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Abstract

This paper defines the concept of feedback Kant-Nash equilibrium for a discrete-time model of resource exploitation by infinitely-lived Kantian and Nashian players, where we define Kantian agents as those who act in accordance with the categorical imperative. We revisit a well-known dynamic model of the tragedy of the commons and ask what would happen if not all agents are solely motivated by self interest. We establish that even without external punishment of violation of social norms, if a sufficiently large fraction of the population consists of Kantian agents, the tragedy of the commons can be substantially mitigated.

JEL-Codes: C710, D620, D710.

Keywords: Kantian equilibrium, rule of behavior, categorical imperative.

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1 Introduction

Even though the theory of the tragedy of the commons (Gordon, 1954, Hardin, 1968) has issued a stern warning against the regime of resource management under common access, economists have become increasingly acquainted with *the Ostrom facts*: many communities have been able to manage their common property resources in a sustainable way (Ostrom, 1990). The key mechanism behind these successful communities is the operation of social norms. There are a number of dynamic models of common property resources where some subset of agents observe social norms. This literature includes the interesting contributions of Sethi and Somanathan (1996), and Breton, Sbragia, and Zaccour (2010). The former paper assumes that agents are myopic, while the latter paper considers far-sighted agents. A common feature of models with social norms is that some subset of agents is endowed with the propensity to punish community members who violate norms.

This paper takes a different approach. We introduce into a model of common property resource a subset of players called Kantian agents and we enquire whether even without punishment against violation, a society that has a sufficiently large number of Kantians can attenuate the tragedy of the commons. For this purpose, we define the concept of feedback Kant-Nash equilibrium in a discrete-time model of resource exploitation by infinitely-lived Kantian and Nashian players.

Our research question is: In a dynamic game of exploitation of a common property resource, does the presence of a group of Kantian agents lead to a higher steady-state welfare and environmental quality? Using an adaptation of the fish-war model of Levhari and Mirman (1980), we show that if Kantian agents constitute a large share of the population, the resource stock can attain a steady state that is sufficiently close to the social optimal.

2 A brief review of the literature on the role of morality and Kantian behavior in economics

The words "Kantian economics" first appeared in the title of an influential paper by Laffont (1975). He asks, "Why is it that (at least in some countries) people do not leave their beer cans on the beaches?" This question is difficult to answer using the Standard

Model of Economic Behaviour. The impact one's own 'welfare' from leaving one's beer cans on the beach is certainly negligible while the effort to properly dispose of them is not. Yet many people would make the required effort. Laffont's explanation is very simple, yet compelling: "Every economic action takes place in the framework of a moral or ethics." He refers to Kant's categorical imperative. Kant wrote that *"There is only one categorical imperative, and it is this: Act only on the maxim by which you can at the same time will that it should become a universal law"* (Kant, 1785; translated by Hill and Zweig, 2002, p. 222). Other eminent economists have also alluded to Kantian behavior in economics (Arrow, 1973; Sen 1977).

Many economists have pointed out that the standard axiom of homo œconomicus is clearly inadequate to explain economic behavior. In fact, as Vernon Smith (2003, p. 465) pointed out, "the values to which people respond are not confined to those... based on the narrowly defined canons of rationality." This quoted sentence has its roots in the work of Adam Smith (1790), where the role of natural sympathies in human activities was discussed at length.[1] Vernon Smith (2003, p. 466) elaborates on this points:[2]

"Research in economic psychology has prominently reported examples where "fairness" considerations are said to contradict the rationality assumptions of the standard socioeconomic science model. But experimental economics have reported mixed results on rationality: people are often better (e.g., in two-person anonymous interactions), in agreement with (e.g., in flow supply and demand markets), or worse (e.g., in asset trading), in achieving gains for themselves and others than is predicted by rational analysis. Patterns of these contradictions and confirmations provide important clues to the implicit rules or norms that people may follow, and can motivate new theoretical hypotheses for examination in both the field and the laboratory. The pattern of results greatly modifies the prevailing, and I believe misguided, rational SSSM, and richly modernizes the unadulterated message of the Scottish philosophers."[3]

For the analysis of certain economic activities, John Roemer (2010, 2015) has proposed a useful mathematical formulation of the Kantian rule of behavior, admitting the possibilities that agents have different cost functions or profit functions. This formulation may be briefly described as follows. Consider an activity that yields negative or positive

[1]Vernon Smith (2003) emphasizes these roots and the importance of Adam Smith's moral philosophy.

[2]I thank a reviewer for drawing my attention to the article of Vernon Smith (2003), and the relevant quote.

[3]For a fully articulate exposition of Adam Smith's philosophical views, see Muller (1993).

externalities, such as playing loud music, or keeping the side walk in front of your house clean and safe. Roemer suggests that, as a Kantian, your current activity level $x > 0$ is morally appropriate if and only if any scaling up or scaling down of that activity level by a factor $\lambda \neq 1$ would make you worse off, were *everyone else* to scale up or down their activity levels by the same proportion. Clearly, Kantian agents are not optimizing in the standard economic sense. They are acting according to a moral norm. As Roemer (2015) puts it, a Kantian agent would explain her behavior as follows:

> *I hold a norm that says: "If I want to deviate from a contemplated action profile (of my community's members), then I may do so only if I would have all others deviate in like manner."* (Roemer, 2015, p. 46.)

