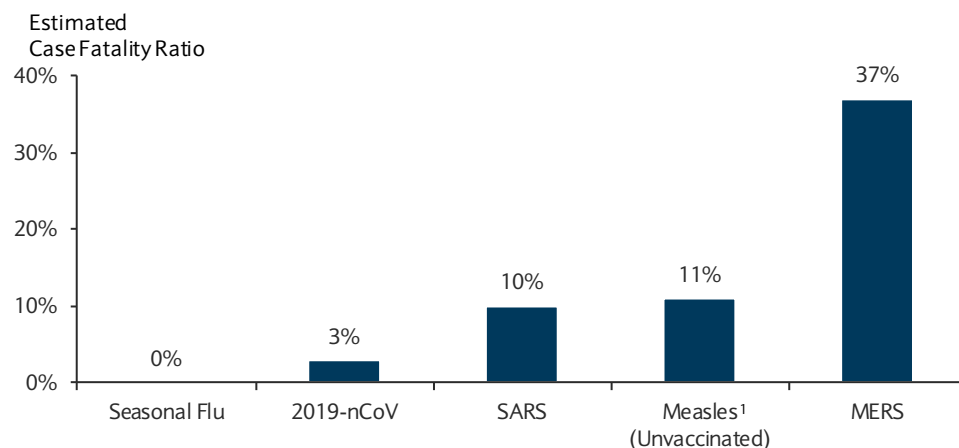


Source: Barclays Research

The fatality rate of the novel coronavirus is estimated to be around 3%, though that estimate may evolve. That CFR is much lower than other recent coronavirus outbreaks SARS (10%) and MERS (37%), or measles for unvaccinated vulnerable populations¹; but is high compared to the seasonal flu which has a mortality rate around 0.05%. It is also worth noting that reports suggest that most deaths were among people who suffered other significant illnesses or general health risk factors.

FIGURE 4

Current Estimates Suggest Novel Coronavirus has Substantially Lower Fatality Rate Than SARS



Source: The Lancet, World Health Organization

How we should think about interpreting future data releases

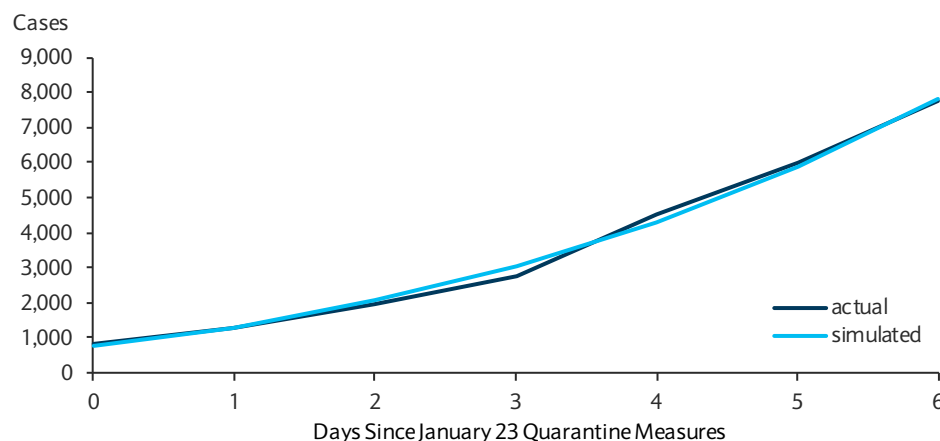
We believe it is so early that there is a very large amount of uncertainty about the potential progression of 2019-nCoV. However, we are able to take the current facts about the outbreak to provide some framing for how to interpret new data as they are released.

¹ Measles case fatality ratios vary significantly by study and context, from an average of 0.15% in some US outbreaks to upwards of 40% in isolated pockets in other parts of the world. For more details see "Estimates of measles case fatality ratios: a comprehensive review of community-based studies", Wolfson et al, 29 September 2008

We can fit an epidemic model to the early portion of the known case volume as a basic (and also naïve) measurement of the effectiveness of those quarantines. China introduced quarantines and travel restrictions starting on 23 January, so we restrict our model fit to the period after the quarantine was imposed. A model fit to the data after that date suggests an R_0 of 2.31, which is consistent with the earlier estimates of a value between 2 and 3. That is lower than the R_0 suggested by a fit to pre-January 23rd data, which is an early indicator that the measures implemented after that are indeed reducing the transmission rate of the virus.

