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School of Accounting Economics and Finance
Working Paper Series 2020

Epidemic Control without Economic Collapse: A Note

Professor Amnon Levy
School of Accounting Economics and Finance
Economics Discipline
University of Wollongong
Wollongong, New South Wales
Australia

WP 20-01

March 2020

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Professor Amnon Levy
Economics Discipline
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Keywords: Epidemics; Testing; Quarantining; Medical Capacity; Treatment Intensity; Herd Immunity; Economic Collapse

1. Introduction

It takes at least four months to develop a vaccine against a new viral disease and several more months until it becomes widely available. Information about the emergence in Wuhan of an acute respiratory disease caused by a novel coronavirus was suppressed by the Chinese regime until February 2020. The subsequent uncontrolled spread of the disease, named Covid-19, to the rest of the world and the reactions of individuals and policy makers to this new disease, to the expected nine-month period without vaccine, to the revealed low capacity of health-care industries, to dependency on medical supply from China and to the infection rate and number of deaths in China, Italy, Spain and New York have led to the adoption of measures that severely restricted work, travels, international trade, attendance of schools and meetings. The implemented measures, as well as fear and panic, have devastated the world economy. A thirty per cent drop in the value of stocks in major equity markets, loss of millions of jobs and severe shortages of essential consumer goods have already been registered during the first three months of the disease.

Recent estimates of the possible person-to-person spread of the Covid-19 (Atkeson, 2020) have been made with the Wang et al.'s (2020) model, in which the current transition from the group of exposed people to the group of infected people is linear in the current number of infected people and also not (directly) dependent on the number of recovered people; namely, no herd immunity. The slow mutation of the novel coronavirus suggests that a significant immunity is gained by recovered people and hence heard immunity can play an important role in suppressing the spread of the disease.

Insight on epidemic control may be gained from Levy et al's (2006) paper on drug control with a logistic diffusion of drug use. The said paper proposes that, due to high full costs of control and the convex-concave nature of the diffusion of drug-use in the population, beyond a critical number of users it is no longer optimal to eliminate the use of drug but to allow convergence to a steady state that accommodates a larger number of users. In the case of epidemics, this proposition is reinforced by herd immunity. This factor and the constrained capacity of the health-care industry and avoidance of economic collapse are taken into account in this analytical note. The notion of economically sustainable epidemic control is introduced in the second section. The epidemic spread, intensity of medical care to a person tested positive and

cost equations are constructed in the third section. A planer's decision problem on tests, quarantine and intensity of medical care is presented in the fourth section.

2. Economically sustainable number of tests

Let,

$t \in (0,T)$ be a time index with *T* indicating a period without a widely available vaccine;

$N(t)$ be the population at time t of a place under consideration;

$S(t)$ be the number of people carrying the epidemic virus at time t, $0 \le S(t) \le N(t)$;

$q(t)$ be the number of people tested at time t, $0 \le q(t) \le N(t)$;

$\theta(t)$ be the fraction of the number of people tested positive and, subsequently, quarantined and hospitalised at time t, $0 \le \theta(t) \le 1$ (in other words, $\theta(t)q(t)$ is the number of people tested positive, quarantined and hospitalised at t);

ε be the fraction of output loss from being quarantined and hospitalised, $0 \le \varepsilon \le 1$;

y be the output, and income, of a non-quarantined person at time t; and

$y_{\min}$ be the minimal per capita output required for maintaining social order and avoiding economic collapse.

To avoid economic collapse, it is required that the per capita output (the left-hand-side term in the following equation) must not fall below $y_{\min}$ at any $t \in (0,T)$:

$$\frac{[N(t)-\theta(t)q(t)\varepsilon]y}{N(t)} \ge y_{\min}. \tag{1}$$

Hence, the economically sustainable number of tests at t is:

$$q(t) \le \left\lfloor \frac{1-(y_{\min}/y)}{\varepsilon\theta(t)} \right\rfloor N(t). \tag{2}$$

A priori, $\theta(t)$ is not known and assessment is required. With $q(t) \ll N(t)$, the test-and-trace method is effective for slowing the spread of the disease during the early stage of the epidemic. However, the spread of the disease outpaces the tracing. As the chain reactions stemming from different infection sources converge to one another, the test-and-trace method becomes more and more complicated and, consequently, expensive and inefficient. Randomize testing is cheaper and provides a more accurate assessment of the prevalence of the epidemic, $S(t)/N(t)$.

The economically sustainable largest number of tests is:

$$q_{\max}(t) = \left\lfloor \frac{1-(y_{\min}/y)}{\varepsilon\theta(t)} \right\rfloor N(t). \tag{3}$$

If the diffusion of the epidemic is logistic and tests are performed at random, $\theta(t)$ increases in the takeoff stage of the epidemic, reaches a peak and then decreases. Consequently, the

economically sustainable highest rate of tests, $q_{\max} / N$, decreases and then increases in the passage of time.

3. Epidemic spread with heard immunity, medical support and cost

Let,

$m(t) \in (0,1)$ be the intensity of medical care given to a hospitalised person at t;

δ be the recovery rate of infected people without hospitalisation at t, time-invariant (for simplicity) and inversely associated with the initial weighted average age of the population;

$\delta[1-\varphi m(t)]$ is the recovery rate of hospitalised people at t, $0<\varphi<1$;

μ is the mortality rate of people carrying the virus without hospitalisation at t, time-invariant (for simplicity) and positively associated with the initial weighted average age of the population; and

$\mu[1-\phi m(t)]$ is the mortality rate of hospitalised people at t, $0<\phi<1$.