Is such a behavioral rule rational? Harsanyi (1980) gives an affirmative answer. It is as if socially responsible individuals made a rational commitment to a comprehensive joint strategy. According to Harsanyi (1980, p. 130), "behavior based on a rational commitment must be classified as truly rational behavior." Harsanyi's concept of rule-utilitarianism (1980) is similar in spirit to Roemer's concept of Kantian equilibrium, even though in philosophy the Kantian doctrine is opposed to the consequentialism that utilitarians advocate (Russell, 1945).

In Laffont (1975) and Roemer (2010, 2015), all individuals are Kantians. This assumption must be relaxed in order to model real world situations, where Kantians and Non-Kantians interact. Papers dealing with such issues include Long (2016, 2017) and Grafton, Kompas, and Long (2017). The present paper belongs to this stream of literature. Its main contribution is to provide an analysis of Kant-Nash equilibrium in a discrete-time framework, where agents use feedback strategies. Specifically, we use here the concept of a generalized Kant-Nash equilibrium. This concept was defined in Long (2017) so that the two extreme cases (called exclusive Kant-Nash equilibrium and inclusive Kant-Nash equilibrium) are special cases of this more general concept. While this paper is not a place for a detailed philosophical discussion, we feel it necessary to expand a bit more on these concepts.

The Kantian categorical imperative (CI for short), "*Act only on the maxim by which you can at the same time will that it should become a universal law,*" seem to suppose that one should do what one would wish everyone else to do. Therefore, it could be argued that the most fundamental property of the CI is its universality. The demand for universality is consistent with the notion of "inclusive Kantians" introduced in Long (2017), where Kantians test the appropriateness of a proposed action level by asking themselves: "what would the world be like if every human being would deviate from this action level in the same way?" (Please refer to Roemer's concept of scaling up, or scaling downm an activity level by a scalar $\lambda > 0$, as mentioned above.)

At the same time, from a practical viewpoint, it would seem more realistic to ask: "what would this community (at this time and this place) be like if all members of the community were to deviate from the proposed action level in the same way?" In asking this question (and bearing in mind that the words "this community" are not unambiguous) it seems that certain subset of humanity or of the current society is being excluded from consideration. This practical argument seems to be in line with the notion of "exclusive Kantians" which was mentioned in Long (2017).

If one agrees that both notions of "inclusive Kantians" and "exclusive Kantians" have certain merit (depending on the scope of application), it would seem natural to encompass both notions in a generalized formulation. Thus, Long (2017) proposes the concept of a generalized Kant-Nash equilibrium, in which Kantians would ask themselves the following question: If I were to deviate from the proposed action level x by scaling it up or down by a factor $\lambda > 0$, what would this community (at this place and this time) be like if some members of society would deviate by the same factor λ, while other members would deviate by a factor μ, where $\mu = (\lambda - 1)\tau + 1$? Clearly, if $\tau = 0$, this means that these members were suppose to stay put (the exclusive case), and if $\tau = 1$, all members are included in the thought experiment (the inclusive case). Then by restricting τ to be in the interval $[0, 1]$, the generalized Kant-Nash equilibrium admits the exclusive Kant-Nash equilibrium and the inclusive Kant-Nash equilibrium as special cases.[4] While this formulation clearly departs from the pure Kantian doctrine, it seems that one can find some partial support among moral philosophers for not adhering to the pure Kantian doctrine. The following paragraph from Johnson and Cureton (2018) may shed some light on this issue:[5]

"All specific moral requirements, according to Kant, are justified by this principle,

[4] A reviewer rightly points out that there is an issue about observability. How does a Kantian know who is a Nashian and who is a Kantian? A partial reply to this criticism would be that, in a model of commom property resource exploitation, a Kantian needs only know the population share of Nashians. In this simple model, there is no need to know if a specific individual one meets is Kantian or Nashian.

[5] I thank a reviewer for this quote.

which means that all immoral actions are irrational because they violate the CI. Other philosophers, such as Hobbes, Locke and Aquinas, had also argued that moral requirements are based on standards of rationality. However, these standards are either instrumental principles of rationality for satisfying one's desires, as in Hobbes, or external rational principles that are discoverable by reason, as in Locke and Aquinas. Kant agreeed with many of his predecessors that an analysis of practical reason reveals the requirement that rational agents must conform to instrumental principles. Yet he also argued that conformity to the CI (a non-instrumental principle), and hence to moral requirements themselves, can nevertheless be shown to be essential to rational agency."

