Can self-testing end infectious disease epidemics? A tentative answer through game theory

Amandine Pepiot[a], **Virginie Supervie**[a], **Romulus Breban**[b]
[a]**Sorbonne Université, INSERM, Institut Pierre Louis d'Épidémiologie et de Santé Publique (INSERM UMR S 1136), Paris, France ;**
[b]**Institut Pasteur, Unité d'Epidémiologie des Maladies Emergentes, Paris, France.**

Amandine Pepiot
amandine.pepiot@iplesp.upmc.fr

Introduction

Progress must be made to reach individuals living with undiagnosed infectious diseases. Indeed, infectious diseases, such as HIV, HCV and sexually transmitted infections (STIs), often go asymptomatic and infected individuals can remain undiagnosed for a long time. As a consequence, individuals do not access treatment that would reduce the infectious disease related morbidity and mortality and the risk of onward transmission.

Tradional testing protocols fall very short of reaching all the undiagnosed individuals. A solution may be provided by the recent introduction of new testing tools, which consist either of **self-testing** for a specific disease (e.g. self-test for HIV) or testing for several diseases at the same time by using **self-sampling** kits (e.g. for HIV and STIs). It is reasonable to assume that these new tools complement existing testing methods and lead to an increase in testing frequency, because they offer advantages (anonymity, accessibility, etc.) that existing testing tools do not necessarily have.

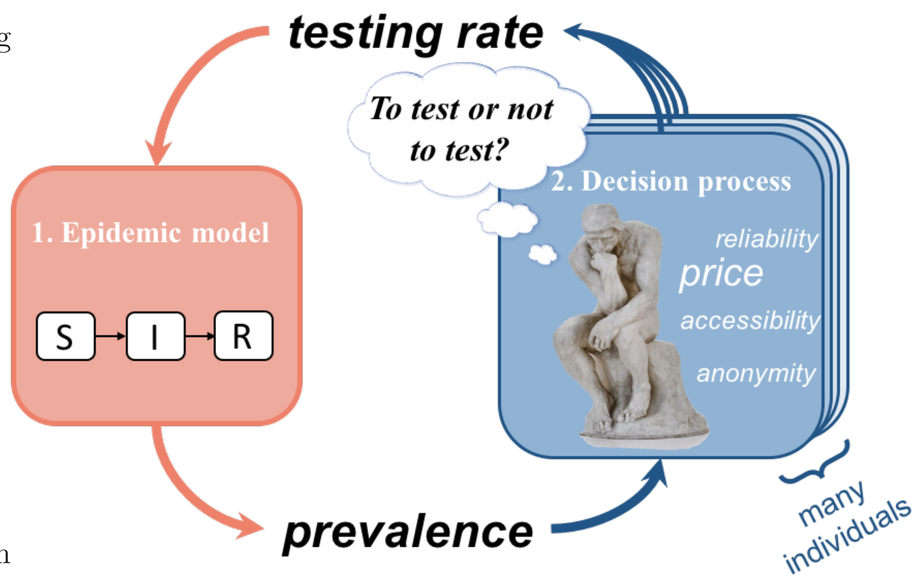
Research questions

- **What testing rate could be achieved with self-testing and self-sampling tools?**
- **What could be the impact of these tools on the infectious diseases epidemics?**

Model

We propose an innovative approach, combining a **transmission and progression epidemic model**, and a **game-theoretic decision model about getting tested**. Individuals decide to get tested within certain epidemiological contexts, which are described through paradigm compartmental epidemic models.

Our project focuses on evaluating the impact of **voluntary testing** on epidemics. We define voluntary testing as a testing strategy that consists of seeking testing depending on the **perceived risk of being infected** and the **perceived pros and cons of getting tested** (e.g. price, accessibility, reliability of the testing tools, etc.). This can be opposed to situations where individuals have no choice but getting tested or are highly encouraged to get tested, such as **symptom-driven testing**, when individuals seek testing due to having infectious disease symptoms, or when testing is highly recommended or mandatory (e.g. COVID tests required for traveling or sanitary pass).



Each individual's decision of voluntary test is indirectly influenced by the decisions of others, since the sum of all decisions determines the testing coverage, the number of new diagnoses, and, consequently, the treatment rate. In turn, this impacts the number of infected individuals and the epidemic progression. The decision model is thus intertwined with the epidemic model.

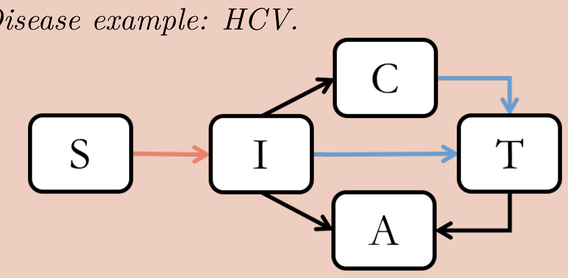
1. Epidemic model

Depending on the disease studied, different compartmental models should be used:

1. SIS model
Disease examples: gonorrhea, syphilis.

2. SIR model
Disease example: HIV.

3. SICAT model
Disease example: HCV.



▶ The total testing rate is a function of the **voluntary testing rate ρ**.

Let $\mathtt{R}(\rho)$ be the effective reproduction number that accounts for the voluntary testing.

