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Self-Commitment-Institutions and Cooperation in Overlapping Generations Games*

Francesco Lancia† Alessia Russo‡

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Abstract

This paper focuses on a two-period OLG economy with public imperfect observability over the intergenerational cooperative dimension. Individual endowment is at free disposal and perfectly observable. In this environment we study how a new mechanism, we call Self-Commitment-Institution (SCI), outperforms personal and community enforcement in achieving higher ex-ante efficiency. Social norms with and without SCI are characterized. If social norms with SCI are implemented, agents might freely dispose of their endowment. As long as they reduce their marginal gain from deviation in terms of current utility, they also credibly self-commit on intergenerational cooperation. Under quite general conditions we find that, even if individual strategies are still characterized by behavioral uncertainty, the introduction of SCI relaxes the inclination toward opportunistic behavior and sustains higher efficiency compared to social norms without SCI. We quantify the value of SCI and investigate the role of memory with different social norms. Finally, applications on intergenerational public good games and transfer games with productive SCI are provided.

JEL Classification: C70, D70, H40

Keywords: Cooperation, Free disposal, Imperfect public monitoring, Memory, Overlapping generation game, Self-Commitment Institution.

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1 Introduction

The study of the conditions, which sustain mutual cooperation among self-interested agents, is a milestone in the social science literature. There are three general ways to enforce mutual cooperative agreements and to achieve efficiency: *i)* Competition, *ii)* formal contracts, and *iii)* informal contracts. As is extensively known, the former fails in presence of market imperfections, while the second collapses in the case of no ex-post verifiability. In these circumstances informal contracts may instead succeed in improving efficiency. Such contracts are defined as equilibrium customary rules of behavior that coordinate individual play, i.e. social norms.[1] Specifically, they consist of infinite repetitions of agents' interactions over time with no court to credibly pre-commit over cooperative behavior, where the value of future interactions serves as the reward and penalty to discipline the agents' current behavior.

Past literature has focused on two types of enforceability mechanisms to sustain social norms: Personal and community enforcement. Under personal enforcement a cheater will only face retaliation by their victim. While, in the case of community enforcement all members of the society react to a deviation. The former is effective when the same sets of players match each other over time (Fudenberg and Maskin, 1986). Nevertheless, in many economic circumstances players change over time. In this scenario community enforcement may achieve efficiency.[2]

Our analysis applies in a theoretical environment in which the traditional types of enforcement rarely work in sustaining cooperative behavior, i.e. overlapping generations (hereafter OLG) games with imperfect public monitoring. In OLG games individuals with a finite life span enter the economy in an asynchronous way and interact with other agents before being replaced by another individual after death.[3] Due to the finite-horizon interaction among players, personal enforcement is very limited and in some cases totally prevented. Furthermore, community enforcement loses its effectiveness when agents imperfectly observe past history.[4] The lack of perfect monitoring introduces an element of moral hazard, which in some circumstances prevents the achievement of full efficiency.[5]

The purpose of this research is to investigate the existence and the role of an alternative enforcement mechanism, which sustains cooperation and improves efficiency, we refer to as Self-Commitment-Institutions (SCI). The economy we study is populated by OLG of homogeneous agents living up two periods: Young and Old. Each agent takes two decisions in the first period of his life, a-action and b-action. Two main features characterize the different choices: *i)* a-action generates a cost for Young and a positive intergenerational externality for elderly agents, whereas b-action does not induce any benefits

[1] See Durlauf and Blume (2011) for an overview of social norms.

[2] As Kandori (1992a) shows, even in the case of trade where agents change partners over time, any feasible rational allocation can be sustained as long as other members of the society, who are not directly involved in the bilateral trading, sanction the defection of agents. To be effective, community enforcement requires the existence of an exogenous, and not manipulable, decentralized information transmission process, which creates labels that make defeating agents recognizable by all members of the community.

[3] One suggestive way to think about OLG games is in terms of organizations, which repeatedly interact. Even if the organizations survive indefinitely over time, individuals with finite life span manage their own governance. Remarkable examples are provided by: The relationships between boards of directors and the shareholders' committees; interaction between regulators and firms; the communitarian and international agreements among member States; the electoral promises between political parties and the electorate.

[4] This assumption seems reasonable in an OLG environment, in which agents live for a finite time and they become aware of previous history through reports transmitted by previous generations in the form of public signals. Lagunoff and Matsui (2004) analyze an environment with a lack of prior memory by focusing on intergenerational message instead of public signals. In the presence of higher degrees of intergenerational altruism and small costs of intergenerational communication, the authors demonstrate that the Folk theorem holds.

[5] The argument is qualitatively similar to those discussed by both Radner et al. (1986) and Abreu et al. (1986) for repeated games environment. Imperfect public observability generates an endogenous cost of monitoring, which makes the best sustainable equilibrium payoff bounded away from fully efficiency. Nevertheless in this scenario, Fudenberg et al. (1994) prove that the Folk theorem applies when a full ranking condition holds and agents play asymmetric public strategies.

in terms of payoffs; *ii)* a-actions are imperfectly observable and generate a public signal, whereas the observability of b-actions is not affected by noise. We define b-action as *self-commitment action* as long as by choosing higher b Young are reducing their marginal gain from deviation on the a-action dimension. Given the sequential nature of the game, subsequent generations are linked through strategic interaction and payoff functions. Intergenerational cooperation emerges in equilibrium as long as Young voluntarily sustain a current cost to generate positive externalities on behalf of the elderly cohort. A fundamental feature of the game is that, due to the two-period life span, the retaliation phase is precluded. At the same time, when the Young punishes the elderly cheater, he does not sustain any direct damage. Clearly, in a static setting intergenerational cooperation is never self-enforced. On the contrary, in a repeated interaction framework different enforcement mechanisms may succeed in improving efficiency. Given that at each time period different generations match each other, in our environment personal enforcement is totally interdicted.

We distinguish social norms into two categories: *i)* Social norms without SCI, and *ii)* social norms with SCI. In the former case agents coordinate their continuation play on the history of public signals. As a consequence, agents rely on community enforcement mechanisms to attain cooperative outcome. The latter associates SCI to community enforcement. Specifically, agents contingent their punishment decisions on both the history of public signals and the previous players' self-commitment actions. Since self-commitment does not lead to positive economic spillover, from an ex-ante point of view a benevolent central planner with full taxation power would never require agents to activate b-action. On the contrary, in a repeated setting with imperfect monitoring, self-commitment decisions can be enforced by achieving higher efficiency.

Intuitively, suppose that the realization of the public signals constitutes the relevant information gathering for current agents' strategic behavior. A social norm on intergenerational cooperation might be enforced by community mechanisms, which require agents to permanently punish as soon as a negative signal is realized. Clearly, this enforcement mechanism turns out to be particularly effective in deterring agents' defection. Nevertheless, it cannot succeed in achieving full efficiency, because with all probability at a certain point in time a negative signal will emerge. As a consequence, intergenerational cooperation will break down, even if no one has actually deviated from the cooperative path. Therefore, in an environment characterized by highly volatile shocks the intergenerational cooperation sustained by community enforcement mechanisms achieves a low level of efficiency. In this scenario suppose that agents at each time period may decide not only whether to sustain intergenerational cooperation, but also if to self-commit, for example through voluntarily reduction of productive time endowment. If agents believe that no one will coordinate their strategy on the observable b-decisions, in equilibrium they decide to never self-commit and only community mechanisms possibly enforce intergenerational cooperation. On the contrary, allow agents to believe that all generations base their strategic behavior on both the public signals and the previous players' self-commitment actions. The mechanism prescribes that if agents do not self-commit, then they are punished by future generations independently from the realization of a public signal. If the Young are patient enough and relatively less risk adverse compared to the elderly agents, then self-commitment becomes a necessary condition to have positive expectations on future gains. Most importantly, self-commitment is also sufficient to sustain cooperation by relaxing the opportunistic behavior of players. By reducing their current marginal gain from deviation agents are also inducing future generations to punish with lower probability in the case of a bad signal, i.e. players become endogenously more optimistic. As a result, the actors' self-commitment fosters the coordination efforts and facilitates cooperative relationships.

The equilibrium outcome is characterized by a trade-off between the SCI value and the effectiveness of monitor technologies. As long as players are able to fully detect earlier generations' defection, SCI acquires no value and community enforcement is sufficient to achieve full efficiency. The existence of an imperfect monitoring technology, along with the possibility of endogenously modifying the marginal benefits from deviations, are necessary for making SCI valuable in repeated OLG settings. This result helps to stress the role of SCI as an institution able to sustain cooperation when the moral hazard issue is a relevant feature of the economic environment. Furthermore, we find that history matters differently depending on whether agents coordinate their continuation play on self-commitment actions or not. In the case of one-period memory over public signals social norms without SCI cannot sustain intergenerational cooperation and autarky is the only sustainable equilibrium. On the contrary, social norms with SCI can sustain higher efficiency as long as agents recall the self-commitment actions exerted by the two previous generations.

Previously, we have stressed the role of SCI excluding the possibility of productively allocating the self-committed resources. A direct application of the basic setup is to allow SCI to be productive, for example in the provision of education. A large corpus of literature exists on intergenerational transfers, which justifies the provision of education for the sustainability of the welfare state. Three main theoretical justifications for investment in education in a context of intergenerational cooperation have been proposed: Altruistic (or bequest) motives, endogenous asset returns, voting and political sharing rules.[6] The possibility of enhancing efficiency in a context characterized by imperfect observability through the implementation of social norms with SCI provides an alternative justification. We describe testable implications in terms of risk aversion and dynamic efficiency conditions which enable SCI to be effective in improving the economy's overall ex-ante efficiency. Under a different perspective, SCI turns out to be also an explanation for education provision alternative to the theory of signaling. In the seminal work of Spence (1973) education is treated as a costly signal to provide employers with information about otherwise unobservable characteristics of potential employees. Differently, we treat education as a self-commitment action, which provides information about otherwise unobserved cooperative actions.[7]

In this paper the concept of Public Perfect Equilibrium (PPE), as developed by Abreu et al. (1990), is adapted to an OLG game in order to characterize the best sustainable equilibrium payoffs generated by each type of social norm and to derive the value of SCI. Furthermore, we discuss the implications in terms of memory and provide two different applications: *i)* Intergenerational public good game with unproductive SCI, *ii)* Intergenerational transfer game with productive SCI. All the proofs are in the appendix.

2 Past literature

This paper draws on two main research strands of literature. The first concerns the study of cooperative behavior in games played by overlapping generations of agents, while the second relates to the analyses

[6] Kaganovich and Zilcha (1999) analyze the interaction between education and social security by adopting an altruistic motive. Boldrin and Montes (2005) formalize public education and PAYG system as two parts of an intergenerational contract where public pension is the return on the investment into the human capital of the next generation. In Lancia and Russo (2011) selfish adults buy insurance for their future old age by paying productive education transfers to their children to raise the labor productivity of the next period. When becoming old they partially grab the bigger output in the form of PAYG transfers by exerting political power in a probabilistic voting environment.

[7] In several economic circumstances we observe agents voluntarily sustain costly action without any direct benefits (extreme but suggestive examples are the initiation ritual in clubs or religious sect). As soon as unobservable heterogeneity in individual types is not considered as relevant factor (which is a plausible assumption in small communities and clubs), a theory of SCI provides a rational justification of the reason why agents should still send costly signals, whereas the signaling theory fails. A historical phenomenon, which can be easly explained in the light of SCI theory, is the evolution of Jewish Ultra-Orthodox schools. As documented by Berman (2000), Yeshiva attendance signals commitment to the community, which in turn provides mutual insurance to members.

of cooperation in a repeated interaction setting under imperfect public monitoring.