3 A dynamic game with Kantian and Nashian players

Consider a community consisting of m infinitely-lived individuals. Let $M = \{1, 2, ..., m\}$ denote the set of individuals. Assume that a subset K of these individuals behave according to the Kantian norm. Without loss, let $K = \{1, 2, ..., k\}$. The complementary set, denoted by $N = \{k+1, k+2, ..., k+n\}$, where $n = m - k$, consists of members that behave in a Nashian fashion.

Let S_t denote the stock of a natural asset (e.g., S_t is the biomass in the community's fishing ground). Let Q_t denote the community's aggregate exploitation from the biomass for consumption, where $Q_t \leq S_t$. The dynamics of the biomass is given by

$$S_{t+1} = F(S_t, Q_t)$$

where $F_S > 0$ and $F_Q < 0$.

Let x_{it} denote the resource exploitation effort by Kantian agent i in period t and y_{jt} the exploitation effort by Nashian agent j in period t. Define

$$X_t = \sum_{i \in K} x_{it},\ X_{-i,t} = X - x_{it},\ Y_t = \sum_{j \in N} y_{jt},\ \ Y_{-j,t} = Y_t - y_{jt}$$

and

$$Q_t = X_t + Y_t$$

The utility level of Kantian agent i in period t is $u_i(x_{it})$, where $u_i(.)$ is a strictly concave and increasing function. Furthermore, we assume that

$$\lim_{x_{it}\to 0} u'(x_{it}) = \infty$$

This ensures that the agent always wants to achieve a strictly positive level of consumption, as long as $S_t > 0$. The same assumption is made for the utility function $u_j(.)$ of Nashian agents.

At each date $z = 1, 2, 3, ...$, the Nashian agent j seeks to maximize her remaining life-time payoff starting from time z (denoted by Ω_{jz}), where

$$\Omega_{jz} = \sum_{t=z}^{\infty} \beta^{t-z} u_j(y_{jt})$$

where $\beta \in (0, 1)$ is the discount factor. In solving her problem, she takes as given (her conjectures of) the feedback extraction rules $\psi_h(.)$ of all other Nashian agents $h \in N - \{j\}$, where

$$y_{ht} = \psi_h(S_t)$$

and the feedback extraction rules $\theta_f(.)$ of Kantian agents $f \in K$, where

$$x_{ft} = \theta_f(S_t)$$

(We assume that their conjectures are correct). Her optimal solution must satisfy the Bellman equation

$$V_{Nj}(S_t) = \max_{y_{jt}} \{u_j(y_{jt}) + \beta V_{Nj}(S_{t+1})\} \tag{1}$$

where $V_{Nj}(S)$ is her value function, and

$$S_{t+1} = F\left(S_t, y_{jt} + \sum_{h\in N-\{j\}} \psi_h(S_t) + \sum_{f\in K} \theta_f(S_t)\right)$$

Kantian agents behave differently. In deciding whether she should choose an exploitation level $x_{it}^* > 0$ or a different level, a Kantian agent i , would ask herself the following question: If I deviate from x_{it}^* by choosing some $x_{it} = \lambda x_{it}^*$, where $\lambda > 0$ and $\lambda \neq 1$, what would happen to my payoff, *assuming all other Kantians would deviate in the same* *way?*[6] Then x_{it}^* is her correct action level if and only if any $\lambda \neq 1$ would result in a lower life-time payoff. That is, x_{it}^* must satisfy the following condition:

$$1 = \arg\max_{\lambda} \{u_i(\lambda x_{it}^*) + \beta V_{Ki}(S_{t+1}(\lambda))\} \tag{2}$$

where $V_{Ki}(S)$ is her value function, and

$$S_{t+1}(\lambda) \equiv F\left(S_t, \lambda x_{it}^* + \sum_{h\in N} \psi_h(S_t) + \sum_{f\in K-\{i\}} \lambda\theta_f(S_t)\right)$$

Condition (2) yields the Kantian choice of exploitation level, $x_{it}^* = \theta_i(S_t)$. Then the following equation holds for Kantians:

$$V_{Ki}(S_t) = u_i(\phi_i(S_t)) + \beta V_{Ki}(S_{t+1}) \tag{3}$$

A Kant-Nash equilibrium is a strategy profile $(\theta_1, ..., \theta_k, \psi_{k+1}, ..., \psi_{k+n})$ that satisfies equations (1), (3), such that the action $x_{it}^* = \theta_i(S_t)$ satisfies the Kantian rule (2), and usual transversality conditions hold.

4 An application: Kant-Nash equilibrium in a modified Levhari-Mirman model

In this section, we apply the concept of Kant-Nash equilibrium to the Levhari-Mirman model of fishery (Levhari and Mirman, 1980). We consider a slightly more general version of the Kantian behavior rule, using the concept of generalized Kant-Nash equilibrium explained in Section 2. We assume that a Kantian agent would use the following test to determine her extraction level.

