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Impacts of environmental issues on an optimal social distancing policy towards the Covid-19 pandemic

Gildas Appéré[1], Muriel Travers[2]

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Abstract

The 2020 Coronavirus COVID 19 pandemic has brutally confronted most national governments with a dilemma between fighting the pandemic and maintaining the economic activity. In a very short time, in the absence of effective vaccines and antivirals, they had to think about the implementation of a social distancing policy the least damaging for the economic activity by defining both its magnitude and its timeline. Depending on the priorities displayed by governments between preserving the economic activity and fighting the spread of the pandemic, social distancing policies can vary significantly. However, it was quickly observed that a social distancing policy has also had immediate positive environmental effects linked to the deep fall in the economic activity. This article models how the degree of environmental awareness in public decision-making acts on the optimal social distancing policy. The main conclusion is that higher consideration by the public authorities of the negative environmental effects generated by the economic activity can consolidate a social distancing policy against the pandemic.

Key words: Economic activity, Optimal control, Pandemic, Pollution, Social distancing policy

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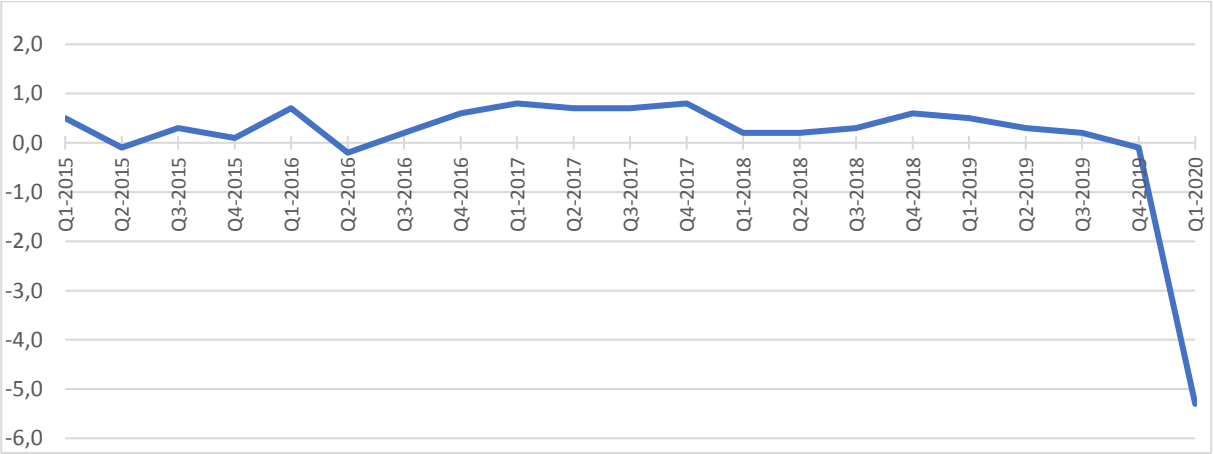
1. Introduction

The COVID-19 outbreak has been declared as the sixth public health emergency of international concern by the WHO (Chakraborty and Maity, 2020). In the absence of fully effective curative vaccines and treatments such as antivirals, social distancing[1] policies aimed at greatly reducing human contact have emerged as the most effective short-term measures in the face of this pandemic (Anderson et al., 2020). Indeed, social distancing contributes to slow down the increase of infected people and they also spread the flow of severely affected people over time (leading to a "social distance flatten curve") in order to avoid a pandemic peak risking to saturate health structures. However, a strict social distancing generates a massive reduction in the economic activity which is highly detrimental, particularly in terms of jobs, income or public debt. Fernandes (2020) estimates that, with a 1.5 months shutdown, the average economic impact of - 4.5% of GDP is expected for all the countries[2] that he analysed. For instance, in the case of France, we can already observe the following steep fall of the GDP for the 1st quarter of 2020:

Figure 1: Evolution (%) of the French Quarterly GDP between 2015 and 2020



Source: From the data of the French National Institute of Statistics and Economic Studies (INSEE, 2020)

The COVID 19 pandemic has therefore brutally subjected the public authorities to a crucial dilemma between the immediate need to protect populations from this disease and the need to avoid an

unprecedented economic crisis having an immediate disastrous effect on the well-being of populations but also in the longer term (e.g. reduced access to healthcare for conditions other than COVID 19). Economically, socially and politically, a strict social distancing is not a viable solution for very long: the longer the social distancing lasts, the less it will be accepted by the population and the higher the risks of legal questioning (e.g. political contestation , public demonstrations, economic pressure, etc.) and illegal questioning (e.g. deviant behaviour towards social distancing measures) will be. Consequently, the question of the more or less strict degree of social distancing as well as its duration has quickly become an important issue for the public authorities, while being under the permanent threat of a brutal reactivation of the pandemic (i.e. a "2nd wave"). In many countries, announcements of a progressive easing schedule for the social distancing policy has appeared early, sometime in the midst of pandemic[3].