The progression of the epidemic can be then portrayed by:

$$\dot{S}(t) = r_0 S(t)\left[1 - \frac{S(t)}{N(t) - \int_0^t \{\delta[1-\varphi(m(\tau)]\theta(t)q(\tau) + \delta[S(\tau) - \theta(t)q(\tau)]\}d\tau - \theta(t)q(t)}\right] - (\delta+\mu)\{[1-\varphi m(t)]\theta(t)q(t) + [S(t) - \theta(t)q(t)]\}. \quad (4)$$

The first term on the left-hand-side of this equation is the number of people currently infected. It is taken to be generated by a logistic diffusion with an intrinsic diffusion rate r_0 (reflecting the place's population density, sanitary standard, climate, etc.) and with an endogenously determined number of susceptible people: population size at t minus the cumulative number of people recovered by *t*, $\int_0^t \{\delta[1-\varphi(m(\tau)]\theta(\tau)q(\tau) + \delta[S(\tau) - \theta(\tau)q(\tau)]\}d\tau$ (the current stock of people with aquired immunity), and also minus the number of people tested positive and, consequently, quarantined at t, $\theta(t)q(t)$. The second term is the sum of the current numbers of recovered hospitalised and not hospitalised sick people. The third term is the sum of the current numbers of hospitalised and not hospitalised sick people who died.

The population growth equation is depicted as:

$$\dot{N}(t) = \eta N(t) - \mu\{[1-\phi m(t)]\theta(t)q(t) + [S(t) - \theta(t)q(t)]\} \quad (5)$$

where, η is the population's natural growth rate and, for simplicity, taken to be time-invariant and inversely associated with the initial weighted average age of the population.

The capacity of the medical industry is assumed to be fixed: $M(t) = M_0$ for every *t*. Consequently, the medical support constraint is:

$$m(t)\theta(t)q(t) \le M_0. \tag{6}$$

When the medical industry's capacity is fully utilized, the intensity of medical care given to each hospitalized infected person is:

$$m(t) = \frac{M_0}{\theta(t)q(t)}. \tag{7}$$

Let,

v be the pecuniary and nonpecuniary value of a quality adjusted life year,

L_0 be the longevity of the population on the eve of the epidemic, and

A_0 be the weighted average age of the population on the eve of the epidemic.

Then the average cost of loss of life in the epidemic is $v(L_0 - A_0)$.

In addition, let

$\alpha q(t)^2$ be the cost of testing $q(t)$ people at time t, $\alpha > 0$;

$\beta[\theta(t)q(t)]^2$ be the cost of facilitating and enforcing the quarantining of $\theta(t)q(t)$ people at time t, $\beta > 0$; and

$\gamma m(t)^2$ be the cost of hospitalising a person tested positive at time t, $\gamma > 0$.

Then, the instantaneous total cost of the epidemic for the place under consideration is:

$$\begin{aligned} c(t) = {} & \{\mu[1-\phi m(t)]\theta(t)q(t) + \mu[S(t) - \theta(t)q(t)]\}v(L_0 - A_0) \\ & + \alpha q(t)^2 + \beta[\theta(t)q(t)]^2 + \gamma m(t)^2\theta(t)q(t) + \theta(t)q(t)\varepsilon y. \end{aligned} \tag{8}$$

4. Planer's decision problem

In the absence of vaccine until the expected date *T*, a planner's decision problem is articulated as choosing the trajectories of the number of tests and intensity of medical care given to a person tested positive (i.e., $q(t)$ and $m(t)$ $\forall t \in (0,T)$) so as to minimize the total cost of the epidemic for the place under consideration over an endogenously determined planning horizon. For simplicity, the sum of instantaneous total cost of the epidemic, in present value, is considered. With ρ representing the rate of time preference of the population, the planer's decision problem is:

$$\min_{\{q(t),m(t)\}} \int_0^T e^{-\rho t} c(t)\, dt$$

where, $c(t)$ is given by equation (8) and subject to the epidemic progression equation (4), the population-growth equation (5), the medical industry's support constraint (6) and the collapse-avoidance condition (1).

The main backdraw in this setting is that the trajectory of the fraction of the number of people tested positive, $\theta(t)$, is not known to the planer. If, as assumed, the diffusion of the epidemic

is logistic and tests are performed at random, $\theta(t)$ increases in the takeoff stage of the epidemic, reaches a peak at some point in time, $\hat{t}$, and then decreases. The planner may huristically assume an inverted U-shaped relationship betweeen θ and t with $\theta(0) > 0$, a peak at $0 < \hat{t} < T$ and elimination of the disease at T, $\theta(T) = 0$:

$$\theta(t) = \theta[(T-\hat{t})^2 - (t-\hat{t})^2], \quad \theta > 0, \hat{t} < 0.5T. \tag{9}$$

Due to complexity, the economically sustained cost-efficient trajectories of the policy measures q and m and their properties cannot be analytically derived from the portrayed optimal control problem. Calibrations of the constructed model can serve for simulating the optimal trajectories of the policy measures for various locations.

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