# Parallel diffusion of innovation and infection

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October 10, 2022

## Introduction

The big idea here is to incorporate the 'innovation diffusion' process that shapes the differential susceptibility predicted by fundamental cause theory (FCT) (Link and Phelan 1995) into a model that also allows clustering of contact along a similar dimension, such as socioeconomic status.

## Diffusion of Innovations

In an earlier paper, Clouston et al. (Clouston et al. 2016) described the life-cycle of a fundamental cause, where they detailed the rise and fall of inequity in access to a given health innovation (See Figure 1). Much like the segregation and transmission model put together by Acevedo-Garcia (Acevedo-Garcia 2000), this has never really been subject to simulation, particularly in the realm of infectious disease epidemiology.

### Capturing innovation 'diffusion' by SES

How can we capture the heterogeneous distribution of innovation access times pictured in Figure 1? Lets start with a simple example, in which there are two groups representing high and low SES individuals. Some proportion $\eta$ of individuals in the population belong to the high-SES group, with the remaining $1 - \eta$ individuals in the lower-SES group.

We can denote $\zeta_L$ as the rate of access for the lower-SES population, and $\tau \geq 1$ as a parameter scaling the rate of access for the high-SES group. We can then express the overall access rate as $\zeta = \eta\tau\zeta_L + (1 - \eta)\zeta_L$

```
## High-ses group innovation access times
accessTimes <- function(pHigh, popSize, tau, zeta) {
```