However, it has quickly become apparent that a social distancing policy, through these negative impacts on the economic activity, has also had immediate environmental effects: for instance, according to the NASA and ESA, a massive air pollution decline between January and March 2020 (ranging from -20 to - 30% for NO2) has been observed in many countries (e.g. China, Italy, France) linked to the decline in economic activity (Muhammad et al, 2020). Similarly, a sharp reduction in noise pollution has been observed due to the reduction in transportation (Zambrano-Monserrate et al. 2020). All of these environmental and health effects constitute secondary benefits (or "co-benefits")[4] which have to be added to the primary benefits expected from social distancing measures and which somewhat mitigate the dramatic effects of the decline in the economic activity.

Consequently, the objective of this article is to analyse how taking into account these immediate environmental positive effects interferes with the social distancing policy towards the pandemic. More specifically, it is a question of showing that a more or less strong environmental awareness of public decision-makers can have indirectly an impact on the progression of the epidemic within a country. The paper is organized as follows. Section 2 details an optimal public decision control model focused on the primary dilemma between maintaining the economic activity versus fighting the

pandemic. Section 3 introduces a more or less strong consideration for the environmental benefits linked to the decline in the economic activity induced by the social distancing policy. Section 4 discusses.

2. Dilemma between fighting the pandemic and maintaining the economic activity without taking into account immediate environmental effects

2.1. An optimal control model of a social distancing policy

Our analysis is based on classic models of optimal control developed in environmental economics to analyse the negative environmental effects of fossil fuel use (e.g. Foster, 1980).

In the absence of social distancing measures, the number of people infected with the virus n(t) is described by a classical logistic growth curve (Verhulst, 1845):

$$\dot{n} = r \times n \times (1 - n/n_{max})$$

- r is the intrinsic growth rate of the pandemic: this intrinsic growth rate depends first of all on the basic reproduction number (R_0), which defines the mean number of secondary cases generated by one primary case, with an expected decline of new infections when $R_0 < 1$ (Nouvellet et al., 2020). It has been estimated for COVID 19 to be around 2.5 in China in the early stages of the pandemic (Anderson et al., 2020). On the other hand, this intrinsic growth rate also depends negatively on the fact that, after a period, cured people are no longer contagious.
- n_{max} is the "biotic capacity" of this virus: the expansion of the pandemic is limited by the finite size of the population that can be infected by this virus[5] in the country.

Social distancing measures c(t) act on the pandemic by reducing the capacity of a person infected by the virus to infect new people[6], that leads to:

$$\dot{n} = r(c) \times n \times (1 - n/n_{max}) \text{ with } r' = r_c < 0.$$

The national economic activity Y is directly affected by the degree of social distancing c(t). On the other hand, given the fact that the people suffering from severe symptoms associated with the COVID 19 virus are overwhelmingly elderly inactive[7], we assume that Y is not directly affected by n(t):

$$Y = Y(c)\ ;\ Y_c < 0\ ;\ Y_n = 0$$

To simplify the analysis, it is also assumed that the economic growth (apart from the effects of COVID 19 on the economic activity) is negligible, because of the short duration of the planning period T considered (e.g. a few weeks) and because the "normal" growth rate of Y (excluding the specific effects of COVID 19) is negligible[8] compared to the effects on Y of COVID 19 through social distancing.

The public authority (social planner) seeks to maximize over a defined planning period[9] T the sum[10] of the instantaneous utility which depends on the level of the economic activity Y and the number of people infected with COVID 19: $U = U(Y(c), n)$; $U_Y > 0$; $U_{YY} < 0$; $U_n < U_{Yn} = 0$.

The dilemma of public authorities facing the pandemic is then formalized by the following optimal control problem:

$$Max\ V[c] = \int_0^T U(Y(c), n)dt$$

Subject to:

$$n^{\cdot} = r(c) \times n \times (1 - n/n_{max})$$

$$n(0) = n_0\ ;\ \text{n(T) free}\ ;\ \text{T fixed terminal time}$$

In order to go further in the analysis, we specify the different functions as follows:

- $Y(c) = \bar{Y}(1-c)^g$ with g corresponding to the magnitude of the social distancing c(t) effect on the economic activity (g > 0) and $\bar{Y}$ corresponding to the index of the "normal" economic activity before the planning period. Therefore:

  $$U(Y(c), n) = \ln\left(Y(c)^{\theta} \times (n+1)^{-(1-\theta)}\right)$$

  with $\theta \in [0\,;1]$ corresponding to the relative importance of the economic activity Y in the utility function compared to the importance of the number of infected people n(t).