The test for the appropriateness of an action level x_i^* that each Kantian agent must carry out consists of asking herself the following question:

"If I were to scale up or scale down of my effort level by any non-negative factor $\lambda \neq 1$,

[6] In this section, for the sake of expositional simplicity, we are assuming that Kantians are exclusive, in the sense explained at the end of section 2. In the next section, we will consider a slightly more general hypothesis about the Kantians.

and if all other Kantian agents in the community, $j \in K - \{i\}$, were to scale up or down their effort levels by the same factor, while the Nashian agents were to scale up or down their effort levels by a factor $\mu(\lambda)$, would my utility level be (weakly) lower?"

In the definition of a Kant-Nash equilibrium that we adopted in Section 3, $\mu(\lambda) = 1$ identically. In this section, we allow $\mu(\lambda)$ to be different from unity. This means that Kantians consider Non-Kantians as members of the community. How should $\mu(\lambda)$ be specified? It seems sensible to suppose that $\mu(\lambda) \neq \lambda$ if and only if $\lambda \neq 1$. An operational specification would be to introduce a parameter τ, such that

$$\mu(\lambda) = (\lambda - 1)\tau + 1 \text{ where } 0 \leq \tau \leq 1 \tag{4}$$

so that $\mu'(\lambda) = \tau \leq 1$. This means that if $\lambda = 1$ (neither scaling up nor down) then $\mu = 1$ too; if $\lambda > 1$ then $\mu(\lambda) \geq 1$, and $\mu(\lambda) \leq \lambda$; and if $\lambda < 1$ (scaling down), then $1 \geq \mu(\lambda) \geq \lambda$. The resulting equilibrium may be called a *generalized Kant-Nash Equilibrium.* The parameter τ may be called the Kantian's *degree of inclusiveness.*

Let $S \in [0, 1]$ be the state variable representing a natural asset at the beginning of the current period. The highest value that S can take is 1. Let S' be the value of S at the beginning of the next period. Extraction in any period is bounded above by the stock level, i.e., $Q_t \leq S_t$. Following Levhari and Mirman (1980), we assume that

$$S' = (S - Q)^{\alpha} \text{ where } 0 < \alpha < 1.$$

We assume the function $u(.)$ is logarithmic, thus $u(x_i) = \ln x_i$. Furthermore, there is a scrap value function

$$Z(S) = \ln(\gamma S), \text{ where } \gamma \geq 0.$$

In their paper, Levhari and Mirman (1980) derived the value function for their infinite horizon game by solving finite-horizon games, and taking the limit as the horizon tends to infinity. We will adopt the same solution procedure for our game.

4.1 Solution for the one-period horizon game

Since all Nashians are identical, and all Kantians behave identically, we will focus on the symmetric generalized Kant-Nash equilibrium. In the one-period-horizon game, each

Nashian agent j chooses y_j to maximize

$$\ln y_j + \beta \left[\ln \gamma + \alpha \ln(S - Q_{-j} - y_j)\right]$$

where $0 < \beta < 1$ is the discount factor. Each Kantian agent i is in equilibrium if and only if

$$\begin{aligned} 1 &= \arg\max_{\lambda} \{\ln \lambda x_i + \\ &\quad \beta \ln \gamma + \alpha\beta \ln\left[S - n\mu(\lambda) y - k\lambda x_i\right]\} \end{aligned}$$

where $\mu(\lambda) = (\lambda - 1)\tau + 1$.

To ensure the existence of a generalized Kant-Nash equilibrium for this specific fishery model, we make the following assumption:

Assumption A1: $1 - \tau(m - k) > 0$.

To satisfy this assumption, that we must rule out the case where $\tau = 1$ and $n \geq 1$. In other words, if there is at least one Nashian, and if Kantians are inclusive (they set $\tau = 1$ in their test), then in this specific fishery model, there does not exist an equilibrium. The intuition is as follows. If all agents are Kantians ($k = m$), then of course an equilibrium exists: it is the cooperative solution. But as soon as an agent changes her moral attitude (i.e., becoming a Nashian), she would want to increase her fish harvest, and the remaining $m - 1$ inclusive Kantians (with $\tau = 1$) would react by catching less, which would unfortunately induce the Nashian to catch more, and so on, and this process does not converge to an equilibrium.[7]

Under assumption A1, there exists a unique generalized Kant-Nash equilibrium for the one-period-horizon game. The equilibrium extraction levels of Nashian and Kantian agents are, respectively,

$$y = \frac{S}{(m-k)(1-\tau) + (1+b)} \ , \ b \equiv \alpha\beta \tag{5}$$

$$x = \left(\frac{1 - \tau(m-k)}{k}\right)\left(\frac{S}{(m-k)(1-\tau) + (1+b)}\right) \tag{6}$$

For the one-period-horizon game, the equilibrium payoff function of a representative

[7] I am indebted to a reviewer for raising this pertinent issue.