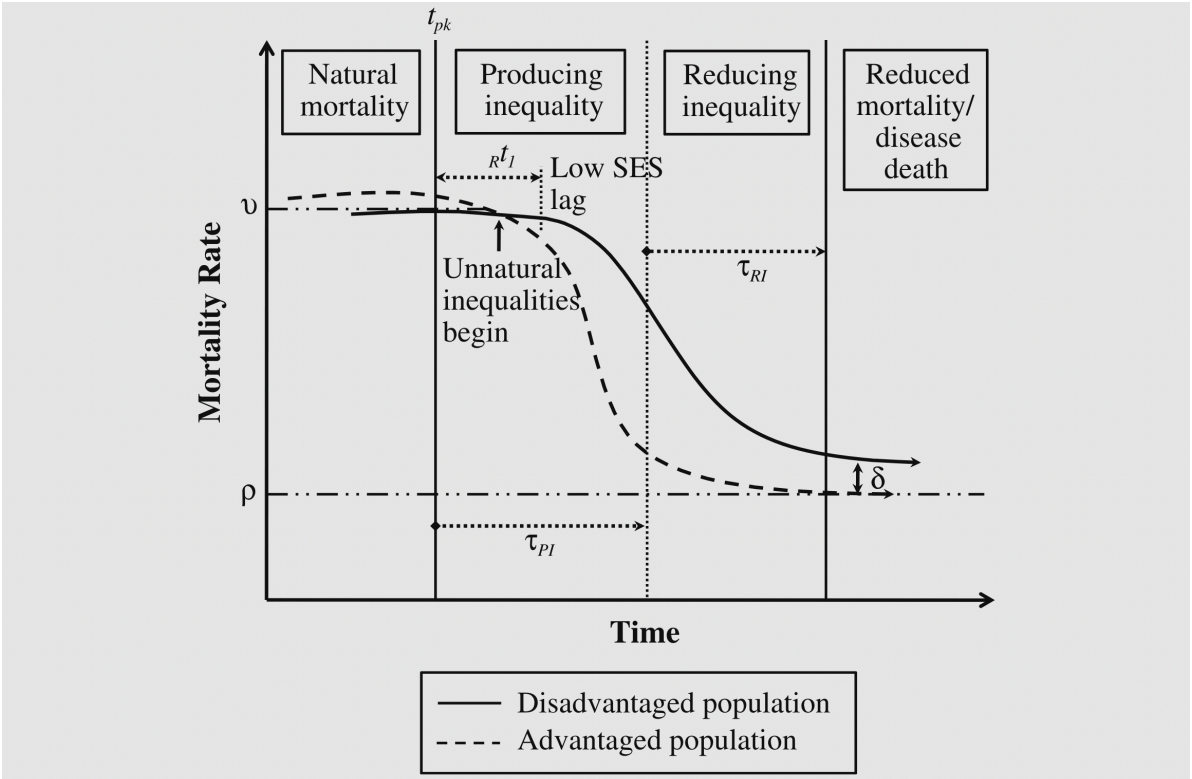


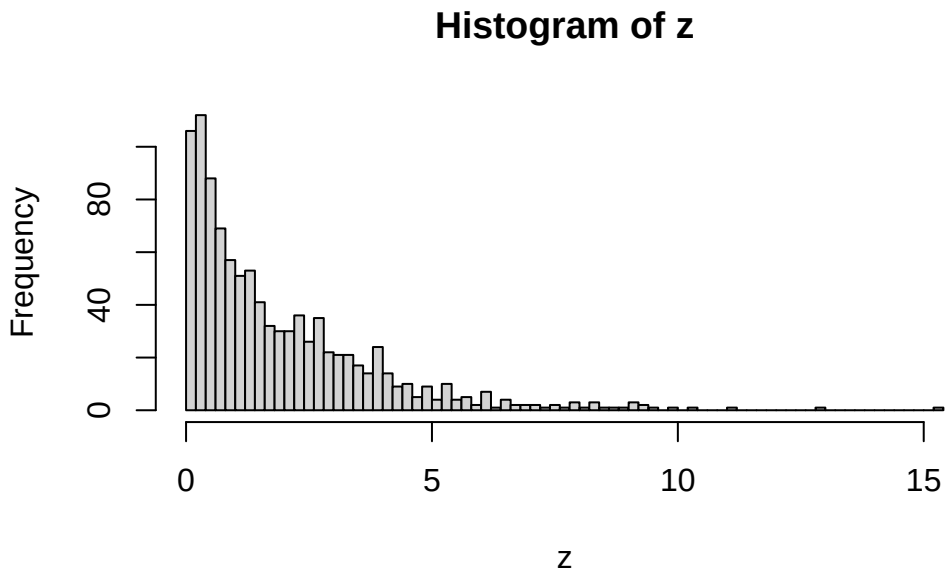

**Fig. 1** Ideal characterization of the history of the risk of mortality for a single hypothetical cause of death as it is increasingly but unequally controlled

Figure 1: Diffusion of health-promoting innovation across levels of SES, replicated from (Clouston et al. 2016)

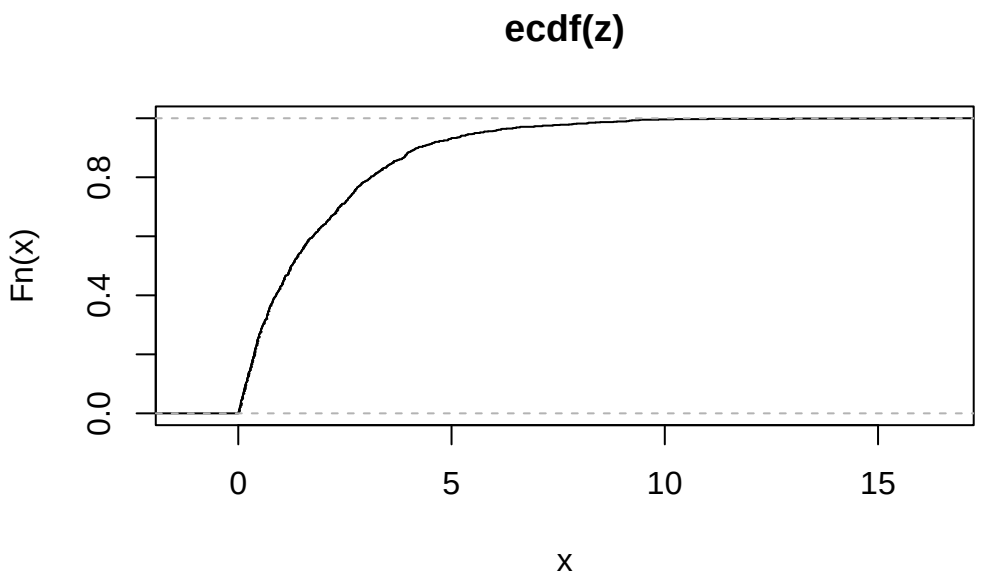
```
nH <- floor(pHigh*popSize)
nL <- popSize-nH
x1 <- rexp(nH, tau*zeta)
x2 <- rexp(nL, zeta)
z <- c(x1,x2)
return(z)
}
```

In this example, the top 20% of the population gets access twice as fast as the lower 80%:

```
z <- accessTimes(0.2, 1000, 2, 0.5)
hist(z, breaks=100)
```