- $r(c) = r(1-c)^d$ with $c \in [0\,;1]$ and d > 0 corresponding to the magnitude of the social distancing effect c(t) on the intrinsic pandemic growth rate. However, the presence of this parameter d preventing soon any analytical resolution (i.e. absence of solution for c(t) conditionally to the values of the co-state variable λ(t)), we assume that d = 1 without loss of generality.

So the Hamilton function associated with this problem is:

$$H(t,n,c,\lambda) = \ln\left(Y(c)^{\theta} \times (n+1)^{-(1-\theta)}\right) + \lambda(t)(\, r \times (1-c) \times n \times (1 - n/n_{max}\,)$$

Since H is differentiable and nonlinear with respect to the social distancing variable c(t), we can apply the usual 1st and 2nd order conditions $\partial H/\partial c = 0$ and $\partial^2 H/\partial c^2 < 0$. We obtain:

$$\frac{\partial H}{\partial c} = -\theta \times g \times \frac{1}{1-c} - \lambda \times\ r \times n \times (1 - n/n_{max}) = 0$$

This equation leads to the following solution of the social distancing c(t) conditionally to λ(t):

$$c(t) = 1 + \frac{\theta \times g}{\lambda \times\ r \times n \times (1 - n/n_{max})}$$

and we check that: $\partial^2 H/\partial c^2 = -\theta \times g/(1-c)^2 < 0$

We now try to find values taken by the co-state variable λ(t) and by the state variable n(t) in order to determine the optimal path for the social distancing c(t) which is the control variable. We use the equation of motion of the co-state variable:

$$\dot{\lambda} = -\frac{\partial H}{\partial n} = \frac{1-\theta}{n+1} - \lambda \times\ r \times (1-c) \times (1 - 2n/n_{max})$$

This differential equation depending on the level of social distancing c(t), we substitute c(t) by its expression as a function of λ(t) obtained previously:

$$\dot{\lambda} = \frac{g \times \theta}{n} + \frac{1-\theta}{n+1} - \frac{g \times \theta}{n_{max} - n}$$

Since this differential equation depends on the number of infected people n(t), it cannot be solved as it is. We therefore consider the equation of movement of the number infected people n(t) described by: $\dot{n} = \partial H/\partial\lambda = r \times (1 - c) \times n \times (1 - n/n_{max})$. We replace the magnitude of social distancing c(t) by its expression as a function of λ(t) and we then obtain: $\dot{n} = -g \times \theta/\lambda$. Consequently, we obtain a system of 2 first order differential equations.

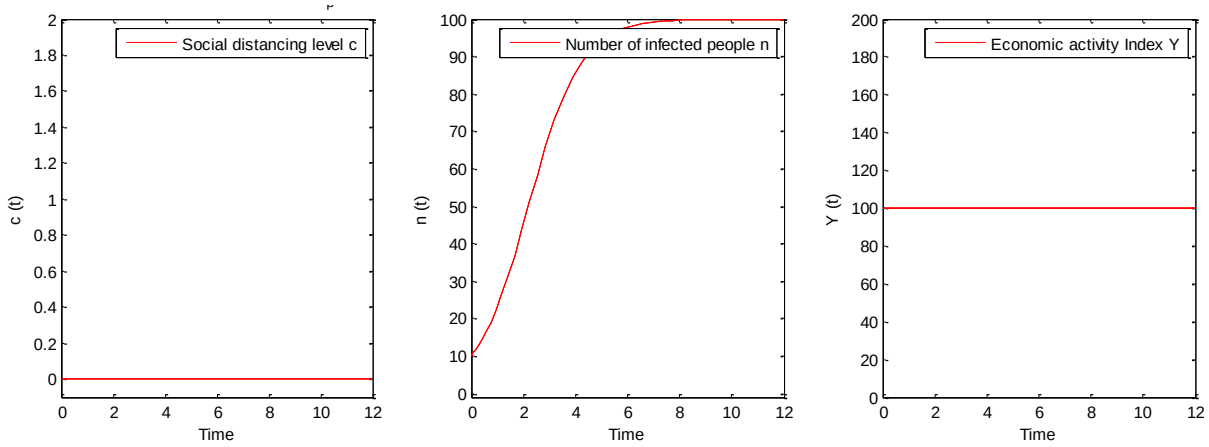
We can already highlight some obvious conclusions for extreme singular situations. If θ = 0 i.e. if the public authorities priority consists in containing the pandemic exclusively whatever its negative consequences for the economic activity, we obtain the obvious results: $\forall t, c(t) = 1$, $\dot{n}(t) = 0$, Y(t) = 0. At the opposite, if θ = 1 i.e. if the public authorities priority consists in preserving the economic activity whatever the consequences concerning the pandemic, we obtain[11]: $\forall t, c(t) = 0, \dot{n}(t) = r \times n \times (1 - n/n_max), Y(t) = \bar{Y}$. Otherwise, this system of 2 first order nonlinear differential equations doesn't display any explicit analytical solution. For this reason, our following analyzes are established on numerical simulations.