Sizeable literature has focused on the study of intergenerational cooperation without considering informational constraints. Starting from the seminal work of Hammond (1975), who examined a non-cooperative game version of Samuelson's consumption-loan model showing that a Pareto efficient allocation is attained by a subgame perfect equilibrium, various Folk Theorems have been proved by more general OLG structures (Cremer (1986), Salant (1988), Kandori (1992b) and Smith (1992)).[8] The main insights from this branch of literature is that any mutually beneficial outcome could be sustained as long as agents are patient and/or live long enough and each individual can perfectly observe the past. More recent papers have studied how the introduction of informational constraints affects the emergence of co-operation and, in turns, the possibility to achieve efficiency in games with repeated interactions. Bhaskar (1998) examines the role of general informational constraints in 2-period Samuelson OLG consumption-loan games. The author shows that if players have finite memory, then Pareto improving transfers are not sustainable in pure strategy equilibria.[9] More severe informational constraints have been introduced in Lagunoff and Matsui (2004) and Lagunoff et al. (2005) who examine OLG games where cheap-talk intergenerational communication is introduced.[10]

Diverging from previous literature, we introduce imperfect public monitoring as informational constraint. Therefore, our paper also refers to a strand of literature that analyzes cooperation in repeated setting where agents adopt public strategies. In the spirit of dynamic programming, Abreu et al. (1990) introduce and illustrate the ideas of self-generating set of equilibrium payoffs and factorization to prove a recursive formulation of the repeated game with imperfect public monitoring. We apply the analysis of repeated games with imperfect public monitoring à la Abreu et al. (1990) to characterize PPE in the OLG setup. Several authors have investigated strongly symmetric PPE equilibria and have applied this equilibrium concept in a rich class of economic problems (Green and Porter (1984), Radner et al. (1986), Abreu et al. (1991)),[11] showing how efficiency cannot typically be attained. Indeed, the equilibrium payoffs turn out to be bounded away from the Pareto frontier.[12] We contribute to the previous literature by analyzing how in OLG games with imperfect public monitoring, where agents are restricted to play strongly symmetric public strategies, cooperation might be sustained by SCI improving ex-ante efficiency.

[8] Cremer (1986) analyses a generalization of the prisoners' dilemma in an OLG setting, to show that cooperation can be sustained through reversion to the Nash equilibrium of the stage game, as long as agents are patient and/or live long enough. Salant (1988) proves the Folk Theorem with particular simple equilibria in two-person games with some restrictions on the payoff functions. Kandori (1992b) extends Salant's analysis for a general N-person games where players in the same cohort interact for a long time, and then are gradually replaced by the next generation of players. Smith (1992) presents a variation and extension of Kandori's model.

[9] In Bhaskar (1998) if agents observe at least the period before their arrival, then optimal transfers are sustainable in mixed strategies setting. However, cooperation turns out to be not robust to small random perturbation. See Cole and Kocherlakota (2005) for an extension of Bhaskar's finite memory setting to the case of imperfect observability.

[10] Lagunoff and Matsui (2004) prove in an OLG game with no prior memory, costly communication and intergenerational altruism, that the Folk Theorem holds when either communication costs are small enough, or individual are sufficiently altruistic. Lagunoff et al. (2005) extend the basic setup by introducing private communication in a dynastic game.

[11] Green and Porter (1984) study Cournot competition characterized by noisy demand in a repeated setting. As main result, firms are prevented from achieving the first-best monopoly profits as long as "price wars" emerge in equilibrium. Radner et al. (1986) present an example of a repeated partnership game with imperfect monitoring in which the set of PPE payoffs turns out to be bounded away from the Pareto frontier even as the discount factor tends to 1. Finally, Abreu et al. (1991) analyze in a similar environment how changes in the timing of information may increase the possibilities for cooperation, starting from an equilibrium allocation, which is constrained efficient.

[12] Fudenberg et al. (1994) prove that under the full ranking condition a Folk theorem applies when agents play asymmetric public strategies.

3 The Model

Consider an OLG game where selfish agents imperfectly observe past history. Time is discrete and indexed by t and runs from zero to infinity. A single agent is born at every date t and plays the role of Young in period t and the role of Old in period $t+1$. Fig. 1 reports the demographic structure of the game.

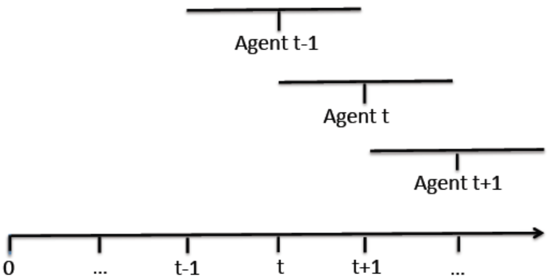

Fig. 1: Demographic Structure of the OLG game

Agents are active in the first period of their life, and completely passive in the second. As a consequence, the game turns out to be characterized by a one-sided enforceability problem at each time, and personal enforcement is interdicted. At each time t the Young face two different actions, $a_t \in A \equiv \{0, a\}$ and $b_t \in B \equiv \{0, b\}$ with $a > 0$ and $b > 0$, where A and B denote the discrete sets of actions. The ex-post intertemporal utility function of generation t, $\upsilon : A^2 \times B^2 \rightarrow \Re$, is a function of both the actions the agent takes when Young and the actions taken by the future player:

$$\upsilon (\mathbf{a}, \mathbf{b}) = u (a_t, b_t) + \delta \omega (a_{t+1}, b_{t+1}) \tag{1}$$

where $\delta \in (0, 1)$ is the individual discount factor, $\mathbf{a} = (a_t, a_{t+1})$ and $\mathbf{b} = (b_t, b_{t+1})$.

Assumption 1 (Preferences) *$u : A \times B \rightarrow \Re$ is non-increasing in both a_t and b_t with $\overline{u} \equiv u (0, 0)$, and $\omega : A \times B \rightarrow \Re$ is increasing in a_t and non-increasing in b_t with $\underline{\omega} \equiv \omega (0, b_t)$ for each $b_t \in B$.*

According to Assumption (1), the action a_t generates a cost when Young and a benefit when Old, whereas the action b_t has a negative impact for both generations. Thus, the autarky payoff turns out to be equal to:

$$\upsilon^{aut} \equiv \overline{u} + \delta \underline{\omega} = u (0, 0) + \delta \omega (0, 0) \tag{2}$$

Definition 1 (Decreasing Differences) *A function $u : A \times B \rightarrow \Re$ has decreasing differences in (a_t, b_t) if the following inequality is satisfied:*

$$u (0, 0) - u (a, 0) \geq u (0, b) - u (a, b) \tag{3}$$

If $u (\cdot)$ has decreasing differences in (a_t, b_t), then the incremental gain to choose a lower a_t (i.e. $a_t = 0$ rather than $a_t = a$) is lower when b_t is higher, i.e. $u (0, b_t) - u (a, b_t)$ is nonincreasing in b_t.[13]

Definition 2 (Self-Commitment Action) *b_t is a self-commitment action if $u (\cdot)$ has decreasing differences in (a_t, b_t).*

[13] The decreasing differences property is symmetric in both actions. From Eq. (3) $u (0, 0) - u (0, b) \geq u (a, 0) - u (a, b)$, i.e. $u (a_t, 0) - u (a_t, b)$ is non-increasing in a_t. As a consequence, if $u (\cdot)$ is twice continuously differentiable, then $\frac{\partial^2 u(a_t, b_t)}{\partial b_t \partial a_t} \geq 0$. According to Topkis (1998), a function characterized by such property is defined supermodular.

We define b_t as self-commitment action whether, by choosing higher b_t, Young are posting a bond by reducing their marginal gains from deviation on the a-dimension.

We focus on self-enforceable intergenerational contracts when agents observe only a public signal, $z \in Z \equiv \{X, Y\}$, of past performances in terms of a-action, where X stands for good signal and Y for bad signal.[14] The conditional distribution, $p_{a_t} \equiv \Pr(z_{t+1}|a_t)$, is denoted by:

$$p_0 \equiv \Pr(Y|0) \tag{4}$$

$$p_a \equiv \Pr(Y|a) \tag{5}$$

Assumption 2 (Monotone Likelihood Ratio Property) *Given $p_0 \in [0,1]$ and $p_a \in [0,1]$ the monotone likelihood ratio property requires $p_a \leq p_0$.*

Assumption (2) guarantees that the probability of receiving a good signal is positively correlated with the agents' a-action. Let us denote with $L \equiv \frac{p_0}{p_a}$ the likelihood ratio, where $L \in [1, \infty)$. If $L = 1$ then $p_0 = p_a$ and, as a consequence, agents cannot detect deviations by observing signals, while if $L = \infty$ then $p_a \to 0$ and $p_0 \to 1$, and agents perfectly detect previous players' deviations.

Definition 3 (OLG game) *The collection (v, p_{a_t}) is referred to as an OLG game with imperfect public monitoring, denoted by $\mathcal{G}(v, p_{a_t})$.*

The efficient allocation implemented by the central planner with full taxation power is equal to:

$$v^* = u(a^*, b^*) + \delta\omega(a^*, b^*)$$

where a^* and b^* are the $\arg\max_{a \in A, b \in B} u(a,b) + \delta\omega(a,b)$. Due to the absence of benefits generated by the players b-decision, optimality requires agents to not self-commit, i.e. $b^* = 0$.

3.1 Public Perfect Equilibrium and Social Norms

We study the best sustainable strongly symmetric Public Perfect Equilibrium (hereafter PPE) of the OLG game. We consider a public randomization device, $(\mu_t)_{t=0}^{\infty}$, as a collection of independent random variables, uniformly distributed on the unit interval. Let us refer to $\mu^t \equiv (\mu_0, \mu_1, ..., \mu_t)$ and $z^t \equiv (z_0, z_1, ...z_t)$ as the vectors of public randomization devices and public signals till time t, respectively. Furthermore, $b^t \equiv (b_0, b_1, ..., b_{t-1})$ is the vector of b-choices taken by agents till time t. Differently from the a-action, the b-decisions are perfectly observable. Consequently, the public history observed by generation t is $h^t \equiv (z^t, b^t, \mu^t) \in \mathcal{H}^t$, where $\mathcal{H}^t$ is the set of possible public histories till time t and $\mathcal{H} \equiv \bigcup_{t \geq 0} \mathcal{H}^t$. For each $s \leq t$ we refer to $z_s(h^t)$, $\mu_s(h^t)$ and $b_s(h^t)$ as the realizations of z_s, μ_s and b_s in the public history h^t, respectively.

For any t-generation we define public strategies as the mappings:

$$\alpha_t : \mathcal{H}^t \to \Delta(A) \text{ such that } \alpha_t\left(h^t\right) \in \Delta(A)$$

and

$$\beta_t : \mathcal{H}^t \to \Delta(B) \text{ such that } \beta_t\left(h^t\right) \in \Delta(B)$$

[14] Although the current living Old directly observes Young's a-action, we avoid the possibility of intergenerational communication, as Lagunoff and Matsui (2004) do.

where $\Delta(A)$ and $\Delta(B)$ denotes the randomized action spaces. Given that all the individuals are ex-ante identical and they can only be distinguished through their history, we restrict the analyses to symmetric strategies, i.e. each player uses the same strategy after every history. Furthermore, we denote the infinite vectors $\boldsymbol{\alpha} \equiv (\alpha_t)_{t=0}^{\infty}$ and $\boldsymbol{\beta} \equiv (\beta_t)_{t=0}^{\infty}$ as the strategy profiles.