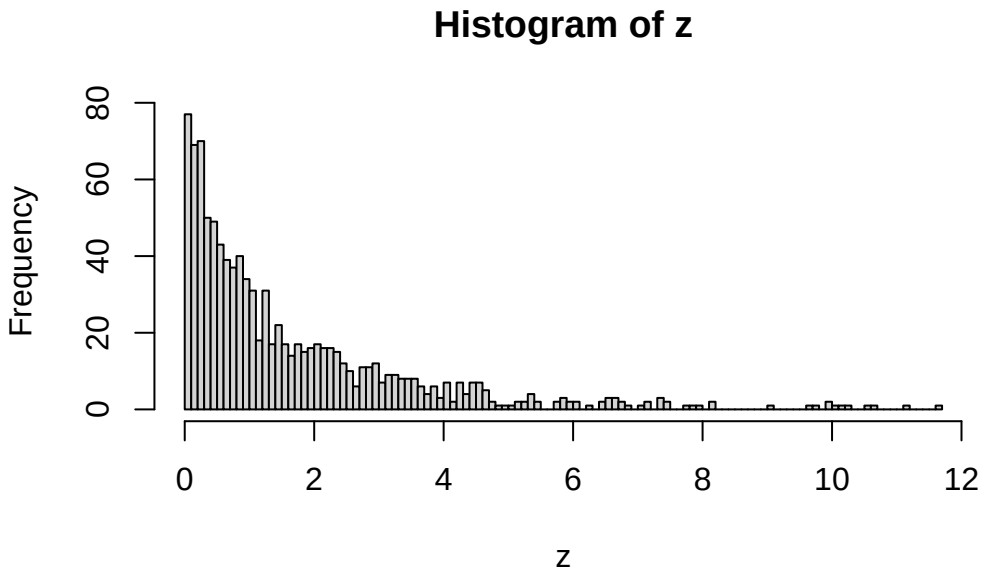



```
plot(ecdf(z))
```

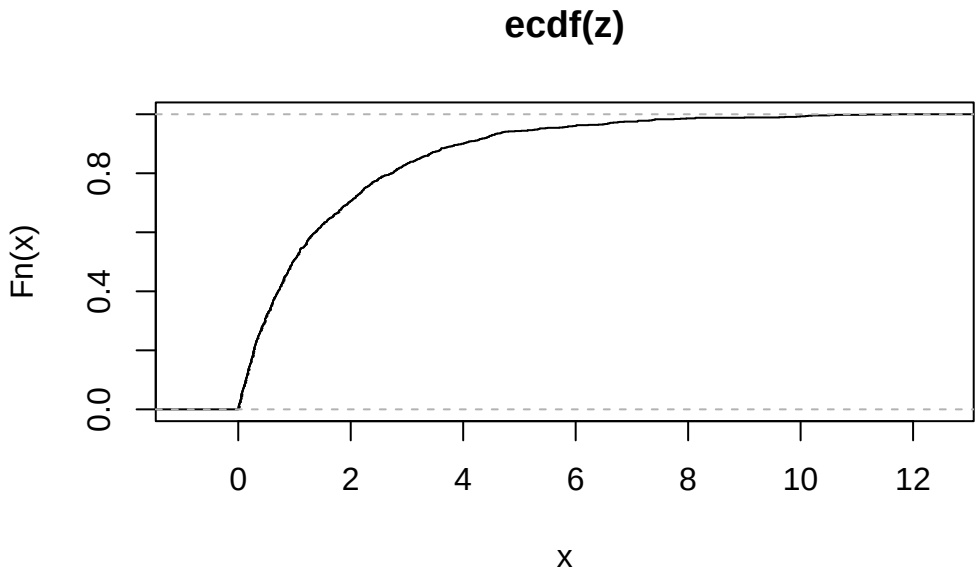



In this one, the rate is much higher at 5 times faster

```
z <- accessTimes(0.2, 1000, 5, 0.5)
hist(z, breaks=100)
```




```
plot(ecdf(z))
```