The **effective reproduction number** $\mathtt{R}$ corresponds to the average number of people infected by an infectious individual during her/his infectious period. The epidemic vanishes if $\mathtt{R} < 1$ and remains if $\mathtt{R} > 1$.

In particular, there exists a rate ρ' such that $\mathtt{R}(\rho') = 1$ and $\mathtt{R}(\rho) \geq 1$ if and only if $\rho < \rho'$.

Then, depending on ρ, the infection prevalence $\Pi(\rho)$ goes towards the equilibrium:

$$\Pi(\rho) = \begin{cases} \Pi^{\mathrm{ES}} & \text{if } \mathtt{R}(\rho) > 1 \\ 0 & \text{if } \mathtt{R}(\rho) \leq 1 \end{cases}$$

where $\Pi^{\mathrm{ES}} = 1 - 1/\mathtt{R}(\rho)$ for the SIS model and $\Pi^{\mathrm{ES}} = a(\mathtt{R}(\rho) - 1)$ for the SIR and SICAT models where a is a model parameter.

2. Decision process

An individual decides to voluntary test according to:

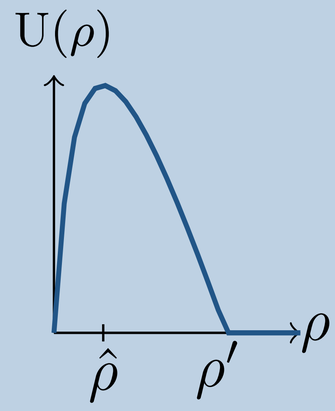
- the perceived risk of being infected ;
- perceived additional pros and cons of testing methods (e.g. accessibility, anonymity, prices, etc.).

To take into account all these parameters, we build a utility function U such as:

$$\mathbf{U}(\boldsymbol{\rho}) = \boldsymbol{\rho}(\boldsymbol{\Pi}(\boldsymbol{\rho}) - \mathbf{c})$$

with

- ρ, the voluntary testing rate;
- Π, the prevalence of the infection (or the probability of being infected);
- c, the addional per-test **cost** that summarizes monetary and non-monetary aspects of voluntary testing, taking values on the whole real axis. In particular, a negative cost is interpreted as a perceived benefit.



Utility theory

Game theory postulates that the value of the rate that maximizes the utility estimates the voluntary testing rate that may be achieved in the population.

We look for the voluntary testing rate ρ that maximizes U and denote it by $\hat{\rho}$ which is a function of c.

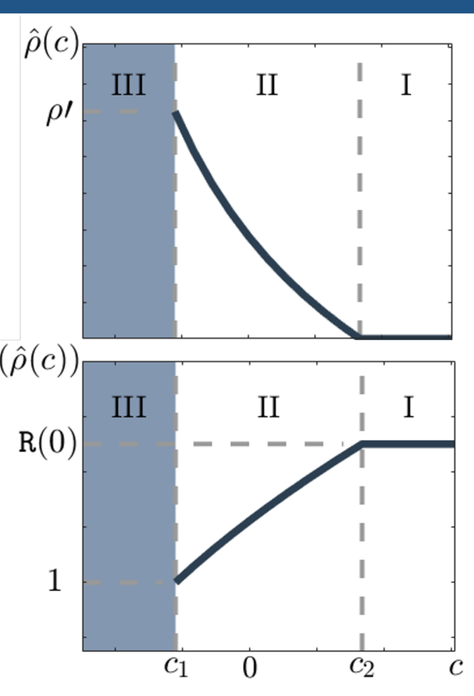
Results

Depending on the perceived per-test cost of voluntary testing c, three scenarios are possible:

- **I.** c is high (i.e. higher than c_2), hence **individuals are not prone to get more tested at all** (i.e. $\mathtt{R}(\hat{\rho}) = \mathtt{R}(0)$);
- **II.** c is between c_1 and c_2: **the epidemic is controlled ($\mathtt{R}(\hat{\rho}) < \mathtt{R}(0)$), but $\hat{\boldsymbol{\rho}}$ is not high enough for disease elimination** ($\mathtt{R}(\hat{\rho}) > 1$);
- **III.** c is low (i.e. lower than c_1), hence individuals are prone to get tested, thus **the disease elimination can be reached** ($\mathtt{R}(\hat{\rho}) < 1$). However, the elimination can be only temporary because once the epidemic is eliminated, individuals perceive the risk of infection as being low and do not find interest to use voluntary testing anymore. Hence, the coverage of voluntary testing decreases and the epidemic dynamics in Region III can enter Region II, where the epidemic reemerges.

The figures on the right illustrate the SIR model, but the results obtained for the SIS and SICAT models are qualitatively similar.

To reach disease elimination, the addional per-test cost c should be negative (i.e. a benefit), lower than the threshold c_1 found analytically. However, elimination can only be temporary.



Conclusion

New testing tools, such as self-tests and self-sampling kits, have been recently introduced. They offer new perceived advantages that other testing methods do not have (anonymity, accessibility, etc.). Therefore, it is expected that testing rates will increase. This could mitigate epidemics down to disease elimination if the perceived cost of voluntary testing is sufficiently low.

In practice, incentives should be given to reduce the cost of voluntary testing and make people test more. This can be done, for instance, by lowering the prices of self-tests and self-sampling tools and/or by increasing their accessibility.