Nashian is denoted by $V_N^{(1)}$, where the superscript indicates that there is only one period to go. Then, using (1), (5), and (6), we obtain

$$V_N^{(1)}(S) = (1+b)\ln S + \eta_N^{(1)} + \phi^{(1)} + \beta \ln \gamma \tag{7}$$

where

$$\eta_N^{(1)} = \ln\left(\frac{1}{(m-k)(1-\tau)+(1+b)}\right)$$
$$\phi^{(1)} = b\ln\left(\frac{b}{(m-k)(1-\tau)+(1+b)}\right)$$

Note that $\phi^{(1)}$ does not have a subscript because this term is the same for Nashian and Kantian players. For Kantians, the equilibrium payoff function function is obtained in a similar fashion, using (3), (5), and (6):

$$V_K^{(1)}(S) = (1+b)\ln S + \eta_K^{(1)} + \phi^{(1)} + \beta \ln \gamma \tag{8}$$

where it can be shown that

$$\eta_K^{(1)} = \ln\left(\frac{(1-\tau(m-k))k^{-1}}{(m-k)(1-\tau)+(1+b)}\right)$$

We observe that Nashians achieve higher payoffs than Kantians. The difference between the payoff is

$$V_N^{(1)}(S) - V_K^{(1)}(S) = \eta_N^{(1)} - \eta_K^{(1)} = \ln\left(\frac{k}{1-\tau(m-k)}\right) > 0$$

4.2 Solution for the two-period-horizon game

Now, consider the game where all agents have two periods to go. All agents know their equilibrium payoffs of the one-period-to-go subgame: they are given by eqs (7) and (8). Then, given the opening stock S, the Nashian agent i chooses the current period extraction level y_i to maximize

$$R_i^{(2)} = u(y_i) + \beta V_{Ni}^{(1)}(S')$$

And Kantians will be in equilibrium if and only if

$$1 = \arg\max_{\lambda} u(\lambda x) + \beta V_{Ki}^{(1)}(S')$$

Thus, if $T = 2$, the Nashian agent's equilibrium exploitation in the first period when there are two periods to go is

$$y_N^{(2)} = \frac{S}{(m-k)(1-\tau) + (1+b) + b^2}$$

and, for Kantians, their equilibrium exploitation is only a fraction of the Nashian agent's exploitation:

$$x_K^{(2)} = \left(\frac{1-\tau(m-k)}{k}\right) y_N^{(2)}$$

The equilibrium payoff functions are as follows. For each Nashian,

$$V_N^{(2)}(S) = (1+b+b^2)\ln S + A_N^{(2)} + B^{(2)} + \beta^2 \ln\gamma$$

with

$$A_N^{(2)} = \eta_N^{(2)} + \beta\eta_N^{(1)}, \text{ with } \eta_N^{(2)} \equiv \ln\left(\frac{1}{(m-k)(1-\tau)+1+b+b^2}\right)$$

and

$$B^{(2)} = \phi^{(2)} + \beta\phi^{(1)}$$

where

$$\phi_N^{(2)} \equiv (1+b+b^2-1)\ln\left(\frac{1+b+b^2-1}{(m-k)(1-\tau)+1+b+b^2}\right)$$

For each Kantian, the equilibrium payoff function is

$$V_K^{(2)}(S) = (1+b+b^2)\ln S + A_K^{(2)} + B^{(2)} + \beta^2 \ln\gamma$$

where

$$A_K^{(2)} = \eta_K^{(2)} + \beta\eta_K^{(1)}$$

$$\eta_K^{(2)} = \ln\left(\frac{(1-\tau(m-k))k^{-1}}{(m-k)(1-\tau)+1+b+b^2}\right)$$

Thus the Nashian payoff exceeds the Kantian payoff by

$$V_N^{(2)}(S) - V_K^{(2)}(S) = A_N^{(2)} - A_K^{(2)} = (1+\beta)\ln\left(\frac{k}{1-\tau(m-k)}\right)$$

In other words, the Kantian payoff is equal to the Nashian payoff minus $(1+\beta)\ln\left[k/\left(1-\tau(m-k)\right)\right]$.

4.3 Solution for the q-period-horizon game

Given the opening stock S, Nashian agent i chooses the first period exploitation level y_i to maximize

$$R_i^{(q)} = u(y_i) + \beta V_{Ni}^{(q-1)}(S')$$

And Kantians will be in equilibrium if and only if

$$1 = \arg\max_{\lambda} u(\lambda x) + \beta V_{Kj}^{(q-1)}(S')$$

For $T = q$, the Nashian agent's equilibrium first period exploitation level is

$$y_N^{(q)} = \frac{S}{(m-k)(1-\tau) + \left(\left(\sum_{s=0}^{q-1} b^s\right) + b^q\right)}$$

and the Kantian agent's exploitation in period 1 is

$$x_K^{(q)} = \left(\frac{1-\tau(m-k)}{k}\right) y_N^{(q)}$$

The value function for Nashians is

$$V_N^{(q)}(S) = \left(\left(\sum_{s=0}^{q-1} b^s\right) + b^q\right)\ln x + A_N^{(q)} + B_N^{(q)} + \beta^q\gamma$$