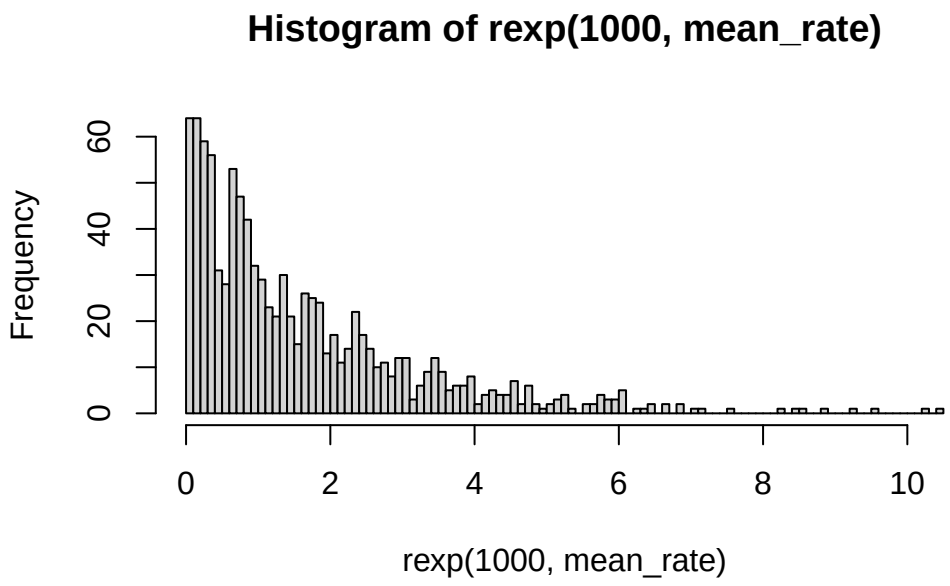



We can compare these visually to the equal-access (or equal rate of access) version as follows:

```
mean_rate <- 1/mean(z)
print(mean_rate)
```

```
[1] 0.6089921
```

```
hist(rexp(1000, mean_rate), breaks = 100)
```



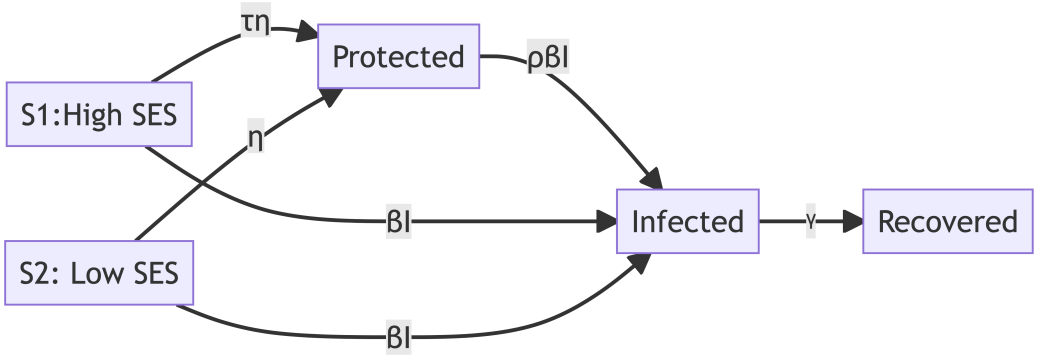

In the heterogeneous rate version, more people have very early access times, with more people with higher-than-average wait times in the right tail of the distribution.

### ODE Model

We can represent this intuition by including separate SES classes in an ODE-based transmission model.

To do this, we can have multiple susceptible states, including a protected state that individuals enter when they get access to the innovation.

In a simple, mass-action version of this model, we have plain-old susceptibility, a protected state that individuals flow into at a constant rate, and infectious and susceptible individuals in all groups mix evenly.



Where:

- $\beta$ is the rate of transmission
- $\rho$ is the reduction in infection risk associated with protection
- $\tau$ is the rate at which lower-SES individuals get access
- $\tau\eta$ is the rate at which individuals in the high-SES group get access to the innovation, where $\tau \geq 1$.

## References


Acevedo-Garcia, Dolores. 2000. "Residential Segregation and the Epidemiology of Infectious Diseases." *Social Science & Medicine* 51 (8): 1143–61. https://doi.org/10.1016/S0277-9536(00)00016-2.

Clouston, Sean A. P., Marcie S. Rubin, Jo C. Phelan, and Bruce G. Link. 2016. "A Social History of Disease: Contextualizing the Rise and Fall of Social Inequalities in Cause-Specific Mortality." *Demography* 53 (5): 1631–56. https://doi.org/10.1007/s13524-016-0495-5.

Link, Bruce G., and Jo Phelan. 1995. "Social Conditions As Fundamental Causes of Disease." *Journal of Health and Social Behavior* 35: 80. https://doi.org/10.2307/2626958.