2.2. Numerical analysis of the various optimal social distancing policies

From the previous analytical model, our simulations are performed by taking the following values, consistent with the initial hypotheses concerning the different functions (T = 12 (for example 12 weeks), $\bar{Y}$ = 100, n_{max} = 100, r = 1). Furthermore, we take d = 1 and g = 1, that signifies respectively proportional effects of social distancing c(t) on r and on Y [12]. The results obtained with extreme values $n(0) = 0$ *and* $n(0) = n_{max}$ coincide with those analytical and logically expected, namely an optimal public policy characterized by an absence of social distancing (c(t) = 0) throughout the planning period and therefore maintaining the economic activity at its "normal" level i.e. $Y(t) = \bar{Y}$. Similarly, if the preferences of the public authorities focus exclusively on preserving the activity economic (θ = 1) (see figure 2), then there will be no social distancing throughout the planning period and the economic activity will remain at its "normal" level. On the other hand, a rapid increase in the

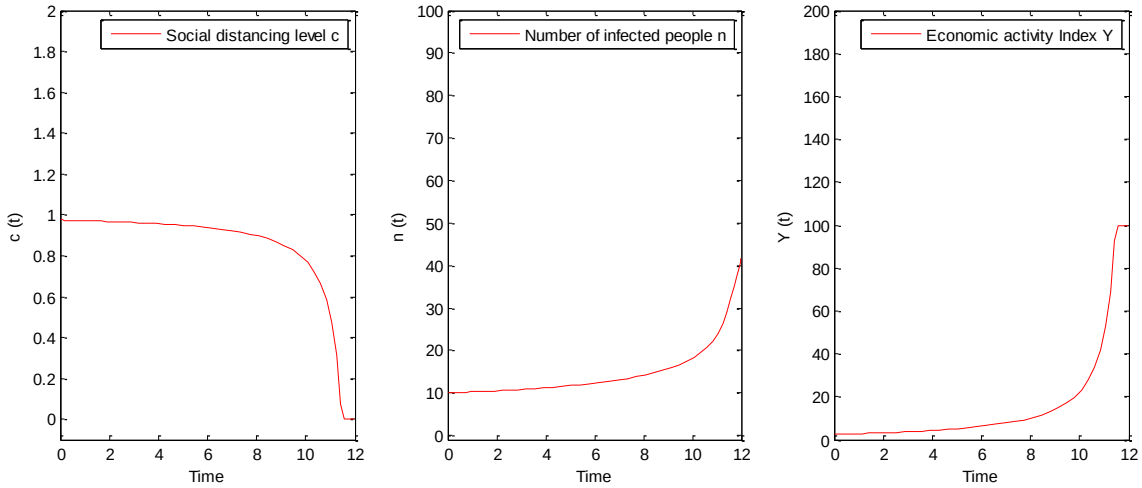
number of infected people can be observed, with a typical pandemic curve reaching its maximum well before the end of the decision period T.

Figure 2: consequences if the public authorities focus exclusively on preserving the economic activity



We now consider 2 intermediate situations, more in line with the observed reality. To schematize the analysis, we characterize what should be an optimal social distancing policy for 2 types of countries according to their relative preference vis-a-vis this dilemma: we consider on the one hand a country whose public authorities have a strong relative preference for the fight against the pandemic (e.g. $\theta = 0.25$) and on the other hand a country whose public authorities have a strong relative preference[13] for maintaining the economic activity (e.g. $\theta = 0.5$) [14]. Numerical analysis indicates that these differences in terms of preferences lead to a shift in the duration and magnitude of the social distancing policy during the planning period. Thus, in the first case ($\theta = 0.25$) (see figure 3), the optimal social distancing policy consists in maintaining, from the initial date of the planning period, a strict social distancing for a long period of time and then gradually easing this social distancing with an acceleration at the end of the period.

