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Repeated games with general discounting ☆

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Abstract

In this paper, we introduce a general class of time discounting, which may exhibit present bias or future bias, to repeated games with perfect monitoring. A strategy profile is called an agent subgame perfect equilibrium if there is no profitable one-shot deviation by any player at any history. We study strongly symmetric agent subgame perfect equilibria for repeated games with a symmetric stage game. We find that the worst punishment equilibrium takes different forms for different types of bias. When players are future-biased or have quasi-hyperbolic discounting, the worst punishment payoff can be achieved by a version of stick-and-carrot strategies. When players are present-biased, the worst punishment path may fluctuate over time forever. We also find that the stage-game minmax payoff does not serve as a tight lower bound for the limit equilibrium payoff set. The worst punishment payoff can be below the minmax payoff with future bias and above the minmax payoff with present bias, even when players are very patient. Lastly, we compare the effect of making players interact more frequently and the effect of making them more patient for a given intertemporal bias structure defined on continuous time.

JEL classification: C73; D03; D43; D90; L13

Keywords: Future bias; Minmax payoff; Present bias; Quasi-hyperbolic discounting; Repeated games; Time inconsistency

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1. Introduction

The theory of repeated games is a very useful tool to analyze cooperation and collusion in dynamic environments. It has been heavily applied in different areas of economics such as industrial organization, dynamic macroeconomics, international trade, etc. The central feature of repeated games is that incentive is provided intertemporally and endogenously. Thus time preference plays a crucial role for the analysis of repeated games. However, almost all existing works on infinitely repeated games assume a particular type of time preference: discounted sum of payoffs/utilities with respect to geometric discounting, which goes back to Samuelson (1937) and is axiomatized by Koopmans (1960). Although geometric discounting is a reasonable and tractable model, it is important to explore other types of time preference to understand which behavioral features depend on the assumption of geometric discounting and which ones do not.[1]

In this paper, we introduce a general class of time discounting, which includes time-inconsistent ones, to repeated games with perfect monitoring. We retain the additivity of payoffs across periods, but any stream of payoffs is discounted by a general discount function that may not decay geometrically.[2] Our formulation of discounting includes geometric discounting, quasi-hyperbolic discounting, and generalized hyperbolic discounting (Loewenstein and Prelec, 1992) as special cases.[3]

We focus on two kinds of discounting: one with *present bias* and one with *future bias*. A player is present-biased if the value of period t payoff relative to period $(t+1)$ payoff is higher for smaller t. Conversely a player is future-biased if the value of period t payoff relative to period $(t+1)$ payoff is lower for smaller t. It is well documented that people often exhibit behavior that is consistent with present bias. There are many real-world phenomena that can be explained by present bias (DellaVigna, 2009). Future bias has received more attention recently.[4] It has been reported that people often exhibit future bias in experimental settings. Furthermore, the size of future-biased subjects is often comparable to that of present-biased subjects in experiments (Halevy, 2015; Olea and Strzalecki, 2014; Sayman and Öncüler, 2009; Takeuchi, 2011).

Clearly time inconsistency can arise in our setting. So we need to make an assumption about how players make a dynamic choice given intertemporal bias. We call a strategy profile an *agent subgame perfect equilibrium* if there is no profitable one-shot deviation by any player at any history.[5] Thus we treat a player as if she is composed of multiple agents who take an action only once at a certain history (Peleg and Yaari, 1973 and, in the context of repeated games, Chade et al., 2008). We study strongly symmetric agent subgame perfect equilibria for repeated games with a symmetric stage game. The class of symmetric stage games we use is standard and includes Cournot and Bertrand competition games as special cases.

Among many equilibria, we focus on the best equilibrium and the worst punishment equilibrium. The worst punishment equilibrium is important as it determines the optimal level of coop-

[1] See Frederick et al. (2002) for a critical review of a variety of models of time preference.

[2] Obara and Park (2017) study a more general class of time preference that is non-additive in the context of repeated games.

[3] Quasi-hyperbolic discounting or so-called β–δ discounting has been applied in many works, including the works of Laibson (1997, 1998) and O'Donoghue and Rabin (1999) to name a few. It is provided with an axiomatic foundation by Hayashi (2003) and Olea and Strzalecki (2014). Quasi-hyperbolic discounting is first introduced to repeated games by Chade et al. (2008).

[4] Loewenstein (1987) has already discussed a form of future bias using the term "reverse time inconsistency."

[5] This equilibrium is also called *Strotz–Pollak equilibrium* in the literature (see, for example, Chade et al., 2008).