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Does Vaccinations Reduce the COVID-19 Infection?

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ABSTRACT

Since the outbreak of COVID-19, each government has been struggling to find the ways of fighting off the coronavirus, with the vaccination being one of the most promising ways of doing it. In Japanese also, the government has started administering the vaccinations to the general public and is now analyzing the data from the recipients. In the present paper, we investigate the vaccine's efficacy by building a simple intertemporal theoretical model. Main result we obtain is that administering the vaccinations can increase number of the infected individuals, contrary what is widely believed.

Key words: coronavirus vaccination, failure probability of coronavirus vaccination, steady state number of the infected individuals, transmission rate of the coronavirus, vaccinated-but-still-infected individuals

INTRODUCTION

Since the outbreak of COVID-19, each government has been struggling to find the ways of fighting off the coronavirus, with the vaccination being one of the most promising ways of doing it. In Japan also, the government has started administering the vaccinations to the general public and is now analyzing the data from the recipients.

In the present paper, we attempt to investigate the vaccine's efficacy by constructing a simple intertemporal theoretical model based on numerous empirical studies, which showed the effects of the COVID-19 on various economic aspects (Barro, Ursua and Weng (2020), Baker, Bloom, Davis, Kost, Sammon and Viratyosin (2020), Baker, Farrokhnia, Meyer, Pagel, and Yannelis (2020), Baker, Bloom, Davis. and Terry (2020), Goede (2020), Ojha and Shubha (2020),Watanabe (2020) and so on), and theoretical works such as Fujita (2020a,b,c). The question we pose here is whether we can prevent the spread of the COVID-19 by the coronavirus vaccinations which are being conducted in many countries.

Structure of this paper is as follows. Section 2 lays out the basic model and section 3 derives the steady state number of the infected individuals. Concluding remarks are made in section 4.

BASIC MODEL

Let us consider an intertemporal economy where time passes continuously and the time horizon is infinite. The economy consists of N individuals, of whom $n(t)$ individuals in period t are infected with the coronavirus. For the sake of simplicity, we assume that all the infected individuals do not present symptoms and that x individuals ,whether she/he is infected or not, randomly in every period receive the coronavirus vaccinations with failure probability of

p×100 %, in a sense p×100 % of the vaccinators have no response. In order to simplify the analysis, we also assume that the vaccinations are effective only once in one period. That is, even if an individual, who was infected in the beginning of period t, successfully received the vaccinations and is not infected any more, she/he could be infected again in period t.

Therefore, we can classify the individuals who received the vaccinations in period t as in Table 1. That is, individuals (1) who were infected in the beginning of period t and are not infected any more by successfully receiving the vaccinations, but could be infected again in period t, whose number is $(1\text{-}p)\frac{n(t)}{N}x$, (2) who were infected in the beginning of period t and are still infected in the same period since vaccinations were not successful, whose number is $p\frac{n(t)}{N}x$, (3) who were not infected in the beginning of period t but are now immune to the coronavirus in period t thanks to the successful vaccinations, whose number is $(1\text{-}p)(1\text{-}\frac{n(t)}{N})x$ and (4) who were not infected in the beginning of period t and can be infected in period t because of the not-successful vaccinations, whose number is $p(1\text{-}\frac{n(t)}{N})x$.

Table 1. Classification of individuals who received the vaccinations in period t

	Received the vaccinations successfully $(1\text{-}p)$	Received the vaccinations not successfully (p)
Infected in the beginning of period t, $(\frac{n(t)}{N}x)$	(1) $(1\text{-}p)\frac{n(t)}{N}x$	(2) $p\frac{n(t)}{N}x$
Not infected in the beginning of period t,$((1\text{-}\frac{n(t)}{N})x)$	(3) $(1\text{-}p)(1\text{-}\frac{n(t)}{N})x$	(4) $p(1\text{-}\frac{n(t)}{N})x$

STEADY STATE NUMBER OF THE INFECTED INDIVIDUALS

In the present paper, among (1)-(4) in Table 1, those who are not supposed to be newly infected in period t are (2) and (3), whose total number is $p\frac{n(t)}{N}x + (1\text{-}p)(1-\frac{n(t)}{N})x$. Since a fraction $\frac{n(t)}{N}$ of those who did not receive vaccinations in period t-1 are still infected in period t, number of those who are not supposed to be newly infected is $p\frac{n(t)}{N}x + (1\text{-}p)(1-\frac{n(t)}{N})x + \frac{n(t)}{N}(N\text{-}x)$.

