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Maximin, viability and sustainability

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The maximin criterion defines the highest utility level that can be sustained in an intergenerational equity perspective. The viability approach makes it possible to characterize all the economic trajectories sustaining a given, not necessarily maximal, utility level. In this paper, we exhibit the strong links between *maximin* and *viability*: we show that the value function of the maximin problem can be obtained in the viability framework, and that the maximin path is a particular viable path. This result allows us to extend the recommendations of the maximin approach beyond optimality, to characterize the sustainability of economic trajectories which differ from the maximin path. Attention is especially paid to non-negative net investment at maximin accounting prices, which is shown to be necessary to maintain the productive capacity of the economy, whether the development path is optimal or not. Our results provide a new theoretical ground to account for sustainability in imperfect economies, based on maximin prices.

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1. Introduction

Discounted utility, the main criterion used for intertemporal choice in economics, defines the Net Present Value of the economy (Weitzman, 2003) and provides a theoretical basis of National Net Product index used for national accounting (Weitzman, 1976; Dasgupta and Mäler, 2000; Arrow et al., 2003).

In the Weak Sustainability paradigm *à la Solow* (Neumayer, 2010), ‘‘sustainability ... must amount to an injunction to preserve the productive capacity for the indefinite future’’ (Solow, 1993, p. 163). A challenge to operationalize sustainability is to determine an index to measure it and define sustainability accounting (Cairns, 2008; Dasgupta, 2009). A first attempt to tackle this challenge is to complete the National Net Product by accounting for all sorts of capital stocks and consumptions, including natural resources depreciation and non-market goods, to obtain a ‘‘comprehensive’’ accounting (Repetto et al., 1989; Asheim, 1994; Weitzman and Löfgren, 1997; Cairns, 2003). Such an approach can be applied to imperfect economies (Arrow et al., 2003). This approach is usually developed in the theoretical vein of discounted utility, which has been criticized in the sustainability literature and qualified as a ‘‘dictatorship of the present’’ by Chichilnisky (1996). Alternative criteria have been proposed to deal with sustainability issues (Heal, 1998). If sustainability requires the sustaining of utility for intergenerational equity concerns, a criterion to address this issue can be the *maximin* (Solow, 1974; Cairns and Long, 2006). This criterion emerges from the Rawls (1971) conception of

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justice and equity. It maximizes the utility of the poorest generation (or the minimal utility over time in a continuous time framework). An interesting feature of this approach is that the maximin path, if egalitarian and efficient, satisfies Hartwick's rule (Withagen and Asheim, 1998; Mitra, 2002), which requires the investing of rents from exhaustible resources in reproducible capital to compensate for the depletion of their stocks (Hartwick, 1977). This rule has been generalized, that is to say that a nil net investment is required to keep the total productivity of all stocks constant, and to sustain the consumption or utility (Dixit et al., 1980). This rule, related to the concept of genuine savings, is argued to be a condition for sustainability and a basis for sustainability accounting (Solow, 1986, 1993). Cairns (2008), however, emphasizes that, even if it is optimal to follow Hartwick's investment rule along egalitarian maximin paths, a nil net investment does not imply sustained utility in distorted economies. For instance, Martinet (2007) shows in an example that following Hartwick's investment rule along a constant consumption path at a level different from the maximin may reduce sustainability. As it is not straightforward to compute the sustainability indicators provided by the maximin approach for real economies (Asheim, 1994), its results are difficult to apply. An important theoretical challenge to address sustainability is thus to extend the recommendations of the maximin approach to study the sustainability of economies that are not at the maximin optimum.

In this paper, we propose a framework to extend maximin beyond optimality. This framework is based on the *viability* approach (Aubin, 1991) or weak-invariance approach (Clarke et al., 1995) which characterizes intertemporal dynamic trajectories regarding their consistency with given state and control constraints. Interpreting viability constraints as minimal rights to be guaranteed to all generations, the viability approach can be used to address the sustainability issue (Martinet and Doyen, 2007; Baumgärtner and Quaas, 2009; Martinet, 2011). It has been notably applied to the sustainable management of renewable resources (e.g., Béné et al., 2001; Doyen and Péreau, 2012; Péreau et al., 2012). In most of these viability studies, the so-called *viability kernel* plays a major mathematical role. This set is the set of all initial (economic) states from which start viable (economic) trajectories, i.e., trajectories respecting the given (sustainability) constraints at all times. Therefore, the viability approach can be used to define all the economic trajectories sustaining a specific, not necessarily maximal, utility level. From that point of view, the viability approach provides a relevant tool to study the sustainability of "sub-optimal economies" which differ from the maximin path.

We exhibit the strong links between *maximin* and *viability*. More specifically, we show that the value function of the maximin problem is the solution of a static optimization problem under constraints involving the viability kernel. Maximin trajectories are shown to be particular viable trajectories, and thus inherit viability properties. Our results are given in a general and abstract framework, and are valid for regular and non-regular maximin problems. Particular emphasis is put on the Hamiltonian formulation of the viability problem, that we interpret as a *weak* Hartwick rule. We relate this result to non-negative net investment *at maximin prices*, and describe how it makes it possible to characterize the sustainability of any development path, providing theoretical grounds for sustainability accounting in imperfect economies.

We first present in Section 2 the links between maximin and viability in terms of states and value functions. We then present in Section 3 how these links allow us to characterize maximin trajectories within the viability framework. In Section 4, we discuss the potential use of our framework, which extends maximin with viability, to examine the sustainability of trajectories which are not maximin paths. The implications of our results in terms of sustainability accounting are presented in Section 5. We conclude in Section 6. The appendix gathers mathematical details and the proofs of propositions (Appendix A), along with an illustration of our results to the canonical Dasgupta–Heal–Solow model often used to investigate sustainability issues (Dasgupta and Heal, 1974, 1979; Solow, 1974; Heal, 1998) (Appendix B).

2. Maximin and viability

2.1. A general dynamic economic model

Consider an economy with n capital stocks (e.g., manufactured capital, labor or natural resources) and m economic decision parameters (e.g., consumption, investment or resource extraction). This economy is characterized by the state $X(t) \in \mathbb{R}^n$ and the control $u(t) \in \mathbb{R}^m$. All the economic dynamics are captured by a function $f : \mathbb{R}^n \times \mathbb{R}^m \mapsto \mathbb{R}^n$ which may involve capital dynamics, production functions or natural resource growth functions. This economy is represented by the controlled dynamic system[1]

$$\dot{X}(t) = f(X(t),u(t)), \quad t \in \mathbb{R}_+. \tag{1}$$

At each time t, states and controls have to belong to some admissibility set represented by q inequalities (e.g., positivity of consumption, irreversibility of investment, availability of labor, scarcity of resources)

$$g_i(X(t),u(t)) \geq 0 \quad \text{for } i = 1,\dots,q. \tag{2}$$

Initial economic state at time $t_0 = 0$ is denoted by $X(t_0) = X_0$. We shall denote by $X(\cdot)$ and $u(\cdot)$ state and control trajectories.

[1] We focus on time autonomous problems for the sake of exposition clarity. Focusing on time autonomous problems excludes the possibility of exogenous technical change; but endogenous technical change can be accounted for (see Martinet and Doyen, 2007, Section 3.4.2.2, for an example in the Dasgupta–Heal–Solow model).

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