Reformulating Eq. (1), the ex-ante payoff for every t-generation conditionally on the history h^t is given by:

$$v\left(a_t, b_t | h^t\right) = u\left(a_t, b_t\right) + \delta \mathbf{E}\left[\omega\left(\alpha_{t+1}\left(h^{t+1}\right), \beta_{t+1}\left(h^{t+1}\right)\right) | h^t\right] \tag{6}$$

where $\mathbf{E}(\cdot|h^t)$ is the expectation operator conditional on information at time t.

Definition 4 (PPE) *A profile $(\boldsymbol{\alpha}, \boldsymbol{\beta})$ is a PPE of $\mathcal{G}(v, p_{a_t})$ if, for each $t \geq 0$:*

i. *$\alpha_t(h^t)$ and $\beta_t(h^t)$ are public strategies;*

ii. *For each public history h^t, the strategies $\alpha_t(h^t)$ and $\beta_t(h^t)$ are Nash equilibrium from that date onwards.*

A particular equilibrium strategy of the OLG game $\mathcal{G}(v, p_{a_t})$ is identified as a social norm, which prescribes a specific behavioral rule. After being established, the social norm continues being in force because agents prefer to conform to that rule, given the expectation that others are going to conform. Consequently, social norms coordinate expectations reducing transaction costs in interactions that possess multiple equilibria.

Definition 5 (Social Norm) *A social norm is a specification of a particular PPE.*

In a strategic interaction framework, social norms are typically sustained by two kinds of enforcement mechanisms: Personal and community enforcement. Under personal enforcement a cheater will only face retaliation by their victim. On the contrary, under community enforcement all members of the society react to a deviation according to specific social norms. Given the peculiar structure of the OLG game described above, in $\mathcal{G}(v, p_{a_t})$ personal enforcement cannot be exerted, and social norms might be sustained only through community enforcement. In this paper we introduce a third enforcement mechanism, we call Self-Commitment-Institution (hereafter SCI). Depending on whether SCI is at work or not, we may distinguish two types of social norms:

Definition 6 (Social Norm without SCI) *A social norm without SCI is a PPE characterized by strategies measurable with respect to h^t/b^t, i.e. $\alpha_t\left(\hat{h}^t\right) = \alpha_t\left(\check{h}^t\right)$ and $\beta_t\left(\hat{h}^t\right) = \beta_t\left(\check{h}^t\right)$ if $\hat{h}^t \equiv \left(z^t, \hat{b}^t, \mu^t\right)$ and $\check{h}^t \equiv \left(z^t, \check{b}^t, \mu^t\right)$ $\forall\ \hat{b}^t \neq \check{b}^t$.*

In this scenario, even if agents perfectly observe the self-commitment actions of previous generations, they condition their continuation play only on the history of public signals.

Definition 7 (Social Norm with SCI) *A social norm with SCI is a PPE characterized by strategies measurable with respect to h^t, i.e. $\exists\ \hat{h}^t \equiv \left(z^t, \hat{b}^t, \mu^t\right)$ and $\check{h}^t \equiv \left(z^t, \check{b}^t, \mu^t\right)$ with $\hat{b}^t \neq \check{b}^t$ such that $\alpha_t\left(\hat{h}^t\right) \neq \alpha_t\left(\check{h}^t\right)$ or $\beta_t\left(\hat{h}^t\right) \neq \beta_t\left(\check{h}^t\right)$.*

Differing from the previous social norm, players might condition their continuation play on the history of both public signals and self-commitment actions.

For the sake of exposition, we provide an equivalent automaton (or state-strategy) representation of social norms as the collection $\Xi \equiv \left\{\Phi, \phi_0, \left(\sigma^i\right)_{i\in\{a,b\}}, Q(\cdot)\right\}$, where Φ is the state space. The state

$\phi_{t+1} \in \Phi$ with $t \geq 0$ is drawn from a distribution $Q\left(\phi_{t+1}|\phi_t, b_t, z_{t+1}\right) \in \Delta(\Phi)$ where ϕ_t is the state at time t. Given the current state, ϕ_t, and the current actions, (a_t, b_t), the distribution over the next-period state, ϕ_{t+1}, takes the form $q\left(\phi_{t+1}|\phi_t, a_t, b_t\right) = \sum_{z_{t+1} \in Z} Q\left(\phi_{t+1}|\phi_t, b_t, z_{t+1}\right) \Pr\left(z_{t+1}|a_t\right)$. The initial state, ϕ_0, is drawn from $q_0 \in \Delta(\Phi)$. Finally, σ_t^i with $i \in \{a, b\}$ is a state-strategy of t-generation which associates to each state an action profile, $\sigma_t^a(\phi_t) \in A$ and $\sigma_t^b(\phi_t) \in B$. Equivalently to Definition (4), a state-strategy profile, $\left(\boldsymbol{\sigma}^a, \boldsymbol{\sigma}^b\right)$ with $\boldsymbol{\sigma}^a = \left(\sigma_t^a\right)_{t=0}^{\infty}$ and $\boldsymbol{\sigma}^b = \left(\sigma_t^b\right)_{t=0}^{\infty}$, is an equilibrium state-strategy, if for each $t \geq 0$ and for each state ϕ_t, the continuation strategy $\left(\sigma_{t+j}^a, \sigma_{t+j}^b\right)_{j>0} \in \Sigma$ is a Nash equilibrium of the continuation game, where Σ is the space of equilibrium state-strategies. A public strategy profile is finite if Φ is a finite set. In terms of state-strategies, the intertemporal payoff function, Eq. (6), is as follows:

$$V\left(\phi_t|\sigma_t^a, \sigma_t^b\right) = u\left(\sigma_t^a(\phi_t), \sigma_t^b(\phi_t)\right) + \delta \sum_{\phi_{t+1} \in \Phi} \omega\left(\phi_{t+1}\right) q\left(\phi_{t+1}|\phi_t, \sigma_t^a(\phi_t), \sigma_t^b(\phi_t)\right) \tag{7}$$

The set of equilibrium payoff, Γ_∞, is the set of functions given by Eq. (7) obtained from equilibrium strategies:

$$\Gamma_\infty = \left\{\upsilon : \Phi \to \Re | \exists \ \left(\sigma_t^a, \sigma_t^b\right) \in \Sigma \text{ such that } \upsilon(\phi_t) = V\left(\phi_t|\sigma_t^a, \sigma_t^b\right) \ \forall \phi_t \in \Phi\right\} \tag{8}$$

Remark 1 *When $\Phi = \mathcal{H}$ then the state-strategy equilibrium coincides with the PPE, reported in Definition (4).*

In the following sections: First, we characterize the best sustainable strongly symmetric pure strategy equilibria payoff under imperfect monitoring sustained by social norms without SCI. Second, we study how social norms with SCI enable agents to attain higher efficiency with respect to the former equilibria allocations. Furthermore, we determine the value of SCI and we show the role of history in the two alternative scenarios. For notational purposes let Γ_∞^j be the finite set of equilibria payoffs attained by implementing the strategy Ξ^j for $j \in \{a, ab\}$, where "a" stands for social norms without SCI and "ab" denotes social norm with SCI.

4 Social Norms without Self-Commitment-Institution

In this section we determine the set of equilibria payoffs in the OLG game where agents coordinate on social norms without SCI, i.e. $\Gamma_\infty^a = [\upsilon_{\min}^a, \upsilon_{\max}^a]$. It is straightforward to show that the worst sustainable equilibrium payoff (the lower bound of Γ_∞^a) of the OLG game is equal to the autarkic payoff, i.e. $\upsilon_{\min}^a = \upsilon^{aut}$. If players always defect independently from the realization of previous public signals, then each generation earns an equilibrium payoff equal to autarky. To determine the best sustainable payoff we adopt the following methodology: First, we consider a particular social norm without SCI, $\tilde{\Xi}^a$, candidate to be a PPE of $\mathcal{G}(\upsilon, p_{a_t})$, and we determine the corresponding best sustainable payoff, $\tilde{\upsilon}_{\max}^a$. Second, we prove that the best equilibrium payoff sustained by social norms without SCI, $\upsilon_{\max}^a$, coincides with $\tilde{\upsilon}_{\max}^a$.

Let us consider the following strategy:

$$\tilde{\Xi}^a : \left(\alpha_t\left(h^t\right), \beta_t\left(h^t\right)\right) = \begin{cases} (0,0) & \text{if } \exists \ s \leq t \text{ such that } z_s\left(h^t\right) = Y \text{ and } \mu_s\left(h^t\right) \geq \mu, \\ (a, 0) & \text{otherwise.} \end{cases} \tag{9}$$

where μ is a cut-off level to be endogenously determined. We can interpret μ as the equilibrium probability each t-generation assigns to the decisions of future generations to not punish conditioning on the realization of a bad signal.

Lemma 1 *Let* $\delta^a \equiv \frac{u(0,0)-u(a,0)}{(p_0-p_a)(\omega(a,0)-\omega(0,0))}$ *and* $\mathcal{C}(a,0) \equiv \frac{u(0,0)-u(a,0)}{L-1}$. *Then the equilibrium payoff set obtained by implementing Eq. (9) is equal to:*

$$\Gamma_\infty^a = \begin{cases} [\upsilon^{aut}, \tilde{\upsilon}^a_{\max}] & if\ \delta \geq \delta^a \\ \{\upsilon^{aut}\} & otherwise \end{cases}$$

with:

$$\tilde{\upsilon}^a_{\max} \equiv u(a,0) + \delta\omega(a,0) - \mathcal{C}(a,0) \tag{10}$$

In view of Lemma (1), let provide the equivalent two-states automaton representation of the social norm described in Eq. (9), i.e. $\tilde{\Xi}^a = \left\{\Phi, \phi_0, \left(\sigma^i\right)_{i\in\{a,b\}}, Q^a(\cdot)\right\}$, with $\phi_t \in \Phi = \left\{\underline{\phi}, \overline{\phi}\right\}$ for each $t \geq 0$, where $\overline{\phi}$ is the cooperation state and $\underline{\phi}$ is the punishment state. The transition probability, $Q^a(\cdot)$, prescribes:

$$Q^a\left(\overline{\phi}|\phi_t, b_t, z_{t+1}\right) = \begin{cases} 1 & if \quad \phi_t = \overline{\phi},\ z_{t+1} = X, & \forall b_t \\ \mu & if \quad \phi_t = \overline{\phi},\ z_{t+1} = Y, & \forall b_t \\ 0 & if \quad \phi_t = \underline{\phi},\ \forall z_{t+1}, & \forall b_t \end{cases} \tag{11}$$

Consistently with Definition (6), a social norm without SCI as $\tilde{\Xi}^a$ is characterized by a transition probability, which maps current states to next-period states by conditioning only on the realization of signals and disregarding the self-commitment decisions exerted by previous generations. The equilibrium state-strategy assigns the following decision rules, $\sigma^a\left(\overline{\phi}\right) = a$ and $\sigma^a\left(\underline{\phi}\right) = 0$, whereas $\sigma^b\left(\overline{\phi}\right) = \sigma^b\left(\underline{\phi}\right) = 0$. Fig. (2) provides a graphical representation of $\tilde{\Xi}^a$.