with

$$A_N^{(q)} = \eta_N^{(q)} + \beta\eta_N^{(q-1)} + \beta^2\eta_N^{(q-2)} + ...\beta^{q-1}\eta_N^{(1)}$$

$$\eta_N^{(q)} \equiv \ln\left(\frac{1}{(m-k)(1-\tau) + \left(\sum_{s=0}^{q-1} b^s\right) + b^q}\right)$$

and

$$B^{(q)} = \phi^{(q)} + \beta\phi^{(q-1)} + ... + \beta^{q-1}\phi^{(1)},$$

$$\phi^{(q)} \equiv \left(\left(\sum_{s=0}^{q-1} b^s\right) + b^q - 1\right) \ln\left(\frac{\left(\sum_{s=0}^{q-1} b^s\right) + b^q - 1}{(m-k)(1-\tau) + \left(\sum_{s=0}^{q-1} b^s\right) + b^q}\right)$$

We can show the Kantian payoff is equal to the Nashian payoff minus $(1 + \beta + \beta^2 + ... + \beta^{q-1}) \ln\left[k/\left(1 - \tau(m-k)\right)\right]$

$$V_N^{(q)}(S) - V_K^{(q)}(S) = \ln\left(\frac{k}{1 - \tau(m-k)}\right)$$

Note that the difference is independent of S. This property is due to the logarithmic function. We conjecture that if we assume a different utility function the difference would depend on S. However, one would have to rely on numerical calculations, asit is probably impossible to find simple closed form solutions.

4.4 The infinite-horizon problem

Taking the limit as q tends to infinity, we obtain the equilibrium strategies of Nashian and Kantian players for the infinite horizon problem. We find that the equilibrium strategies of the Nashians and the Kantians depend only on the current stock level, S, and are independent of the calendar time. For Nashians,

$$y = \frac{(1-b)S}{(m-k)(1-\tau)(1-b) + 1}$$

and for Kantians,

$$x = \left(\frac{1 - \tau(m-k)}{k}\right) \frac{(1-b)S}{(m-k)(1-\tau)(1-b) + 1}$$

The value function of the representative Nashian is

$$V_N(S) = \frac{1}{1-b} \ln S + \frac{1}{1-\beta} \ln\left[\frac{1-b}{(m-k)(1-\tau)(1-b) + 1}\right]$$

$$+\frac{1}{1-\beta}\left(\frac{b}{1-b}\right) \ln\left(\frac{b}{(m-k)(1-\tau)(1-b) + 1}\right)$$

and the value function of the representative Kantian is

$$V_K(S) = V_N(S) - \frac{1}{1-\beta} \ln\left(\frac{k}{1-\tau(m-k)}\right)$$

Along the equilibrium path,

$$S_{t+1} = \left(\frac{b}{(m-k)(1-\tau)(1-b)+1}\right)^{\alpha} S_t^{\alpha}$$

The steady state level of the stock is

$$S^* = \left(\frac{b}{(m-k)(1-\tau)(1-b)+1}\right)^{\frac{\alpha}{1-\alpha}}$$

It is easy to verify that the steady state is stable: starting at any positive S_0, the stock will converge to S^*.

Using the above analysis, we obtain the following results. (Detailed proofs are available upon request.)

Proposition 1: *The Kant-Nash equilibrium in feedback strategies display the following properties.*

(a) *$V_N(S)$ is increasing in τ (in the Kantians' degree of inclusiveness) and in k (the population share of Kantians).*

(b) *A sufficient condition for $V_K(S)$ to increase in k is $\tau m - 1 \geq 0$.*

(c) *Assume that $\tau m - 1 > 0$, and that k is sufficiently large such that $1-\tau(m-k) > 0$. Then as k increases from k to $k+1$ or higher values, the gap between $V_N(S) - V_K(S)$ become smaller.*

(d) *The steady state stock increases in k.*

(e) *The steady state stock increases in τ provided that Assumption A1 is satisfied.*

(f) *The pure Nash steady state stock level , i.e., when $n = m$, is smaller than the Kant-Nash steady state level if $k \geq 2$.*

5 Extension: the case where the resource yields amenity values

This section extends the model to the case where the resource has amenity values. Assume that members of the community enjoy a public good: the amenity services provided by the biomass. Assume that the amenity service level in period t depends on both the stock level S_t and the exploitation activities, Q_t

$$G_t = G(S_t, Q_t)$$

with $G_S > 0$ and $G_Q < 0$. The utility level of Kantian agent i in period t is

$$U(x_{it}, G_t) = u_i(x_{it}) + w_i(G_t)$$

The same assumption is made for the utility function of Nashian agents. Assume and the amenity service level is given by

$$G_t = G\left(S_t, y_{j\tau} + \sum_{h \in N - \{j\}} \psi_h(S_t) + \sum_{f \in K} \theta_f(S_t)\right)$$

We now modify the model of Levhari and Mirman (1980) to allow for the enjoyment of environmental quality (amenitiy services). The parameter for this enjoyment is denoted by $g \geq 0$. (In the model of Levhari and Mirman (1980), $g = 0$ identically, and there are no Kantian agents.)