We assume each of the vaccinated-but-still-infected individuals (*i.e.*, (3) in Table1) transmits the virus to α individuals, thinking falsely that they are not infected any more. We also assume, for the simplicity of the analysis, that those who did not receive vaccinations and are infected individuals (i.e., not-vaccinated-and-infected individuals) keep avoiding the Three Cs carefully, and hence do not transmit the virus to any individuals.

Among the α individuals each of the vaccinated-but-still-infected individuals transmits the virus to, a fraction of $\{1-\frac{p\frac{n(t)}{N}x+(1-p)(1-\frac{n(t)}{N})x+\frac{n(t)}{N}(N-x)}{N}\}$ is newly infected. Thus, we can express $n(t+1)$ as

$$n(t+1)=n(t)-(1\text{-}p)\frac{n(t)}{N}x + p\frac{n(t)}{N}x\alpha\{1-\frac{p\frac{n(t)}{N}x+(1-p)(1-\frac{n(t)}{N})x+\frac{n(t)}{N}(N-x)}{N}\}. \quad (1)$$

Letting n^* denote the steady state number of the infected individuals and substituting $n(t+1)=n(t)= n^*$ into equation (1), we have the condition n^* should satisfy as

$$(1-p)\frac{n^*}{N}x = p\frac{n^*}{N}x\alpha\{1-\frac{p\frac{n^*}{N}x+(1-p)(1-\frac{n^*}{N})x+\frac{n^*}{N}(N-x)}{N}\}. \quad (2)$$

By solving n^* with respect to (2), we have

$$n^*=(1-\frac{1-p}{p\alpha})N\frac{1-\frac{(1-p)x}{(1-\frac{1-p}{p\alpha})N}}{1-\frac{2(1-p)x}{N}}. \quad (3)$$

Thus, we see that

(1) n^* is an increasing function of x if $\frac{1-p}{(1-\frac{1-p}{p\alpha})N} < \frac{2(1-p)}{N}$;

(2) n^* is a decreasing function of x if $\frac{1-p}{(1-\frac{1-p}{p\alpha})N} > \frac{2(1-p)}{N}$

Since $\frac{1-p}{(1-\frac{1-p}{p\alpha})N} \lessgtr \frac{2(1-p)}{N}$ is equivalent to $\alpha \gtrless \frac{2(1-p)}{p}$, we have the following Proposition.

Proposition

(1)If $\alpha > \frac{2(1-p)}{p}$, n* is an increasing function of x;

(2)if $\alpha < \frac{2(1-p)}{p}$, n* is a decreasing function of x.

The area where α and p satisfy $\alpha > \frac{2(1-p)}{p}$ and $\alpha < \frac{2(1-p)}{p}$ are, respectively, expressed as (1) (*i.e.*, above $\alpha = \frac{2(1-p)}{p}$) and (2) (*i.e.*, below $\alpha = \frac{2(1-p)}{p}$) in Figure1.

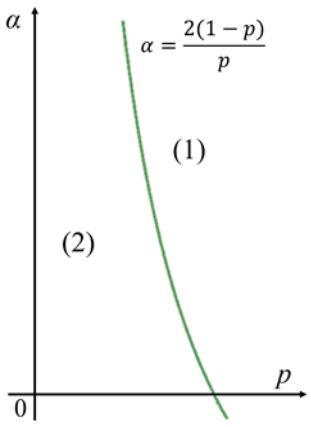


Figure1: Area where coronavirus prevails or not

From Proposition (1), we can say that the more individuals receive the coronavirus vaccinations, the more infected individuals exist if the transmission rate of coronavirus, α, is large enough to satisfy $\alpha > \frac{2(1-p)}{p}$.

CONCLUSIONS

We began this research wishing to contribute to the progress of the studies on how to solve the coronavirus problems. The result we got was more surprising than we had expected, that is, administering the vaccinations can increase the number of the infected individuals.

In the present paper, we made simplifying assumptions, such as, the vaccinations is effective only once in one period, not-vaccinated-and-infected individuals do not transmit the virus to anyone, and so on. Thus, it is necessary to examine the robustness of our results in a more general framework. It is of interest to incorporate economic aspects into the present paper's model. We will undertake such analyses in future research.

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