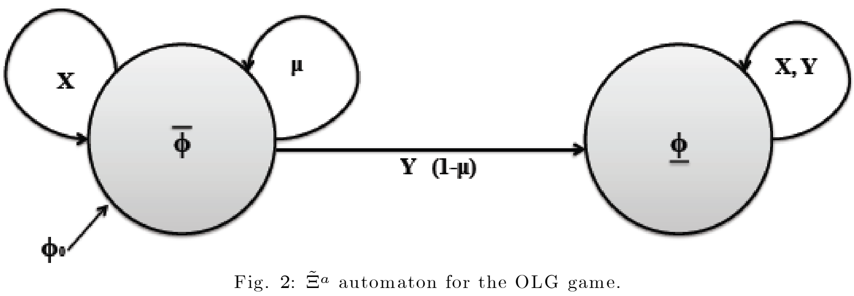

Fig. 2: $\tilde{\Xi}^a$ automaton for the OLG game.

Agents start to play cooperatively, i.e. $\phi_0 = \overline{\phi}$. They stay there until the realization of both a bad signal and a sufficiently high level of μ_s. After that they start playing a permanent punishment and, in turn, intergenerational cooperation is no longer sustained. Since $\underline{\phi}$ is activated on the equilibrium path and agents cannot exit this phase, $\tilde{\Xi}^a$ implies loss of efficiency and induces boundedness of the strongly symmetric equilibrium payoffs. Using Eq. (7), in cooperation state the intertemporal payoff is as follows:

$$\upsilon\left(\bar{\phi}\right) = u(a,0) + \delta \sum_{\phi_{t+1}\in\Phi} \omega\left(\phi_{t+1}\right) q^a\left(\phi_{t+1}|\bar{\phi}, a, 0\right) \tag{12}$$

where the expected continuation value in the case of cooperation when Young is equal to:

$$\sum_{\phi_{t+1}\in\Phi} \omega\left(\phi_{t+1}\right) q^{a}\left(\phi_{t+1}|\bar{\phi}, a, 0\right) \equiv \left[p_a\mu + (1-p_a)\right]\omega(a,0) + p_a(1-\mu)\,\omega(0,0)$$

In the punishment state the intertemporal value is:

$$v\left(\underline{\phi}\right) = v^{aut} \tag{13}$$

For the strategy described in Eq. (9) to be an equilibrium, it must be true that in the cooperative phase players prefer to play $\sigma^{a}\left(\overline{\phi}\right) = a$ rather than to deviate to $\sigma^{a}\left(\overline{\phi}\right) = 0$:

$$v\left(\bar{\phi}\right) \geq u(0,0) + \delta \sum_{\phi_{t+1}\in\Phi} \omega\left(\phi_{t+1}\right) q^{a}\left(\phi_{t+1}|\bar{\phi}, 0, 0\right) \tag{14}$$

where the expected continuation value in the case of defection when Young is equal to:

$$\sum_{\phi_{t+1}\in\Phi} \omega\left(\phi_{t+1}\right) q^{a}\left(\phi_{t+1}|\bar{\phi}, 0, 0\right) \equiv \left[p_0\mu + (1-p_0)\right]\omega(a,0) + p_0(1-\mu)\,\omega(0,0)$$

Plugging Eq. (12) into Eq. (14) and solving for μ we get:

$$\mu \leq \overline{\mu}^{a} \equiv 1 - \frac{u(0,0) - u(0,a)}{\delta\left(p_0 - p_a\right)\left(\omega(a,0) - \omega(0,0)\right)} \tag{15}$$

$\overline{\mu}^{a}$ is clearly strictly less than one. Furthermore, it is non negative as long as:

$$p_a \leq p_0 - \frac{u(0,0) - u(a,0)}{\delta\left(\omega(a,0) - \omega(0,0)\right)} \tag{16}$$

On the other hand, it must be true that in the punishment phase players prefer to play $\sigma^{a}\left(\underline{\phi}\right) = 0$ rather than to deviate to $\sigma^{a}\left(\underline{\phi}\right) = a$:

$$v\left(\underline{\phi}\right) \geq u(a,0) + \delta \sum_{\phi_{t+1}\in\Phi} \omega\left(\phi_{t+1}\right) q^{a}\left(\phi_{t+1}|\underline{\phi}, 0, 0\right)$$

which is trivially satisfied. For $v\left(\bar{\phi}\right)$ to be the best sustainable equilibrium payoff of strategy $\tilde{\Xi}^{a}$, Eq. (15) must be satisfied with equality. Otherwise, we can increase μ and thereby $v\left(\bar{\phi}\right)$ implied by the Eq. (12) without violating the equilibrium condition, Eq. (14). Plugging $\mu = \overline{\mu}^{a}$ into $v\left(\bar{\phi}\right)$ allows to determine the max payoff, $\tilde{v}^{a}_{\max}$, as in Eq. (10). The inefficiency due to the presence of imperfect monitoring is fully captured by the term $\mathcal{C}(a,0)$, which represents the endogenous cost of monitoring. The higher the likelihood ratio (i.e. the higher the probability to detect deviations), the lower the cost of monitoring. Furthermore, the function $\mathcal{C}(\cdot)$ is increasing in the gain from deviation in terms of current utility. Consequently, by using strongly symmetric public strategies, the equilibrium payoff is necessarily bounded above and full efficiency can never be attained.[15]

Proposition 1 *If the best sustainable payoff obtained by implementing social norms without SCI in the*

[15] Kandori and Obara (2006) showed in a prisoners' dilemma game how players can sometimes make better use of information by adopting private strategies and how efficiency in repeated game with imperfect public monitoring can be improved. In the intergenerational game described so far, because of the one-side enforceability structure and the timing of the game, private strategies do not succeed in improving efficiency.

OLG game $\mathcal{G}(\upsilon, p_{a_t})$ is higher than autarky, i.e. $\upsilon^a_{\max} > \upsilon^a_{\min}$, then $\upsilon^a_{\max} = \tilde{\upsilon}^a_{\max}$.

Proof. *(See appendix).* ■

The result in Proposition (1) is equivalent to that achieved by Abreu et al. (1990) in infinite repeated game with imperfect public monitoring. The main difference is that we consider an OLG game characterized by one-sided enforceability at each period. Interestingly, the equilibrium strategy reported in Eq. (9) is sustained as PPE of $\mathcal{G}(\upsilon, p_{a_t})$ under Eq. (16), which is more restrictive than the monotone likelihood ratio requirement reported in Assumption (2).

5 Social Norms with Self-Commitment Institution

In this section we introduce SCI as an alternative enforcement mechanism, which enables agents to attain a higher payoff even if PPE are restricted to strongly symmetric strategies. We determine the finite set of equilibrium payoff achieved by social norms with SCI, i.e. $\Gamma^{ab}_\infty = [\upsilon^{ab}_{\min}, \upsilon^{ab}_{\max}]$. Following the equivalent argument to Section (5), $\upsilon^{ab}_{\min} = \upsilon^{aut}$. To determine the best sustainable payoff consider the following particular social norm with SCI, $\tilde{\Xi}^{ab}$:

$$(\alpha_t(h^t), \beta_t(h^t)) = \begin{cases} (0,0) & \text{if } \exists\ s \leq t \text{ such that} \begin{cases} z_s(h^t) = Y \text{ and } \mu_s(h^t) \geq \mu \\ b_{s-1}(h^t) = 0\ \forall\ z_s(h^t) \end{cases}, \\ (a,b) & \text{otherwise.} \end{cases} \tag{17}$$

Lemma 2 *Let $\delta^{ab} \equiv \frac{u(0,b)-u(a,b)}{(p_0-p_a)(\omega(a,b)-\omega(0,0))}$ and $\mathcal{C}(a,b) \equiv \frac{u(0,b)-u(a,b)}{L-1}$. Then the equilibrium payoff set obtained by implementing Eq. (9) is equal to:*

$$\Gamma^{ab}_\infty = \begin{cases} [\upsilon^{aut}, \tilde{\upsilon}^{ab}_{\max}] & \text{if } \delta \geq \delta^{ab} \\ \{\upsilon^{aut}\} & \text{otherwise} \end{cases}$$

with:

$$\tilde{\upsilon}^{ab}_{\max} \equiv u(a,b) + \delta\omega(a,b) - \mathcal{C}(a,b) \tag{18}$$

The social norm described in Eq. (17) has the following equivalent three-states automaton representation, $\tilde{\Xi}^{ab} = \left\{\Phi, \phi_0, (\sigma^i)_{i\in\{a,b\}}, Q^{ab}(\cdot)\right\}$, with $\phi_t \in \Phi = \left\{\underline{\phi_1}, \underline{\phi_2}, \overline{\phi}\right\}$ for each $t \geq 0$, where $\overline{\phi}$ is the cooperation state, and $\underline{\phi_1}$ and $\underline{\phi_2}$ are different punishment states generated by the two possible deviations. The transition probability, $Q(\cdot)$, prescribes:

$$Q^{ab}(\overline{\phi}|\phi_t, b_t, z_{t+1}) = \begin{cases} 1 & if & \phi = \overline{\phi},\ z_{t+1} = X, & b_t > 0 \\ \mu & if & \phi = \overline{\phi},\ z_{t+1} = Y & b_t > 0 \\ 0 & if & \phi = \overline{\phi},\ \forall z_{t+1}, & b_t = 0 \\ 0 & if & \phi \in \left\{\underline{\phi_1}, \underline{\phi_2}\right\},\ \forall z_{t+1}, & \forall b_t \end{cases} \tag{19}$$

Consistently with Definition (7), a social norm with SCI as $\tilde{\Xi}^{ab}$ is characterized by a transition probability, which maps current states to next-period states by conditioning on both the realization of signals and the self-commitment decisions exerted by previous generations. The equilibrium state-strategy assigns the following decision rules, $\left(\sigma^a(\overline{\phi}) = a, \sigma^b(\overline{\phi}) = b\right)$ and $\left(\sigma^a\left(\underline{\phi_\tau}\right) = 0, \sigma^b\left(\underline{\phi_\tau}\right) = 0\right)_{\tau\in\{1,2\}}$. Fig.

(3) provides a graphical representation of $\tilde{\Xi}^{ab}$.

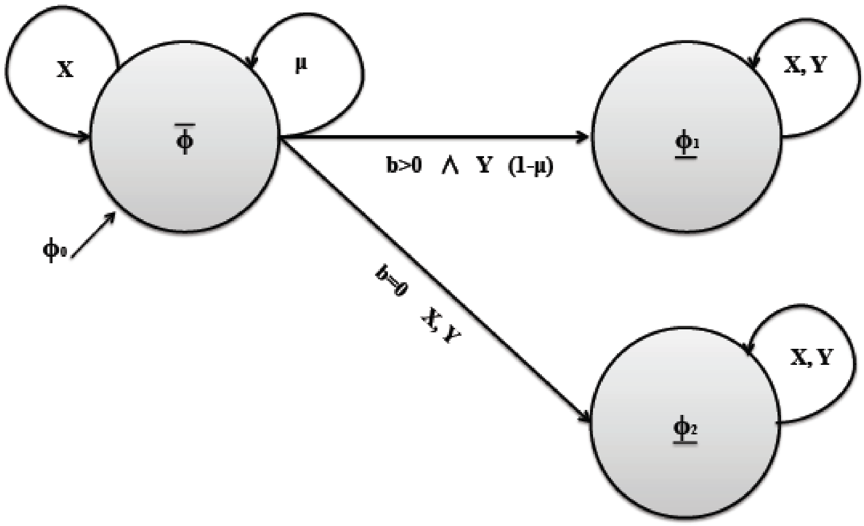

Fig. 3: $\tilde{\Xi}^{ab}$ automaton for the OLG game.

Differing from the strategy reported in Eq. (9), the implementation of SCI requires the activation of a second type of punishment phase. The two punishment phases are distinguished because of the possible deviations exerted by previous generations. Agents start to play cooperatively, i.e. $\phi_0 = \overline{\phi}$, and stay there until:

1. Players observe a bad signal and believe that the realization of the signal is induced by a non-cooperative decision exerted by the previous generation, i.e. they move to $\underline{\phi_1}$;
2. Players observe $b_s = 0$ for any possible realization of public signals, i.e. they move to $\underline{\phi_2}$.