Figure 3: consequences if the public authorities have a strong relative preference for the preservation of the population against the pandemic

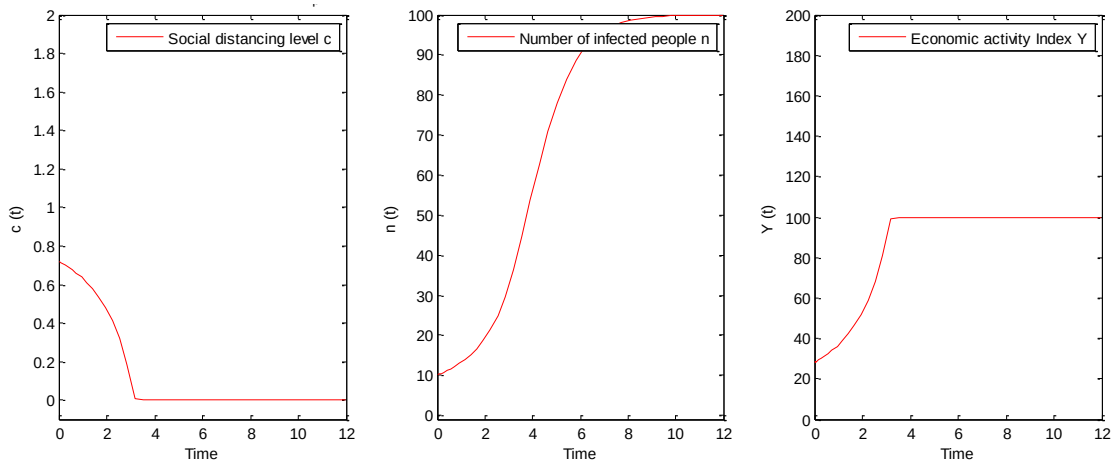


This social distancing policy leads to a severe drop in the economic activity which only quickly recovers at the end of the planning period. Likewise, the number of infected people remains at a low level and increases more quickly at the end of the planning period in connection with the easing of social distancing, while remaining well below the maximum number n_{max}. This configuration is logical and corresponds fairly well to the situation encountered by many countries (e.g. Germany, China) with, in particular, the fear by some scientists of a scenario describing a possible sharp increase in the number of infected people following the easing of the social distancing : for instance, a report in June 2020 of the Imperial London College states that "As many countries are easing social-distancing policies, our analysis illustrates that sustainable lifting of population-wide social-distancing measures should be undertaken very carefully and replaced with equally effective control measures, such as thorough contact-tracing" (Nouvellet et al. 2020).

In the second case (θ = 0.5) (See figure 4), the social distancing optimal policy also consists in imposing a social distancing (but not total) from the initial date of the planning period then operating

very early an easing of this social distancing in order to restore economic activity as quickly as possible, but at the cost of a large assumed increase in the number of infected people.

Figure 4: consequences when the public authorities have a strong relative preference for the preservation of the economic activity



The interest of this numerical simulation is to show that the degree of relative preference for the economic activity compared to the fight against the pandemic results in a more or less long period of social distancing but, in no case, in a reversal of the timing of social distancing: a public policy based on a low initial social distancing followed by a “late social distancing” to cope with the sudden increase in the number of infected people appears not to be an optimal policy, even for a country with a strong relative preference for maintaining the economic activity. In the same vein, a "stop & go" policy of social distancing carried out on a discretionary basis according to the evolution of the pandemic during the planning period does not seem optimal either.

3. Dilemma between fighting the pandemic and maintaining the economic activity taking into account immediate environmental effects

The integration of the environmental issue into this primary dilemma is directly inspired by models of optimal control pollution (e.g. Foster, 1980 ; Rozenberg et al., 2020). In our short-term pandemic decision-making model, we only consider the immediate (instantaneous) environmental effects

induced by the economic activity. Thus, at each instant t, the environmental pollution or nuisances P(t) are an increasing function of the instantaneous level of the economic activity Y(t):

$$P(t) = P(Y(t)) \text{ with } P_Y > 0.$$

These pollution or nuisances act negatively on utility: $U = U(Y(c), n, P(Y))$ with $U_P < 0$

The primary public authorities dilemma facing the COVID 19 pandemic becomes:

$$Max\ V[c] = \int_0^T U(Y(c), n, P(Y))dt$$

Subject to: $\dot{n} = r(c) \times n \times (1 - n/n_{max})$

$n(0) = n_0$

$n = n(T)$ free ; T fixed terminal time

We take the same specifications from the previous model and we specify the link between P and Y as follows: $P(Y) = Y^h$ with h > 0. The problem becomes:

$$Max\ V[c] = \int_0^T ln\big(Y(c)^\theta \times (n+1)^{-(1-\theta)} \times (P(Y)+1)^{-\theta_p}\big)dt$$

Subject to: $\dot{n} = r(1-c)^d \times n \times (1 - n/n_{max})$

$n(0) = n_0$

$n = n(T)$ free ; T fixed terminal time

With : θ_p represents the public authorities' preference vis-à-vis the negative immediate environmental effects of the economic activity.

