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Strategic exploitation with learning and heterogeneous beliefs

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ABSTRACT

We study the effect of learning with heterogeneous beliefs on the exploitation of a renewable common-pool resource. To that end, we extend the Great Fish War model of Levhari and Mirman (1980) to a learning environment in which several agents interact strategically and learn about the distribution of the stochastic evolution of the resource. We find that the effect of anticipation of learning with heterogeneous beliefs is twofold. First, the anticipation of learning makes future payoffs more uncertain, which induces the agents to decrease present exploitation due to the *precautionary motive*. Second, under heterogeneity of beliefs, there is a *differential informational externality* that induces the agents to increase or decrease present exploitation. We also perform a comparative analysis on the Cournot–Nash equilibrium with learning by studying the effect of optimism and riskiness on resource exploitation.

Introduction

In the presence of a common-pool resource, strategic interactions play an important role in determining the behavior of agents and thus the evolution of the resource. Strategic exploitation of common-pool resource was first studied by Levhari and Mirman (1980) in a deterministic framework. However, agents exploit a resource under less information. This was initially considered by Brock and Mirman (1972) in the context of optimal stochastic growth, building on earlier studies of positive growth under uncertainty (Mirman, 1972, 1973). Recently, Antoniadou et al. (2013) studied strategic interactions and the tragedy of the commons in the context of an exploitation of a common-pool resource under uncertainty.[1] The motivation for studying stochastic rather than deterministic growth was to reduce the information available to the agent in order to provide more realistic results. Indeed, in a deterministic environment, each agent is assumed to have perfect foresight of the effect of his exploitation on the evolution of the resource. Adding uncertainty about the evolution of the stock means that the agent does not need to know the precise effect of his exploitation on the future stock.

In addition to facing uncertainty via random variables, there is another important type of uncertainty that has not yet been studied in dynamic games, i.e., uncertainty about the distribution of the random variables. In other words, agents face uncertainty not only about the evolution of the natural resource, but also about the true distribution generating the shocks in the economy. Therefore, because the true distribution is unknown, agents form initial (prior) beliefs about it. Moreover, with the observation of informative signals, rational agents learn by updating their prior beliefs to reduce uncertainty.[2] In a

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[1] Mirman and Spulber (1985) examined exploitation decisions with uncertainty under perfect competition, while Mirman and Spulber (1984) compared competitive allocations with optimal allocations of renewable resources under uncertainty. Fesselmeyer and Santugini (2013) studied the effect of environmental risk on a common resource extraction and the tragedy of the commons.

[2] Learning plays an important role in natural resource exploitation, as mentioned in Hoel (1978), and Miller and Lad (1984). Miller and Lad (1984) considered a two-period model of uncertainty with a single-agent as a decision maker. In the second period, the decision maker observes the value experienced for the random variable in the first period. He uses this value to update his belief for the second period by using the Bayesian updating rule.

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recent paper, Koulovatianos et al. (2009) (KMS henceforth)[3] analyzed the behavior of a single-agent decision maker, in a growth model of Bayesian learning in which the true distribution of the stochastic variable is not known. However, in many cases, several agents jointly exploit a common stock of a resource and face uncertainty about the structure of the economy (e.g. a river on the border of two countries, a gold field being exploited by many goldsmiths). In other words, there are strategic interactions implying that agents anticipate not only what the other agents do, but also their future learning. Moreover, with several agents, prior beliefs might not be the same across agents.[4]

The purpose of the paper is to study the effect of Bayesian learning in a dynamic game of resource exploitation in which agents have different beliefs. To that end, we extend the Great Fish War model of Levhari and Mirman (1980) to a learning environment. We consider several agents exploiting a common-pool renewable resource. The renewability function of the resource is affected by a stochastic variable whose distribution is unknown to the agents. Specifically, the distribution depends on an unknown parameter. The exploiters of the resource form prior beliefs about this parameter. We allow these prior beliefs to vary across agents. After observing the past realizations of the renewability variable, and using Bayesian methods, each agent updates his prior belief. Given prior beliefs, an agent exploits the resource while considering the effect of his own exploitation and the exploitation of the others on future stock. In addition, the agents anticipate learning by taking into account belief updating for all agents.[5] As mentioned in KMS, the anticipation of learning is a source of risk because it makes the future more stochastic in that future beliefs are unknown.