After that they start playing a permanent punishment and intergenerational cooperation is no longer sustained. Using Eq. (7), in the cooperative state the intertemporal payoff function is equal to:

$$v\left(\overline{\phi}\right) = u\left(a, b\right) + \delta \sum_{\phi_{t+1} \in \Phi} \omega\left(\phi_{t+1}\right) q^{ab}\left(\phi_{t+1} | \bar{\phi}, a, b\right) \tag{20}$$

where the expected continuation value in the case of cooperation when Young is:

$$\sum_{\phi_{t+1} \in \Phi} \omega\left(\phi_{t+1}\right) q^{ab}\left(\phi_{t+1} | \bar{\phi}, a, b\right) \equiv \left[p_a \mu + (1 - p_a)\right] \omega\left(a, b\right) + p_a\left(1 - \mu\right) \omega\left(0, 0\right)$$

In the punishment states the intertemporal values are:

$$v\left(\underline{\phi_1}\right) = v\left(\underline{\phi_2}\right) = v^{aut}$$

The strategy $\tilde{\Xi}^{ab}$ is an equilibrium if and only if in each phase the prescribed actions satisfy the incentive requirements. For the strategy in Eq. (17) to be an equilibrium, it must be true that in the cooperative phase agents prefer to play $\sigma^a\left(\overline{\phi}\right) = a$ and $\sigma^b\left(\overline{\phi}\right) = b$ rather than either to deviate to $\sigma^a\left(\overline{\phi}\right) = 0$ and $\sigma^b\left(\overline{\phi}\right) = b$:

$$v\left(\overline{\phi}\right) \geq u\left(0, b\right) + \delta \sum_{\phi_{t+1} \in \Phi} \omega\left(\phi_{t+1}\right) q^{ab}\left(\phi_{t+1} | \bar{\phi}, 0, b\right) \tag{22}$$

where the expected continuation value in the case of defection when Young is given by:

$$\sum_{\phi_{t+1}\in\Phi} \omega\left(\phi_{t+1}\right) q^{ab}\left(\phi_{t+1}|\bar{\phi},0,b\right) \equiv \left[p_0\mu + (1-p_0)\right]\omega(a,b) + p_0(1-\mu)\,\omega(0,0)$$

or, alternatively, to deviate to $\sigma^a\left(\overline{\phi}\right)=0$ and $\sigma^b\left(\overline{\phi}\right)=0$, which implies:

$$\upsilon\left(\overline{\phi}\right) \geq u(0,0) + \delta \sum_{\phi_{t+1}\in\Phi} \omega\left(\phi_{t+1}\right) q^{ab}\left(\phi_{t+1}|\bar{\phi},0,0\right) \tag{23}$$

The deviation $\sigma^a\left(\overline{\phi}\right)=a$ and $\sigma^b\left(\overline{\phi}\right)=0$ is dominated by the inequality reported in Eq. (23) and thus disregarded. By simultaneously solving Eqs. (22) and (23), we get $\mu \in M \equiv \left[\underline{\mu}^{ab}, \overline{\mu}^{ab}\right]$ where:

$$\overline{\mu}^{ab} \equiv 1 - \frac{u(0,b) - u(a,b)}{\delta\left(p_0 - p_a\right)\left(\omega(a,b) - \omega(0,0)\right)} \tag{24}$$

and:

$$\underline{\mu}^{ab} \equiv \frac{u(0,0) - u(a,b)}{\delta p_a\left(\omega(a,b) - \omega(0,0)\right)} - \frac{1-p_a}{p_a}$$

To be feasible, i.e. $M \neq \varnothing$, we require:

$$p_a \leq \frac{\delta\left(\omega(a,b) - \omega(0,0)\right) - \left(u(0,0) - u(a,b)\right)}{\delta\left(\omega(a,b) - \omega(0,0)\right) - \left(u(0,0) - u(0,b)\right)} p_0 \tag{25}$$

$\overline{\mu}^{ab}$ is clearly strictly less than one and is non negative as long as:

$$p_a \leq p_0 - \frac{u(0,b) - u(a,b)}{\delta\left(\omega(a,b) - \omega(0,0)\right)} \tag{26}$$

On the other hand, it is trivial to prove that the incentive constraints in punishment phases are always satisfied. To determine the maximal element of Γ^{ab}_{∞} we look for the appropriate μ, which maximizes the individual payoff without violating the incentive constraints given by Eqs. (22) and (23), i.e. $\mu = \overline{\mu}^{ab}$. Plugging $\mu = \overline{\mu}^{ab}$ into $\upsilon\left(\overline{\phi}\right)$ we determine the best sustainable payoff, $\tilde{\upsilon}^{ab}_{\max}$, given by Eq. (18). As before, the inefficiency arising out of imperfect monitoring is captured by the term $\mathcal{C}(a,b)$. By self-committing agents reduce the endogenous cost of monitoring, $\frac{\partial \mathcal{C}(\cdot)}{\partial b} < 0$. Even if the two punishment phases, $\underline{\phi_1}$ and $\underline{\phi_2}$, appear to be very similar in nature, they are substantially different. While $\underline{\phi_1}$ is activated on the equilibrium path as in $\tilde{\Xi}^a$, $\underline{\phi_2}$ is an out of equilibrium punishment path. Since the b-decision is perfectly observable and agents are immediately punished if they decide not to self-commit, in equilibrium they always choose to sustain the cost. However, the existence of such off-the-equilibrium punishment path reduces the need of on equilibrium punishment: As long as, by self-committing agents reduce their current gain from deviation, then they decide to cheat future generations over the intergenerational transfer decision with a lower probability. As a consequence, intergenerational cooperation under imperfect monitoring is easier sustained, achieving ex-ante higher efficiency, as the next subsection shows.

Proposition 2 *If the best sustainable payoff obtained by implementing social norms with SCI in the OLG game $\mathcal{G}\left(\upsilon, p_{a_t}\right)$ is higher than autarky, i.e. $\upsilon^{ab}_{\max} > \upsilon^{ab}_{\min}$, then $\upsilon^{ab}_{\max} = \tilde{\upsilon}^{ab}_{\max}$.*

Proof. *(See appendix).* ■

Proposition (2) states that the highest payoff attained by social norms with SCI is exactly equal to the best sustainable equilibrium payoff achieved by the strategy $\tilde{\Xi}^{ab}$.[16]

5.1 Value of Self-Commitment-Institutions

What is the price that agents were willing to pay for SCI? In this section we determine the gain in efficiency attained by implementing social norms that adopt SCI, compared to social norms that do not require SCI, i.e. $\Pi \equiv \upsilon_{\max}^{ab} - \upsilon_{\max}^{a}$. The following Lemma holds.

Lemma 3 *If $\Pi > 0$ then $\overline{\mu}^{ab} > \overline{\mu}^{a}$.*

Proof. *(See appendix).* ■

We can interpret Lemma (3) from a behavioral perspective. As long as by self-committing agents reduce their marginal gains from deviation in terms of current utility, the next-period generation is induced to believe with higher probability that the realization of bad signals is generated by exogenous shocks rather than uncooperative actions. Consequently, the condition $\overline{\mu}^{ab} > \overline{\mu}^{a}$ is necessary for the achievement of gains in efficiency through the implementation of social norms with SCI. Plugging the equilibrium values of the public randomization devices into the transition probabilities given by Eqs. (11) and (19), we obtain that the following inequality holds:

$$Q^{a}\left(\overline{\phi}|\overline{\phi},\cdot,X\right) - Q^{a}\left(\overline{\phi}|\overline{\phi},\cdot,Y\right) > Q^{ab}\left(\overline{\phi}|\overline{\phi},b,X\right) - Q^{ab}\left(\overline{\phi}|\overline{\phi},b,Y\right) > 0$$

This condition illustrates the leverage effect generated by self-commitment as bonding mechanism. In equilibrium, by self-committing, players are induced in exerting higher effort, dampening the next period volatility.

Three constraints must simultaneously be checked in order to evaluate the feasible value of SCI:

i) *Optimality*: $\Pi > 0$;

ii) *Non negativity*: $\bar{\mu}^{a} > 0$;[17]

iii) *Feasibility*: $M \neq \varnothing$.

The latter two constraints guarantee that both social norms with and without SCI are feasible, whereas the first constraint quantifies the gain in efficiency.

Proposition 3 *Let $\underline{\delta} \equiv \frac{u(0,0)-u(0,b)}{(\omega(a,b)-\omega(0,0))-\left(\frac{u(0,b)-u(a,b)}{u(0,0)-u(a,0)}\right)(\omega(a,0)-\omega(0,0))}$. If $\delta > \underline{\delta}$ then a non-empty parametric space exists, P, where Ξ^{ab} improves efficiency compared to Ξ^{a} for each $(p_0, p_a) \in P$, i.e. $\Gamma_{\infty}^{a} \subseteq \Gamma_{\infty}^{ab}$.*

Proof. *(See appendix).* ■

In the parametric space P the benefits coming from the implementation of SCI (i.e. the reduction in the endogenous cost of monitoring) are larger with respect to the costs generated by the self-commitment

[16] $\tilde{\Xi}^{ab}$ prescribes to reverse to the worst sustainable equilibrium as soon as a player decides not to self-commit. The out-of-equilibrium beliefs, which sustain $\tilde{\Xi}^{ab}$ as PPE of the game $G(\upsilon, p_{a_t})$, requires zero continuation values in the case of $\sigma_t^b(\phi_t) = 0$ for some $t > 0$. This is actually just one of the possible equilibrium strategies, which delivers the best sustainable payoff among social norms with SCI. Indeed, it is possible to relax such out-of-equilibrium beliefs, introducing an additional correlation device, we denote $(\theta_t^{\kappa})_{t=0}^{\infty}$, which enables agents to not be punished both after a bad signal, $\kappa = Y$, and a good signal, $\kappa = X$, if the realization of θ_t^{κ} is sufficiently high.

[17] Under Lemma (1), as long as $\bar{\mu}^{a} \geq 0$, then also $\bar{\mu}^{ab} \geq 0$. Consequently, it is sufficient to check the conditions under which the former inequality holds.

decision. Specifically, higher the benefits perceived from intergenerational cooperation when Old, larger the parametric space in which social norms with SCI achieve higher efficiency.

From a political economy perspective, an implication of the model is that the implementation of policies, which introduce upper limits to the possibility of self-commitment actions, hampers cooperation by creating distortions and depressing individual welfare. Furthermore, the optimal taxation/redistribution scheme crucially depends on the correct understanding of the actual social norm at work. Suppose agents coordinate their continuation play on social norms with SCI, then policies which aim to reduce Young poverty, for example subsidizing their endowment, are totally ineffective: The unique consequence would be a reduction of self-commitment credibility for next generations and, therefore, lower ex-ante utility.

Finally, given $\frac{\partial \Pi(p_0,p_a)}{\partial p_0} < 0$, $\frac{\partial \Pi(p_0,p_a)}{\partial p_a} > 0$ and $\left|\frac{\partial \Pi(p_0,p_a)}{\partial p_a}\right| > \left|\frac{\partial \Pi(p_0,p_a)}{\partial p_0}\right|$, it follows that:

$$\sup\left\{(p_0, p_a) \in P\right\} = \arg \max_{(p_0,p_a)\in P} \Pi\left(p_0, p_a\right)$$

The price of SCI attains the highest value when the monitoring technology is characterized by the worst feasible performance, namely in the point $(p_0, p_a) \in P$, whose Euclidean distance from the perfect monitoring scenario, $p_0 = 1$ and $p_1 = 0$, is maximized. This result helps to stress the role of self-commitment as an institution, which sustains efficient cooperation when the moral hazard issue is explicitly considered and monitoring technologies are ineffective.