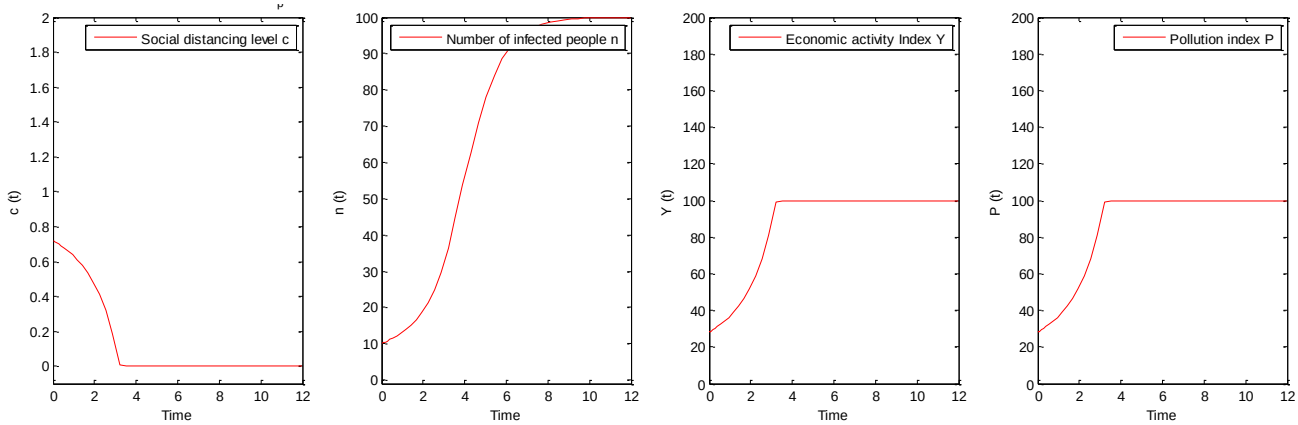
We keep the writing $Y(c)^\theta \times (n+1)^{-(1-\theta)}$ in order to keep explicit the primary dilemma between maintaining the economic activity and fighting the pandemic. In this way, the environmental effects issue appears here more as an element which "disturbs" this primary dilemma and not as the 3rd element of a new "Economy - Pandemic - Environment" dilemma[15].

As before, the absence of an explicit analytical solution leads us to focus on analysis based on numerical simulations. In the absence of specific elements concerning the relationship between the economic activity Y and its negative immediate environmental effects P, we consider these effects as

proportional (h = 1)[16], which leads to a pollution curve P(t) strictly identical to the economic activity curve Y(t).

We first check that if pollution P does not enter the utility function explicitly (i.e. $\theta_p = 0$), the social distancing policy will obviously be unchanged from the primary dilemma (and for instance $\theta = 0.5$) and pollution P will increase as the economic activity resumes following a gradual social distancing easing (see figure 5).

Figure 5: consequences when pollution does not enter the utility function explicitly



We now analyse the effects of increasingly taking into account of environmental effects in the preferences of public authorities in the context of the primary dilemma between economic activity and pandemic. Numerical analysis[17] indicate that taking into account the immediate negative environmental effects of the economic activity logically modifies the policy of social distancing in the logical way, namely a prolongation in time of the initial period of social distancing, whatever the initial profile of the social distancing policy.

Without being very surprising, these results (see figures 6a, 6b, 6c) have the advantage of showing an apparent correlation between taking environmental concerns into account and fighting the progression of the pandemic, even if it is in no way a causality link between these 2 elements: it is above all to note that the reduction in environmental effects following the fall in the economic activity constitutes a co-benefit of the social distancing policy and consequently contributes more or less strongly (according to the environmental preferences of the public decision-makers) to legitimize a severe social distancing policy.

Figures 6: Respective effects of higher environmental preferences (θ_p)