The level of environmental services delivered to the agents during period t is assumed to be

$$G_t = G(S_t, X_t) = S_t - Q_t$$

And we suppose that

$$U(x_i, G) = \ln x_i + g \ln G \text{ where } g > 0.$$

The equilibrium for the one-period game is similar to the one described in the preceding section, with only a minor modification, namely

$$y = \frac{S}{(m-k)(1-\tau)+(1+g+b)} \ , \ b \equiv \alpha\beta$$

$$x = \left(\frac{1-\tau(m-k)}{k}\right)\left(\frac{S}{(m-k)(1-\tau)+(1+g+b)}\right)$$

$$V_N^{(1)}(S) = (1+g+b)\ln S + \eta_N^{(1)} + \phi^{(1)} + \beta \ln \gamma$$

$$\eta_N^{(1)} = \ln\left(\frac{1}{(m-k)(1-\tau)+(1+g+b)}\right)$$

$$\phi^{(1)} = (g+b)\ln\left(\frac{g+b}{(m-k)(1-\tau)+(1+g+b)}\right)$$

Similarly, for the two-period model, one makes only a few modifications, such as

$$R_i^{(2)} = U(y_i, G(S, Q_{-i}+y_i)) + \beta V_N^{(1)}(S')$$

Then, if $T = 2$, the Nashian agent's equilibrium exploitation in the first period when there are two periods to go is

$$y_N^{(2)} = \frac{S}{(m-k)(1-\tau)+(1+g)(1+b)+b^2}$$

and, for Kantians, their equilibrium exploitation is only a fraction of the Nashian agent's exploitation:

$$x_K^{(2)} = \left(\frac{1-\tau(m-k)}{k}\right) y_N^{(2)}$$

The equilibrium payoff functions are as follows. For each Nashian,

$$V_N^{(2)}(S) = ((1+g)(1+b)+b^2)\ln S + A_N^{(2)} + B^{(2)} + \beta^2 \ln \gamma$$

with

$$A_N^{(2)} = \eta_N^{(2)} + \beta\eta_N^{(1)}, \text{ with } \eta_N^{(2)} \equiv \ln\left(\frac{1}{(m-k)(1-\tau)+(1+g)(1+b)+b^2}\right)$$

and

$$B^{(2)} = \phi^{(2)} + \beta\phi^{(1)}$$

where

$$\phi_N^{(2)} \equiv ((1+g)(1+b)+b^2-1)\ln\left(\frac{(1+g)(1+b)+b^2-1}{(m-k)(1-\tau)+(1+g)(1+b)+b^2}\right)$$

For each Kantian, the equilibrium payoff function is

$$V_K^{(2)}(S) = ((1+g)(1+b)+b^2)\ln S + A_K^{(2)} + B^{(2)} + \beta^2\ln\gamma$$

where

$$A_K^{(2)} = \eta_K^{(2)} + \beta\eta_K^{(1)}$$

$$\eta_K^{(2)} = \ln\left(\frac{(1-\tau(m-k))k^{-1}}{(m-k)(1-\tau)+(1+g)(1+b)+b^2}\right)$$

Thus the Nashian payoff exceeds the Kantian payoff by

$$V_N^{(2)}(S) - V_K^{(2)}(S) = A_N^{(2)} - A_K^{(2)} = (1+\beta)\ln\left(\frac{k}{1-\tau(m-k)}\right)$$

In other words, the Kantian payoff is equal to the Nashian payoff minus $(1+\beta)\ln\left[k/\left(1-\tau(m-k)\right)\right]$.

For $T=q$, the Nashian agent's equilibrium first period exploitation level is

$$y_N^{(q)} = \frac{S}{(m-k)(1-\tau)+\left(\left(\sum_{s=0}^{q-1} b^s\right)+b^q\right)}$$

and the Kantian agent's exploitation in period 1 is

$$x_K^{(q)} = \left(\frac{1-\tau(m-k)}{k}\right) y_N^{(q)}$$

The value function for Nashians is

$$V_N^{(q)}(S) = \left((1+g)\left(\sum_{s=0}^{q-1} b^s\right) + b^q\right)\ln x + A_N^{(q)} + B_N^{(q)} + \beta^q\gamma$$

with

$$A_N^{(q)} = \eta_N^{(q)} + \beta\eta_N^{(q-1)} + \beta^2\eta_N^{(q-2)} + ...\beta^{q-1}\eta_N^{(1)}$$

$$\eta_N^{(q)} \equiv \ln\left(\frac{1}{(m-k)(1-\tau)+(1+g)\left(\sum_{s=0}^{q-1} b^s\right)+b^q}\right)$$

and

$$B^{(q)} = \phi^{(q)} + \beta\phi^{(q-1)} + ... + \beta^{q-1}\phi^{(1)},$$

$$\phi^{(q)} \equiv \left((1+g)\left(\sum_{s=0}^{q-1} b^s\right)+b^q-1\right)\ln\left(\frac{(1+g)\left(\sum_{s=0}^{q-1} b^s\right)+b^q-1}{(m-k)(1-\tau)+(1+g)\left(\sum_{s=0}^{q-1} b^s\right)+b^q}\right)$$