5.2 Memory

In the previous sections we have shown how the implementation of social norms with SCI may outperform social norms without SCI in terms of ex-ante efficiency by assuming agents perfectly recall the past history. Nevertheless, on the one hand, this assumption seems to be unreasonable, especially in OLG environments characterized by informational constraints like imperfect observability. On the other hand, the representation of Abreu et al. (1990), traditionally adopted to characterize equilibria in repeated settings with imperfect public monitoring, relies crucially on players' ability to keep track of arbitrarily long histories of past events. These elements justify recent studies, which are questioning the role of memory in sustaining mutual cooperation in imperfect monitoring scenarios.[18]

The main objective of this subsection is to evaluate whether and how history matters in sustaining good payoffs when agents coordinate their expectation on different social norms. The state-strategy equilibrium representation helps us in providing a simple characterization of PPE with finite memory. We assume the most restrictive informational requirement: Agents imperfectly observe past history and have one-period memory over the public signal. We denote by Γ_1^j with $j \in \{a, ab\}$ the set of equilibrium payoff in the one-period memory case.

First, consider social norms without SCI.

Definition 8 (Social Norm without SCI with One-Period Memory) *A social norm without SCI with one period memory over public signals is a PPE characterized by strategies measurable with respect to* $h^t / \left(h^{t-1}, b_{t-1}\right)$, *i.e.* $\alpha_t\left(\hat{h}^t\right) = \alpha_t\left(\check{h}^t\right)$ *and* $\beta_t\left(\hat{h}^t\right) = \beta_t\left(\check{h}^t\right)$ *if* $\hat{h}^t \equiv \left(\hat{h}^{t-1}, z_t, \hat{b}_{t-1}, \mu_t\right)$ *and* $\check{h}^t \equiv \left(\check{h}^{t-1}, z_t, \check{b}_{t-1}, \mu_t\right)$ $\forall\ \hat{h}^{t-1} \neq \check{h}^{t-1}$ *and* $\hat{b}^t \neq \check{b}^t$.

In Section (5) we have shown that in the infinite memory case the highest payoff is sustained by a two-state strategy. Since agents perfectly recall past history, they are always aware of the potential

[18] Cole and Kocherlakota (2005) examine the extent to which the set of equilibrium payoffs with infinite-memory strategies is a good approximation to the set of equilibrium payoffs with arbitrarily long finite-memory strategies in a standard repeated setting with imperfect public monitoring.

histories driving toward each state. Consequently, they can discriminate between the two states by associating different values. Specifically, when agents are patient enough, cooperation might be enforced in equilibrium achieving the payoffs $\upsilon\left(\underline{\phi}\right) = \upsilon^{aut} = \upsilon^{a}_{\min}$ and $\upsilon\left(\overline{\phi}\right) = \upsilon^{a}_{\max}$ with $\upsilon^{a}_{\max} > \upsilon^{a}_{\min}$.

Corollary 1 *$\forall\, \delta \in (0,1)$ $\Gamma^{a}_{1} = \{\upsilon^{aut}\}$.*

Proof. *(See appendix).* ■

In the case of one-period memory, community punishment can be contingent only on the observation of the last signal realization. A strategy like the one described in (9) is not sustained as PPE of the finite-memory-version OLG game. Suppose that the t-player observes a bad signal, $z_t = Y$, and a sufficiently high realization of μ_t, such that he should act in the punishment state according to the state-strategy, $\sigma^{a}\left(\underline{\phi}\right) = 0$ and $\sigma^{b}\left(\underline{\phi}\right) = 0$. Given that she can affect through her action the probability of next-period signal realization (which will be the uniquely relevant information for the next generation's decisions), she might have incentives to deviate from the prescribed strategy, i.e. $\sigma^{a}\left(\underline{\phi}\right) = a$ and $\sigma^{b}\left(\underline{\phi}\right) = 0$, as long as by deviating she achieves a higher payoff. A similar argument can be replicated in the cooperation state. Given that agents cannot statistically discriminate between the two states, they are actually playing an observationally equivalent one-state strategy, whose unique equilibrium payoff is $\upsilon^{a}_{\max} = \upsilon^{a}_{\min}$. Therefore, by coordinating on social norms without SCI in the case of one-period memory, generations cannot gather incentives to promote intergenerational cooperation.

Now we consider social norms with SCI.

Definition 9 (Social Norm with SCI with One-Period Memory) *A social norm with SCI with one period memory over public signals is a PPE characterized by strategies measurable with respect to $\left(h^{t}/h^{t-1}\right) \cup b^{t}$, i.e. $\alpha_t\left(\hat{h}^{t}\right) = \alpha_t\left(\check{h}^{t}\right)$ and $\beta_t\left(\hat{h}^{t}\right) = \beta_t\left(\check{h}^{t}\right)$ if $\hat{h}^{t} \equiv \left(\hat{z}^{t-1}, b^{t-1}, \hat{\mu}^{t-1}, z_t, b_{t-1}, \mu_t\right)$ and $\check{h}^{t} \equiv \left(\check{z}^{t-1}, b^{t-1}, \check{\mu}^{t-1}, z_t, b_{t-1}, \mu_t\right)$ $\forall\ \hat{z}^{t-1} \neq \check{z}^{t-1}$ and $\hat{\mu}^{t-1} \neq \check{\mu}^{t-1}$.*

As shown in the previous Sections, when agents perfectly recall past history and coordinate their continuation play also on self-commitment actions the highest payoff is sustained by a three-state strategy. One of the two punishment states is never activated in equilibrium, but, as long as the out-of-equilibrium transition probability $Q^{ab}\left(\overline{\phi}|\phi_t, 0, z_{t+1}\right) = 0$ is sustained in equilibrium, it endogenously create a leverage effect on the equilibrium continuation value.

Corollary 2 *$\forall\, \delta \in (0,1)$ $\Gamma^{ab}_{1} = \Gamma^{ab}_{\infty}$.*

Proof. *(See appendix).* ■

If agents have one-period memory over public signals but recall the self-commitment actions exerted by previous generations, then cooperation can be enforced as equilibrium outcome of social norms with SCI. Specifically, in order to sustain $Q^{ab}\left(\overline{\phi}|\phi_t, 0, z_{t+1}\right) = 0$ and induce no generation to renegotiate on the self-commitment decisions in the punishment phase, it is sufficient that agents recall the b-decision exerted by the last two generations . Consequently, the strategy that sustains the best payoff in the case of one-period memory over public signals becomes a two-state strategy, where $\upsilon\left(\underline{\phi}\right) = \upsilon^{aut}$ and $\upsilon\left(\overline{\phi}\right) = \tilde{\upsilon}^{ab}_{\max}$ as in Eq. (18).[19] Interestingly, given that the absorbing punishment state is never activated in equilibrium, intergenerational cooperation is sustained over time.

[19] As in Bhaskar (1998), the implementation of mixed strategies makes intergenerational cooperation sustainable when agents have limited information over past history. In this game the possibility to credibly coordinate continuation play on observable self-commitment actions makes the cooperative outcome robust to small perturbation.

6 Applications

To show the main results we provide some applications. A natural interpretation of self-commitment actions is in terms of free disposal of individual endowment, for example unit of time. It could be used for both productive (for example education) and unproductive scope (for example conspicuous leisure). In order to put emphasis on the different nature of self-commitment actions, we consider two different applications of the theoretic framework developed in the previous sections: *i)* Intergenerational public good game with unproductive SCI, and *ii)* intergenerational transfer game with productive SCI. Let us adopt the following parametric economy: $u(\kappa) = 1 - \exp(-\gamma\kappa)$ and $\omega(\kappa) = 1 - \exp(-\eta\kappa)$ with $\gamma, \eta > 0$.

6.1 Intergenerational Public Good Game with Unproductive SCI

Consider an intergenerational public good game. At each time the Young are endowed with one unit of productive time, and Old have an endowment, which is normalized to zero. At the beginning of each period the Young face two different decisions: *i)* The share of time endowment to devote to the production of consumption goods by adopting a linear technology, i.e. $1 - b_t$; *ii)* the amount of transfers, $(1 - b_t) a_t$, to be used for the production of intergenerational public goods. Consider the following discrete action space, $a_t \in A = \{0, a\}$ and $b_t \in B = \{0, b\}$ with $a, b \in (0, 1)$. At each time the economy produces a single homogenous public good according to a linear technology, i.e. $g_t = (1 - b_t) a_t$. To emphasize the intergenerational conflict we assume that only elderly agents enjoy the public good provision. The individual resource constraint when Young turns out to be equal to $c_t = (1 - b_t)(1 - a_t)$, where c_t is the consumption level when Young. The ex-post individual intertemporal utility is equal to:

$$v_t = 1 - \exp(-\gamma c_t) + \delta(1 - \exp(-\eta g_{t+1}))$$

Consistently with the theoretical framework: b-action is perfectly observable, whereas a-action is imperfectly observable by future generations through public signals.[20] According to Definition (2), b_t is a self-commitment action: By voluntarily reducing their working time endowment, agents are lowering the gains they might obtain by deviating on the intergenerational cooperative dimension.[21]

According to Eq. (24), $\bar{\mu}^{ab} = 1 - \frac{1}{\delta(p_0 - p_a)} \frac{\exp(-\gamma(1-a)(1-b)) - \exp(-\gamma(1-b))}{1 - \exp(-\eta a(1-b))}$. By applying Lemma (3) a necessary condition to achieve higher efficiency with SCI is $\frac{\partial \bar{\mu}^{ab}}{\partial b} \geq 0$. On the parametric space (γ, η) this implies that η is sufficiently larger than γ, i.e. the Young are less risk adverse compared to elderly agents. In the opposite case the inverse relation holds, i.e. $\frac{\partial \bar{\mu}^{ab}}{\partial b} < 0$. Two main forces drive this result: *i)* Due to their relative high risk aversion, by self-committing Young grow poorer and increase their marginal gain from deviation on the public good provision; *ii)* due to their relative lower risk aversion, elderly enjoy lower benefits from intergenerational cooperation.

We now apply the statement in Proposition (3) to evaluate the feasible price for the adoption of SCI. If $\delta > \underline{\delta}$ then the following constraints simultaneously must hold:

i) *Optimality*: $p_a \geq \frac{\delta(\exp(-\eta a(1-b)) + \exp(-\eta a)) + (\exp(-\gamma(1-a)(1-b)) - \exp(-\gamma(1-a)))}{\delta(\exp(-\eta a(1-b)) + \exp(-\eta a)) + (\exp(-\gamma(1-b)) - \exp(-\gamma))} p_0$;

ii) *Non negativity*: $p_a \leq p_0 - \frac{\exp(-\gamma(1-a)) - \exp(-\gamma)}{\delta(1 - \exp(-\eta a))}$;

[20] The signal provides information about the provision of public good, which is precluded whether $a = 0$ for each b_t. As a result, it depends by the a-action, independently from the self-commitment action.

[21] b-action can be thought as conspicuous leisure.

iii) *Feasibility*: $p_a \leq \frac{\delta(1-\exp(-\eta a(1-b)))-(\exp(-\gamma(1-a)(1-b))-\exp(-\gamma))}{\delta(1-\exp(-\eta a(1-b)))-(\exp(-\gamma(1-b))-\exp(-\gamma))} p_0$.