Figure 6a: on the optimal social distancing policy

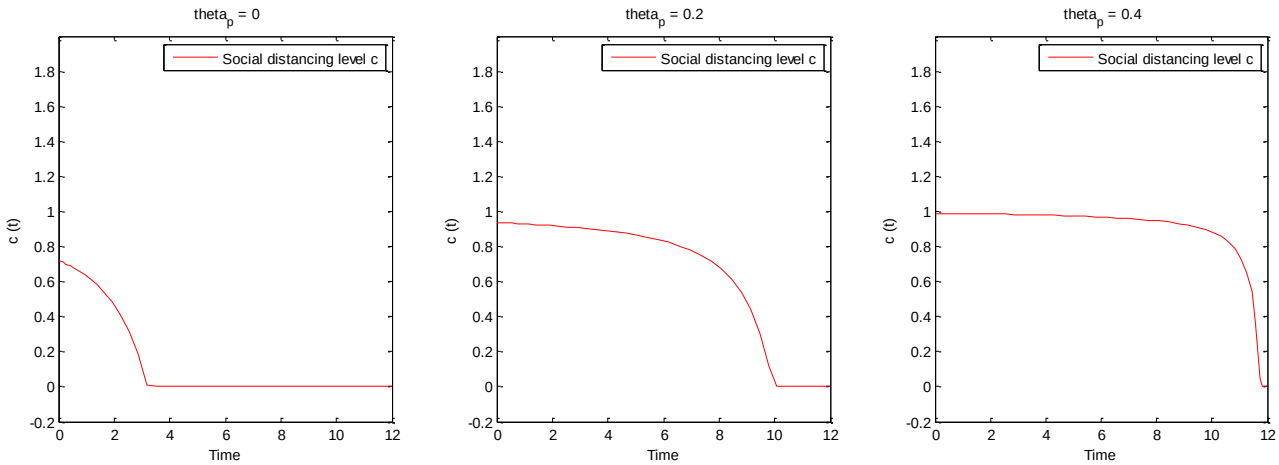
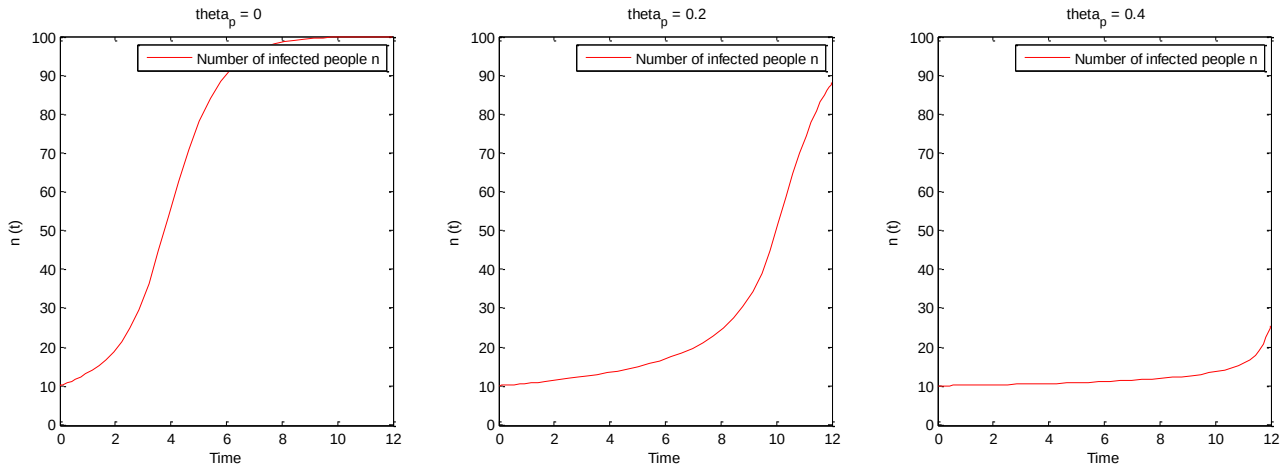
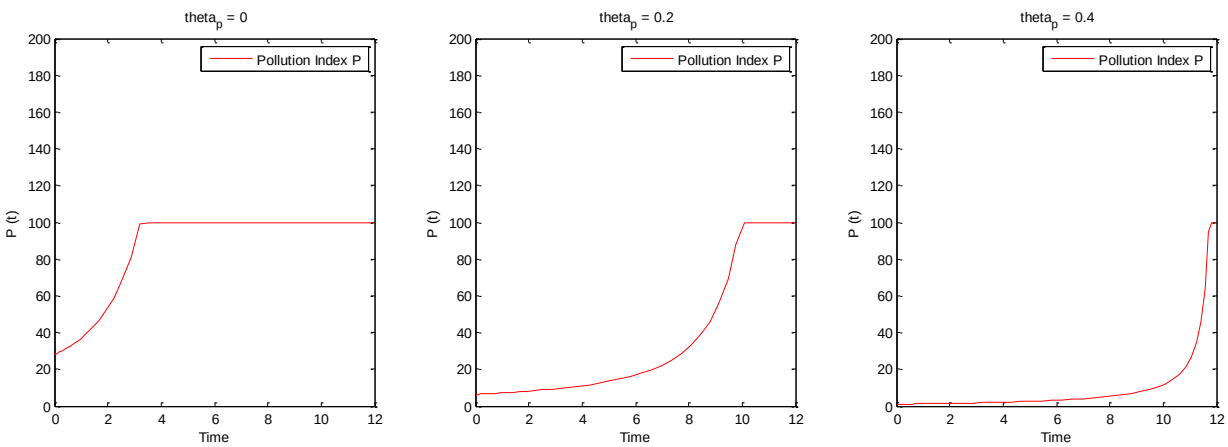


Figure 6b: on the evolution of the number of infected people



Figures 6c: on the pollution induced by the economic activity



In terms of pro-environmental prospects, it may be important in the coming months to measure scientifically the real extent of the reductions in environmental pollution and nuisances resulting from the social distancing policies observed in many countries. Thus, a communication policy on these environmental co-benefits of social distancing can be both a tool for the public health and a tool for the environment protection[18].