We present two sets of results. We begin by characterizing the unique Cournot–Nash equilibrium in which agents learn using Bayesian methods. We study the effect of anticipating learning on the equilibrium. To that end, we compare the Cournot–Nash equilibrium with learning with the benchmark equilibrium of adaptive learning. In adaptive learning, agents form beliefs but are rationally bounded because they do not anticipate changes in their beliefs. The difference between the learning Cournot–Nash equilibrium and adaptive learning Cournot–Nash equilibrium allows us to capture the effect of learning as a source of risk. In the single-agent case studied by KMS, present exploitation decreases when the agent faces risk from anticipation of learning. In a game with heterogeneous beliefs, this is not necessarily the case. The direction of the effect of learning depends on the degree of optimism of the agents about the future stock of the resource. The effect of learning is twofold. First, as in the single-agent case, anticipating learning induces the agents to decrease present exploitation due to the precautionary motive. Second, with heterogeneous beliefs, agents are a source of an informational externality on one another. Indeed, heterogeneity in beliefs adds a *differential informational externality*. Specifically, each agent has to take into account the beliefs and the anticipation of other agents whose beliefs are different from his own belief. For a given agent, unlike the precautionary motive, the *differential informational externality* may increase or decrease his exploitation. For instance, if an agent is too optimistic (about the availability of the future stock) relative to the other agents, he increases his exploitation when anticipating learning. The overall effect of anticipating learning depends on the relative strength of the precautionary motive effect and the *differential informational externality* effect.[6]

We perform a comparative analysis by studying the effect of changes in beliefs. We first study the impact of an increase in an agent's optimism on present exploitation. More optimism on the part of one agent reduces the marginal cost of exploitation of that agent, while it increases the marginal cost of exploitation of the other agents. Therefore, the agent's own present exploitation is increased while the other agents decrease their present exploitations. This result follows from the fact that a more optimistic agent anticipates a higher future stock of the resource, and believes that a future shortage is less likely. In turn, because the more optimistic agent exploits more, the other agents see the need to make a greater effort to contribute to the savings in order to have the stock they desire for the future. Second, we analyze the effect of a riskier belief on exploitation using the concept of second-order stochastic dominance. A riskier belief about the future stock leads the agent to decrease his exploitation while it leads the other agents to increase their exploitation. The reason is that riskier belief about the unknown distribution increases the marginal cost of exploitation of the agent who considers that the renewability becomes riskier. However, because the agent with a riskier belief decreases his exploitation, the other agents get more leeway to exploit the resource, even though their beliefs remain unchanged. The need for them not to harvest is lesser.

The issue of learning has also been addressed extensively in the literature on climate change (CO_2 emission and International Environment Agreements (IEA)), pioneered by Ulph and Ulph (1997), Na and Shin (1998), Ulph (2004), Baker (2005), Kolstad (2007), Kolstad and Ulph (2008, 2011), Dellink and Finus (2012), and Karp (2012). In these papers, the uncertainty concerns the damage from emissions, and the effect of learning on the success of an IEA, CO_2 emission, and on global welfare is studied. In some respects, this literature on learning has some characteristics that make it different from

(*footnote continued*)
Miller and Lad (1984) found that learning does not necessarily imply a more conservative decision. In Miller and Lad (1984) there is no structural uncertainty and no anticipation of learning. Rather, decisions are sequential, and the amount of learning depends on the action taken in the first period.

[3] KMS for Koulovatianos, Mirman and Santugini.

[4] Beliefs reflect the agents' opinions about the renewability of the resource. Opinions may vary across individuals. See for example Budescu et al. (1995). Mirman and Santugini (in press) studied the effect of learning on the investment and consumption decision with strategic interactions. In Mirman and Santugini (in press) beliefs are homogeneous.

[5] In our model, there is no experimentation as in Mirman et al. (1993, 1994).

[6] In the literature on learning in the context of climate change, Baker (2005) obtained a similar result. Baker (2005) studied the effect of learning on countries' CO_2 emissions. He found that, for the single-decision-maker model, learning leads to a reduction in emissions. The reverse might hold for the multiple-decision-maker, depending on the correlation of damage across countries.