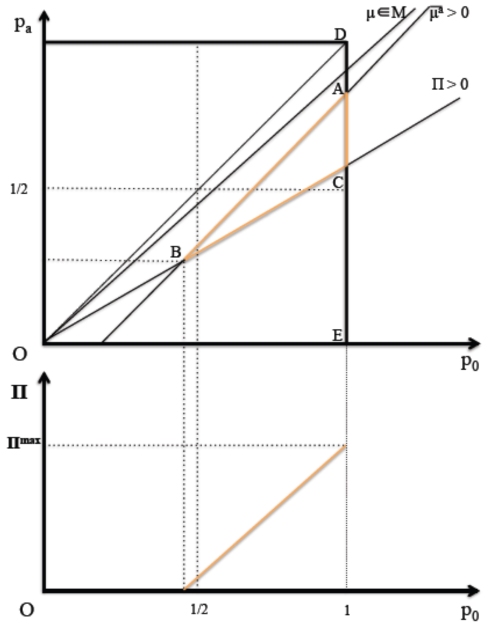

Fig. 4: Value of Self-Commitment-Institution

Fig. (4) plots the feasibility space, P, and the corresponding SCI-value, Π, considering the upper envelope of the triangle ABC and plotting over p_0. The point $A = \left(1, 1 - \frac{\exp(-\gamma(1-a))-\exp(-\gamma)}{\delta(1-\exp(-\eta a))}\right)$ represents the point in which Π achieves the maximum value, whereas $\Pi = 0$ in the two extremes B and C. Note that on the 45° line (OD) the monitoring technology is the least efficient, whereas E is the point of perfect observability. As stated in Section (6.1), SCI attains the highest price when evaluated at the feasible point whose distance from the fully imperfect monitoring region is minimized.

6.2 Intergenerational Transfer Game with Productive SCI

Now we consider b-action as productive investment and a-action as intergenerational consumption good transfer.[22] In this context the positive impact of SCI is further magnified by growth motives. By adopting this slight change of the theoretic environment we provide a new justification for the emergence of education provision as an instrument to sustain intergenerational contracts, out of the traditional altruistic and asset return arguments. We denote by c_t^1 and c_{t+1}^2 the consumption levels when Adult and Old, respectively. Young do not consume. At each time t Adults face two different actions, a_t and b_t. They split their time endowment between production and education of their children, b_t. Furthermore, they choose the amount of consumption good to be transferred to current living Old. When Young agents transform the received time endowment in human capital, which is used for next period production. Let $\psi(b_{\tau-1}, b_\tau) \equiv 1 + \zeta(b_{\tau-1}) - b_\tau$, where $\zeta(\cdot)$ represents a decreasing return to scale human capital technology, i.e. $\zeta_b \geq 0$ and $\zeta_{bb} \leq 0$. Consequently, the individual resource constraints are $c_t^1 = \psi(b_{t-1}, b_t)(1 - a_t)$ and $c_{t+1}^2 = \psi(b_t, b_{t+1}) a_{t+1}$.

The first best allocation attained by the central planner with full taxation power is equal to $(a^*, b^*) = \arg\max_{a \in A, b \in B} 1 - \exp(-\gamma\psi(b)(1-a)) + \delta(1 - \exp(-\eta\psi(b)a))$. Note that, due to the positive spillover effects generated by the self-commitment decision, an interior level of $b^* > 0$ exists. Under perfect moni-

[22] We deal with a three-period-OLG model to enable b-decisions to be productive with one period lag. This demographic change does not modify the main structure of the model depicted in the previous sections.

toring, the allocation (a^*, b^*) can be sustained as a subgame perfect equilibrium of the intergenerational game. Rangel (2003) shows how the existence of a_t (i.e. *backward transfers*) sustains the investment in b_t (i.e. *forward transfers*). Without the former the productive investment turns out to be inefficiently low due to hold-up problems. Moving in an imperfect monitoring environment we invert Rangel's perspective. We show how the self-commitment action (*forward transfers*) plays a relevant role in sustaining intergenerational cooperation by reducing players' opportunistic behavior.

Productive SCI generate two effects. The first is related to *technological* reasons and is quantify by the gain:

$$\gamma^T(b) \equiv \chi_1 + \delta\chi_2$$

where $\chi_1 \equiv \exp(-\gamma(1-a)) - \exp(-\gamma\psi(b)(1-a))$ and $\chi_2 \equiv \exp(-\eta a) - \exp(-\eta\psi(b)a)$. Under decreasing return to scale of human capital technology, $\gamma^T(b)$ is always greater than zero. The second effect is instead related to *strategic* reasons, as widely discussed in the previous sections, whose impact is quantified by:

$$\gamma^S(b) \equiv \mathcal{C}(a, 0) - \mathcal{C}(a, b)$$

Let us denote by $\rho \equiv \left|\frac{c u_{cc}}{u_c}\right|$ the coefficient of relative risk aversion. The following Proposition states the conditions under which social norms with SCI outperform social norms without SCI in the strategic component.

Proposition 4 *Social norms with productive SCI improve ex-ante efficiency in the strategic component,* $\gamma^S(b) \geq 0$*, in the following cases:*

i) *dynamic inefficiency and relative risk aversion greater or equal to one, i.e.* $\psi_b > 0$ *and* $\rho \geq 1$*;*

ii) *dynamic efficiency and relative risk aversion lower than one, i.e.* $\psi_b \leq 0$ *and* $\rho < 1$*.*

Proof. *(See appendix).* ■

Proposition (4) resumes the sufficient conditions to meet the *decreasing differences* property in a scenario characterized by productive SCI. Furthermore, it delivers simple and potentially testable implications. A society characterized by a dynamic efficient growth path (i.e. $\psi_b \leq 0$), where agents cannot increase their intertemporal utility by reducing their consumption and by increasing investment in human capital, may support the implementation of social norms with productive SCI in order to reduce opportunistic behavior on the dimension of intergenerational cooperation. When the economy is instead characterized by dynamic inefficient growth path (i.e. $\psi_b > 0$) and community coordinates on social norms with SCI, opportunistic behavior on the intergenerational cooperative dimension might be even exacerbated, partially reducing the overall ex-ante efficiency. However social norms with SCI are still desirable in the case of dynamic inefficiency as long as agents have sufficiently high relative risk aversion, which partially reduces the gain from deviation.

7 Conclusions

In this paper we have focused on OLG games characterized by imperfect public monitoring, where agents are restricted to play strongly symmetric public strategies. We have studied how the implementation of social norms with SCI improves ex-ante efficiency compared to social norms without SCI. When agents coordinate their strategies on the self-commitment actions of previous generations, the society attains higher welfare.

There are two main features we require to be satisfied in order to achieve this stark result. First, self-commitment decisions must be fully observable by future generations. Second, by self-committing agents endogenously change their current marginal gain from deviation. If all players coordinate on both community and self-commitment enforcement mechanisms and agents are patient enough, then players are more willing to cooperate even after the realization of a bad signal and, consequently, higher ex-ante efficiency is supported in equilibrium.

A wide range of economic settings exists in which our theoretic results may be conveniently applied. Stochastic environments characterized by high volatility and repeated interactions among organizations, whose members have fixed-term mandates, are particular adept at exploring the positive impact of social norms where agents coordinate their expectations on the self-commitment decisions of the other players. Real applications will be in the context of self-enforcing intergenerational risk sharing and self-enforcing international agreements.

In this study we have limited our analyses to the comparison between two types of social norms. Future research will focus on the study of the endogenous emergence of social norms in a more general repeated setting. Specifically, by adopting an evolutionary approach, we may wonder whether and how a community, which relied initially on social norms without SCI, may have incentives to switch to social norms with SCI, or viceversa.

8 Appendix

Proposition (1). To determine the maximum symmetric equilibrium payoff $\upsilon^a_{\max}$ of the set Γ^a_∞, as defined in Eq. (8), we solve the following linear programming problem:

$$\upsilon^a_{\max} = \max_{a_t\in A, b_t\in B, \upsilon^a_{\max}, \upsilon^a_{\min}, \omega:\Phi\to\Re} u(a_t, b_t) + \delta \sum_{z_{t+1}\in Z}\sum_{\phi_{t+1}\in\Phi} \omega(\phi_{t+1}) Q^a(\phi_{t+1}|\phi_t, \cdot, z_{t+1}) \Pr(z_{t+1}|a_t)$$

s.t.:

i. $\upsilon^a_{\max} = u(\bar{a}, \bar{b}) + \delta \sum_{z_{t+1}\in Z}\sum_{\phi_{t+1}\in\Phi} \omega(\phi_{t+1}) Q^a(\phi_{t+1}|\phi_t, \cdot, z_{t+1}) \Pr(z_{t+1}|\bar{a})$

ii. $\upsilon^a_{\min} = u(\underline{a}, \underline{b}) + \delta \sum_{z_{t+1}\in Z}\sum_{\phi_{t+1}\in\Phi} \omega(\phi_{t+1}) Q^a(\phi_{t+1}|\phi_t, \cdot, z_{t+1}) \Pr(z_{t+1}|\underline{a})$

iii. $\upsilon^a_{\max} \geq u(\hat{a}, \hat{b}) + \delta \sum_{z_{t+1}\in Z}\sum_{\phi_{t+1}\in\Phi} \omega(\phi_{t+1}) Q^a(\phi_{t+1}|\phi_t, \cdot, z_{t+1}) \Pr(z_{t+1}|\hat{a})\ \forall \hat{a} \neq \bar{a}, \hat{b} \neq \bar{b}$

iv. $\upsilon^a_{\min} \geq u(\hat{a}, \hat{b}) + \delta \sum_{z_{t+1}\in Z}\sum_{\phi_{t+1}\in\Phi} \omega(\phi_{t+1}) Q^a(\phi_{t+1}|\phi_t, \cdot, z_{t+1}) \Pr(z_{t+1}|\hat{a})\ \forall a \neq \underline{a}, \hat{b} \neq \underline{b}$

v. $\upsilon^a_{\max} \geq \upsilon^a_{\min}$

We denote by $(\underline{\omega}, \overline{\omega}) \in \Re^2$ the extreme values of promised payoff, i.e. $\underline{\omega} = \omega(0,0)$ and $\overline{\omega} = \omega(a, 0)$, such that $\omega(\underline{\phi}) = \underline{\omega}$ and $\omega(\overline{\phi}) = \overline{\omega}$, where $\{\underline{\phi}, \overline{\phi}\} \in \Phi$.