FIGURE 5

Our Simple Epidemic Model Fits the Existing Data Well



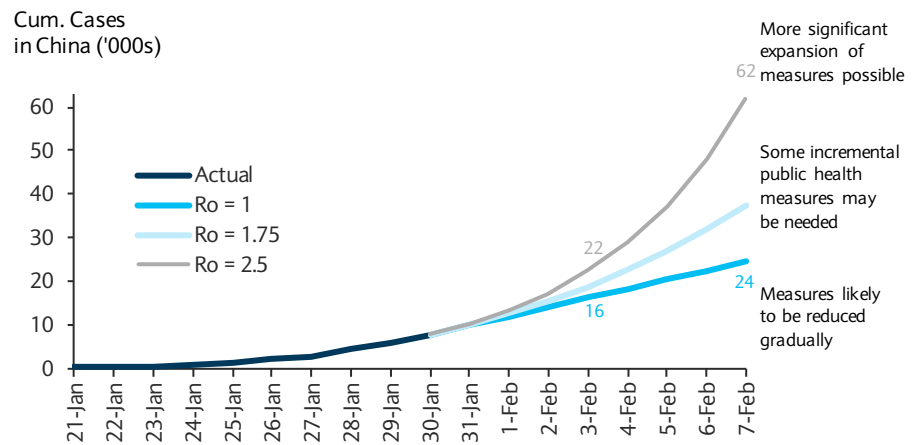
Source: WHO, Barclays Research

This model can also give us a lens for interpreting new data as it is released. The incubation has been reported to be on average around 5 to 7 days. The most significant expansion of containment measures was announced on 23 January 2020 which means we should see the rate of transmission from post-quarantine exposed individuals entering the data shortly. The next week will be more informative about the post-quarantine reproduction number. We can estimate the cumulative cases in China under different R_0 assumptions, and think about the policy reaction function if for different outcomes suggested by the data:

- If R_0 drops to below 1, the epidemic enters a phase of exponential decay. In that case, we expect the containment measures already implemented would be considered successful, and would gradually be phased out as infectious cases move to the recovered state. Looking forward a week, that would imply cumulative infections below 16.2k as of Monday, 3 February, and below 24.5k as of Friday, 7 February.
- If R_0 is between 1 and 1.75, it would suggest that containment has been partially successful, but some incremental measures are still required to reduce the transmission rate further. In that case, we would expect moderate incremental tightening of quarantines and travel restrictions. That would be implied by cumulative infections between 24.5k and 37.6k by Friday, 7 February.
- If R_0 is tracking to remain above 1.75, we would expect to see 37.6k or more cumulative infections by 7 February, and would also expect a more concerted effort to significantly increase the response.

FIGURE 6

The Next Week Will Offer A View Into Whether Incremental Public Health Measures Are Likely to Be Implemented to Control the Spread of Novel Coronavirus



Source: WHO, Barclays Research

With regard to other countries, the earliest data (when cases are in the single digits) tends to be stochastic. Unless and until cases rise into the hundreds, this sort of curve fitting is not informative. In our view, it is too early to attempt a similar exercise for other geographies, and it may not become relevant at all if early control measures are effective.

Appendix: Model Code

For clients interested in modeling results on their own, we are including sample python code for fitting an SEIR model to case data.

```
import numpy as np
from scipy.integrate import odeint
from scipy.optimize import minimize
import pandas as pd

china_cases = [278, 309, 571, 830, 1297, 1985, 2741, 4537, 5997, 7736]
china_cases = china_cases[3:] # only post-quarantine data
cases = pd.DataFrame({'cases': china_cases})

def get_SEIR(N, S0, E0, I0, R0, t, beta, gamma, sigma):
    t = np.linspace(0, t, t)
    def derivatives(y, t, N, beta, gamma, sigma):
        S, E, I, R = y
        dSdt = -beta * S * I / N
        dEdt = beta * S * I / N - sigma * E
        dIdt = sigma * E - gamma * I
        dRdt = gamma * I
        return dSdt, dEdt, dIdt, dRdt
    y0 = S0, E0, I0, R0
    result = odeint(derivatives, y0, t, args=(N, beta, gamma, sigma))
    S, E, I, R = result.T
    return pd.DataFrame({'S': S, 'E': E, 'I': I, 'R': R, 't': t})

def loss_from_cumulative_cases(x, cases, N, S0, sigma):
    beta, gamma, E0, I0, R0 = x
    t = len(cases)
    simulation = get_SEIR(N, S0, E0, I0, R0, t, beta, gamma, sigma)
    simulation['cases'] = simulation['I'] + simulation['R']
    #simulation['cumulative_cases'] = simulation['cases'].cumsum()
    #final = simulation['cumulative_cases'].values[-1]
    #rmse = np.sqrt(((simulation['cumulative_cases'] - cases['cases'])**2).sum() / float(t))
    rmse = np.sqrt(((simulation['cases'] - cases['cases'])**2).sum() / float(t))
    return rmse

N = 1380000000
I0, E0, R0 = china_cases[0] - 100, 200, 100
S0 = N - I0 - R0 - E0

beta0 = 1.07
gamma0 = 1. / 3.6
sigma0 = 1. / 5.2

x0 = beta0, gamma0, E0, I0, R0
args = cases, N, S0, sigma0
result = minimize(loss_from_cumulative_cases, x0, args=args,
                  tol=1e-12,
                  #method='Nelder-Mead',
                  method='TNC',
                  options={'maxiter': 10000},
                  bounds=[(0., 200), (0.0, 20), (0, 30000), (0, china_cases[0]), (0,
china_cases[0])])
```

```
)  
x = result.x  
print(result)  
beta, gamma, E, I, R = x  
  
R0 = beta / gamma  
R0
```

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