The Kantian payoff is equal to the Nashian payoff minus $(1+\beta+\beta^2+...+\beta^{q-1})\ln\left[k/\left(1-\tau(m-k)\right)\right]$

$$V_N^{(q)}(S) - V_K^{(q)}(S) = \ln\left(\frac{k}{1-\tau(m-k)}\right)$$

By taking the limit as q tends to infinity, we can obtain the equilibrium strategies of Nashian and Kantian players for the infinite horizon problem. The equilibrium strategies depend only on S. For Nashians,

$$y = \frac{(1-b)S}{(m-k)(1-\tau)(1-b)+(1+g)}$$

and for Kantians,

$$x = \left(\frac{1-\tau(m-k)}{k}\right)\frac{(1-b)S}{(m-k)(1-\tau)(1-b)+(1+g)}$$

The value function of the representative Nashian is

$$V_N(S) = (1+g)\frac{1}{1-b}\ln S + \frac{1}{1-\beta}\ln\left[\frac{1-b}{(m-k)(1-\tau)(1-b)+(1+g)}\right]$$

$$+\frac{1}{1-\beta}\left(\frac{g+b}{1-b}\right)\ln\left(\frac{g+b}{(m-k)(1-\tau)(1-b)+(1+g)}\right)$$

and that of the representative Kantian is

$$V_K(S) = V_N(S) - \frac{1}{1-\beta} \ln \left(\frac{k}{1 - \tau(m-k)} \right)$$

Along the equilibrium path,

$$S_{t+1} = \left(\frac{g+b}{(m-k)(1-\tau)(1-b) + (1+g)} \right)^{\alpha} S_t^{\alpha}$$

The steady state level of the stock is

$$S^* = \left(\frac{g+b}{(m-k)(1-\tau)(1-b) + (1+g)} \right)^{\frac{\alpha}{1-\alpha}}$$

Starting at any positive S_0, the stock will converge to S^*.

We obtain the following result:

Proposition 2: *The Kant-Nash equilibrium in feedback strategies display all the properties stated in Proposition 1, and the foolowing addtional property: Regardless of the sign of* $\tau m - 1$, *if* g *is sufficiently great, then an increase in* k *will increase social welfare.*

6 Concluding Remarks

The idea that pro-socialness can help attenuate the tragedy of the commons has a long history. One finds it discussed in the works of Adam Smith (1790), Scott Gordon (1954), Jean-Jacques Laffont (1975), Eleanor Ostrom (1990), Roemer (2010, 2015), and many others. Most of these discussions have been set in a static framework. Our contribution is two-fold: First, we formalise the concept of interaction between Kantian agents and Nashian agents. Second, we apply the concept of Kant-Nash equilibrium to a dynamic game and show how it may shed light on games of common property resource exploitation when not all agents are Nashian. We have been able to show that social welfare increases with the Kantian population share: Given the total population, as the percentage share of the Kantians increases, social welfare increases as a result. It is hoped that our discussions of ethics could go some way to de-emphasize the 'homo œconomicus' conception of human behavior taught in standard economics courses. Of course, we must be aware of Arrow's caution: “One must not expect miraculous transformations in human behavior. Ethical codes, if they are viable, should be limited in scope.” (Arrow, 1973, p. 316).

An interesting idea for future research is the study of evolutionary dynamics toward a Kantian society.[8] According to Clément et al. (2000), the process of achieving universal justice is far from being straightforward for Kant (1795). It would necessitate the establishment of a Society of Nations, in other words a global social contract:

“Kant asserts at the same time that the future of our species is ultimately the rule of law and universal peace, and that, nevertheless, the establishment of public justice - the greatest problem for the human species, the most difficult one -can never be considered as a settled affair, and only the establishment of a "society of nations" subject to international law will allow man access to peace and the rule of law (the condition for true autonomy) and truly overcome his original savagery.”[9]

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[8] A small step in this direction has been taken in Long (2018), using an overlapping generation models in which parents have incentives to transmit prosocialness to their children

[9] The above paragraph is translated from the French text: “Kant affirme à la fois que le devenir de notre espèce a pour finalité le règne de la loi et la paix universelle, et que, pourtant, l’établissement de la justice publique- le “plus grand problème pour l’espèce humaine, le plus difficile- ne peut jamais être considéré comme une affiare réglée. Seule l’établissement d’une “société des nations” soumise à une législation internationale, permetra à l’homme d’accéder à la paix et à l’ordre juridique (condition de toute véritable autonomie) et de surmonter véritablement sa sauvagerie originelle.” I thank a reviewer for this reference.

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