4. Discussion

Our model does not take into account long-term positive environmental effects such as the effects on the accumulation of greenhouse gases: for instance, according to Meles et al (2020), due to a lower economic activity resulting from the COVID-19 crisis, existing policy measures concerning greenhouse gas emissions could achieve the 40% target sooner than 2030. The long-term environmental consequences of COVID 19 can then be analysed through an optimal control model considering pollution as a stock that accumulates over time (e.g. Foster, 1980; Chakravorty et al., 2006). However, from our point of view, it is not necessarily relevant to include these long-term environmental effects of a social distancing policy, knowing that the current pandemic dilemma is a very immediate and transient decision over a relatively short planning period compared to the long-term issue of global warming. Furthermore, it is also possible that there is a positive link between the preference for the environment and the preference for the health protection and therefore that: $\theta_p = f(\theta)$ with $f' < 0$. This endogenization of θ_p would further oppose optimal policies of social distancing between countries whose public decision-makers have a strong preference for the economic activity and countries whose public decision-makers take more account of environmental and health issues conjointly. Finally, alongside measures of social distancing, there are also other immediate measures against the pandemic, in particular by using protective equipment (masks, gloves, plexiglass windows and more generally a large use of disposable plastic) having an immediate negative effect on the environment (e.g. via an increase of plastic waste into the environment). This

creates another type of dilemma for pandemic control instruments with divergent effects on the economic activity and the environment: on the one hand, measures more based on protective equipment (with neutral or even positive effects on the economic activity but with negative immediate effects on the environment) on the other hand, measures based on social distancing (with positive immediate effects on the environment but with a very negative impact on the economic activity).

Notes

[1] We use a broad definition of social distancing, including quarantine measures for infected people, border closings and lockdown.

[2] 30 countries including the most developed countries (United States, China, Japan, Germany, India, United Kingdom, France, Italy, Brazil, Canada, etc.)

[3] For instance, the French government announced on April, 28 2020 the progressive social distancing easing dates set for May 11, and June 2, 2020 (http://www.assemblee-nationale.fr/)

[4] This positive impact is named by Muhammad et al. (2020) as a "Blessing in Disguise".

[5] We make the assumption that people infected with the virus cannot be infected a second time, either because they are immune or because they are deceased. This seems to be the case with COVID 19. In addition, n_{max} is not necessarily equal to the total population of a country: this depends on many factors such as for example the existence or not of cross-immunity.

[6] To make the modelling easier, we assume that the control variable c(t) is a continuous variable i.e. the public authorities can decide on a precise degree of the social distancing (and not just a few discrete levels). Furthermore, to simplify the analysis, it is assumed that the degree of the social distancing can act immediately on the observed number of infected people (i.e. negligible incubation time).

[7] For instance, Rothana and Byrareddy (2020) estimate that the median age of the deaths was 75 years among the reported cases of COVID 19 in Wuhan (China) as of January 25, 2020.

[8] For example, in the case of France, the annual GDP growth rate was 1.3% in 2019 (INSEE, 2020) i.e. 0.11% per month, while the projections for 2020 mention (May 2020) a drop of - 8% in GDP.

[9] This way of thinking seems realistic with the way of communicating from governments in various countries which have set targets in terms of dates and not in terms of results (e.g. a free terminal time T would correspond to the date when there would be no more new cases of COVID 19).

[10] This sum is not discounted, especially since it is a very short-term public decision problem (a few weeks).

[11] Other qualitative analyzes could be obtained provided that the values of the parameters are further specified (e.g. $g = 1$, $\theta = 0.5$)

[12] The values of these parameters can be modified, without fundamentally changing the meaning of the analyzes proposed subsequently.

[13] We stress that this is a relative preference: this does not mean that the public authorities knowingly place no value on the question of the number of infected people, but only that they give priority to the preservation of the economic activity (and vice versa for public authorities showing a strong preference for containing the number of infected people).

[14] Since the impact of θ on Y is not linear, $\theta = 0.5$ already corresponds in fact to a strong relative preference for the economic activity.

[15] We could have written $Y(c)^{\theta_Y} \times (n+1)^{-\theta_n} \times (P(Y)+1)^{-\theta_p}$ which does not change the resolution of the model.

[16] Again, the value of this parameter h can be changed, without fundamentally changing the meaning of the analysis proposed subsequently.

[17] For this simulation, we take $\theta = 0.5$ (strong preference for the economic activity relative to the fight against the pandemic) in order to make more visible the effects of an increase in preferences for environmental effects (increase in θ_p).

[18] However, we must be aware that this attitude linking environment benefits and pandemic issue can be criticized by emphasizing its "opportunistic" character (i.e. by taking advantage of a huge health crisis to advance the environmental cause).

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