Let us start from the initial condition $\phi_0 = \overline{\phi}$. It straightforward to show that with infinite memory the worst sustainable payoff is autarky, i.e. $\upsilon^a_{\min} = \upsilon^{aut}$, therefore $\underline{a} = 0$ and $\underline{b} = 0$. To enforce cooperation in equilibrium $\upsilon^a_{\max} > \upsilon^a_{\min}$. On the contrary profiles with $\upsilon^a_{\max} = \upsilon^a_{\min}$ are not suitable to provide incentives for generations to cooperate. Since in the case of social norms without SCI agents do not coordinate their continuation play on self-commitment actions exerted by previous generations, then it follows that $\overline{b} = 0$. To determine the best sustainable payoff the incentive compatible constraint (iii) must be satisfied with equality. Plugging Eq. (i) into (iii) and rearranging we obtain:

$$\sum_{z_{t+1}\in Z}\left((\Pr(z_{t+1}|\bar{a}) - \Pr(z_{t+1}|0)) \sum_{\phi_{t+1}\in\Phi} \omega(\phi_{t+1}) Q^a(\phi_{t+1}|\overline{\phi}, \cdot, z_{t+1}) \right) = \frac{u(0,0) - u(\bar{a}, 0)}{\delta} \tag{28}$$

To have $\upsilon^a_{\max}$ strictly higher than $\upsilon^a_{\min}$ we require:

$$\sum_{z_{t+1}\in Z}\sum_{\phi_{t+1}\in\Phi} \omega(\phi_{t+1}) Q^a(\phi_{t+1}|\overline{\phi}, \cdot, z_{t+1}) \Pr(z_{t+1}|0) > \underline{\omega} \tag{29}$$

$$\sum_{z_{t+1}\in Z}\sum_{\phi_{t+1}\in\Phi} \omega(\phi_{t+1}) Q^a(\phi_{t+1}|\overline{\phi}, \cdot, z_{t+1}) \Pr(z_{t+1}|\bar{a}) > \frac{u(0,0) - u(\bar{a}, 0)}{\delta} + \underline{\omega} \tag{30}$$

After some manipulations, from Eq. (29) we obtain:

$$(\overline{\omega} - \underline{\omega}) \left[p_0 Q^a(\overline{\phi}|\overline{\phi}, \cdot, Y) + (1 - p_0) Q^a(\overline{\phi}|\overline{\phi}, \cdot, X)\right] > 0$$

which implies $Q^a(\overline{\phi}|\overline{\phi}, \cdot, z_{t+1}) > 0$ for at least some z_{t+1}. Furthermore, from Eq. (30) it follows that:

$$Q^a(\overline{\phi}|\overline{\phi}, \cdot, Y) > \frac{u(0,0) - u(\bar{a}, 0)}{\delta(\overline{\omega} - \underline{\omega}) p_{\bar{a}}} - \frac{1 - p_{\bar{a}}}{p_{\bar{a}}} Q^a(\overline{\phi}|\overline{\phi}, \cdot, X) \tag{31}$$

Finally, using Eq. (28), the following condition must hold:

$$Q^a\left(\overline{\phi}|\overline{\phi},\cdot,Y\right) = Q^a\left(\overline{\phi}|\overline{\phi},\cdot,X\right) - \frac{u(0,0)-u(\bar{a},0)}{\delta\left(\overline{\omega}-\underline{\omega}\right)(p_0-p_{\bar{a}})} \tag{32}$$

Eq. (32) implies that self-enforceability of $\bar{a}=a$ can be sustained in equilibrium as long as:

$$Q^a\left(\overline{\phi}|\overline{\phi},\cdot,X\right) = 1 \text{ and } Q^a\left(\overline{\phi}|\overline{\phi},\cdot,Y\right) = 1 - \frac{u(0,0)-u(a,0)}{\delta\left(\overline{\omega}-\underline{\omega}\right)(p_0-p_a)} \tag{33}$$

where $\delta \geq \delta^a \equiv \frac{u(0,0)-u(a,0)}{(\overline{\omega}-\underline{\omega})(p_0-p_a)}$. If $\delta < \delta^a$ then only $\bar{a}=0$ can be enforced in equilibrium. Plugging Eq. (33) into constraint (i) we obtain the result. ■

Proposition (2). Equivalently to Proposition (1), to determine the maximum symmetric equilibrium payoff $\upsilon^{ab}_{\max}$ of the set Γ^{ab}_{∞}, we solve the following linear programming problem:

$$\upsilon^{ab}_{\max} = \max_{a_t\in A, b_t\in B, \upsilon^a_{\max}, \upsilon^a_{\min}, \omega:\Phi\to\Re} u(a_t,b_t) + \delta\sum_{z_{t+1}\in Z}\sum_{\phi_{t+1}\in\Phi}\omega\left(\phi_{t+1}\right)Q^{ab}\left(\phi_{t+1}|\phi_t,b_t,z_{t+1}\right)\Pr\left(z_{t+1}|a_t\right)$$

s.t.:

i. $\upsilon^{ab}_{\max} = u\left(\bar{a},\bar{b}\right) + \delta\sum_{z_{t+1}\in Z}\sum_{\phi_{t+1}\in\Phi}\omega\left(\phi_{t+1}\right)Q^{ab}\left(\phi_{t+1}|\phi_t,\bar{b},z_{t+1}\right)\Pr\left(z_{t+1}|\bar{a}\right)$

ii. $\upsilon^{ab}_{\min} = u\left(\underline{a},\underline{b}\right) + \delta\sum_{z_{t+1}\in Z}\sum_{\phi_{t+1}\in\Phi}\omega\left(\phi_{t+1}\right)Q^{ab}\left(\phi_{t+1}|\phi_t,\underline{b},z_{t+1}\right)\Pr\left(z_{t+1}|\underline{a}\right)$

iii. $\upsilon^{ab}_{\max} \geq u\left(\hat{a},\hat{b}\right) + \delta\sum_{z_{t+1}\in Z}\sum_{\phi_{t+1}\in\Phi}\omega\left(\phi_{t+1}\right)Q^{ab}\left(\phi_{t+1}|\phi_t,\hat{b},z_{t+1}\right)\Pr\left(z_{t+1}|\hat{a}\right)\ \forall\hat{a}\neq\bar{a},\hat{b}\neq\bar{b}$

iv. $\upsilon^{ab}_{\min} \geq u\left(\hat{a},\hat{b}\right) + \delta\sum_{z_{t+1}\in Z}\sum_{\phi_{t+1}\in\Phi}\omega\left(\phi_{t+1}\right)Q^{ab}\left(\phi_{t+1}|\phi_t,\hat{b},z_{t+1}\right)\Pr\left(z_{t+1}|\hat{a}\right)\ \forall\hat{a}\neq\underline{a},\hat{b}\neq\underline{b}$

v. $\upsilon^{ab}_{\max} \geq \upsilon^{ab}_{\min}$

Let us start from the initial condition $\phi_0 = \overline{\phi}$. As in Proposition (1), $\upsilon^{ab}_{\min} = \upsilon^{aut}$ and, therefore, $\left(\underline{a},\underline{b}\right) = (0,0)$. To characterize the best sustainable payoff in the case of social norms with SCI, constraint (iii) must hold with equality as follows:

$$\upsilon^{ab}_{\max} \geq \max_{\left(\hat{a},\hat{b}\right)\neq\left(\bar{a},\bar{b}\right)} u\left(\hat{a},\hat{b}\right) + \delta\sum_{z_{t+1}\in Z}\sum_{\phi_{t+1}\in\Phi}\omega\left(\phi_{t+1}\right)Q^{ab}\left(\phi_{t+1}|\phi_t,\hat{b},z_{t+1}\right)\Pr\left(z_{t+1}|\hat{a}\right) \tag{34}$$

Let us first assume that the most profitable deviation is $\left(\hat{a},\hat{b}\right) = \left(0,\bar{b}\right)$, to be checked after. Then, it implies that the following inequality must be satisfied:

$$\begin{aligned}
Q^{ab}\left(\overline{\phi}|\overline{\phi},\bar{b},Y\right) \quad &> \quad \frac{u(0,0)-u\left(0,\bar{b}\right)}{\delta\left(\overline{\omega}-\underline{\omega}\right)p_0} + \frac{p_0Q^{ab}\left(\overline{\phi}|\overline{\phi},0,Y\right)+(1-p_0)\,Q^{ab}\left(\overline{\phi}|\overline{\phi},0,X\right)}{p_0} \\
&\quad -\frac{1-p_0}{p_0}Q^{ab}\left(\overline{\phi}|\overline{\phi},\bar{b},X\right) \\
&> \quad \frac{u(\overline{a},0)-u\left(0,\bar{b}\right)}{\delta\left(\overline{\omega}-\underline{\omega}\right)p_0} + \frac{p_{\overline{a}}Q^{ab}\left(\overline{\phi}|\overline{\phi},0,Y\right)+(1-p_{\overline{a}})^{ab}\,Q\left(\overline{\phi}|\overline{\phi},0,X\right)}{p_0} \\
&\quad -\frac{1-p_0}{p_0}Q^{ab}\left(\overline{\phi}|\overline{\phi},\bar{b},X\right)
\end{aligned}$$

From Eq. (34), we obtain:

$$\sum_{z_{t+1}\in Z}\left(\left(\Pr\left(z_{t+1}|\bar{a}\right)-\Pr\left(z_{t+1}|0\right)\right)\sum_{\phi_{t+1}\in\Phi}\omega\left(\phi_{t+1}\right)Q^{ab}\left(\phi_{t+1}|\overline{\phi},\bar{b},z_{t+1}\right)\right)=\frac{u\left(0,\bar{b}\right)-u\left(\bar{a},\bar{b}\right)}{\delta} \tag{35}$$

Note that, under decreasing differences utility, $u\left(0,\bar{b}\right)-u\left(\bar{a},\bar{b}\right)<u\left(0,0\right)-u\left(\bar{a},0\right)$, by using Eqs. (28) and (35), the following inequality holds:

$$Q^{ab}\left(\overline{\phi}|\overline{\phi},\bar{b},X\right)-Q^{ab}\left(\overline{\phi}|\overline{\phi},\bar{b},Y\right)<Q^{a}\left(\overline{\phi}|\overline{\phi},\cdot,X\right)-Q^{a}\left(\overline{\phi}|\overline{\phi},\cdot,Y\right)$$

To have $\upsilon^{ab}_{\max}$ higher than $\upsilon^{ab}_{\min}$ we require:

$$\sum_{z_{t+1}\in Z}\sum_{\phi_{t+1}\in\Phi}\omega\left(\phi_{t+1}\right)Q^{ab}\left(\phi_{t+1}|\overline{\phi},\bar{b},z_{t+1}\right)\Pr\left(z_{t+1}|0\right) > \frac{u\left(0,0\right)-u\left(0,\bar{b}\right)}{\delta}+\underline{\omega} \tag{36}$$

$$\sum_{z_{t+1}\in Z}\sum_{\phi_{t+1}\in\Phi}\omega\left(\phi_{t+1}\right)Q^{ab}\left(\phi_{t+1}|\overline{\phi},\bar{b},z_{t+1}\right)\Pr\left(z_{t+1}|\bar{a}\right) > \frac{u\left(0,0\right)-u\left(\bar{a},\bar{b}\right)}{\delta}+\underline{\omega} \tag{37}$$

From Eq. (36) we obtain:

$$Q^{ab}\left(\overline{\phi}|\overline{\phi},\bar{b},Y\right)>\frac{u\left(0,0\right)-u\left(0,\bar{b}\right)}{\delta\left(\overline{\omega}-\underline{\omega}\right)p_0}-\frac{1-p_0}{p_0}Q^{ab}\left(\overline{\phi}|\overline{\phi},\bar{b},X\right) \tag{38}$$

whereas from Eq. (37) it follows that:

$$Q^{ab}\left(\overline{\phi}|\overline{\phi},\bar{b},Y\right)>\frac{u\left(0,0\right)-u\left(\bar{a},\bar{b}\right)}{\delta\left(\overline{\omega}-\underline{\omega}\right)p_{\bar{a}}}-\frac{1-p_{\bar{a}}}{p_{\bar{a}}}Q^{ab}\left(\overline{\phi}|\overline{\phi},\bar{b},X\right) \tag{39}$$

Finally, using Eq. (35), the following condition must hold:

$$Q^{ab}\left(\overline{\phi}|\overline{\phi},\bar{b},Y\right)=Q^{ab}\left(\overline{\phi}|\overline{\phi},\bar{b},X\right)-\frac{u\left(0,\bar{b}\right)-u\left(\bar{a},\bar{b}\right)}{\delta\left(\overline{\omega}-\underline{\omega}\right)\left(p_0-p_{\bar{a}}\right)} \tag{40}$$

Using Eqs. (38), (39) and (40), self-enforceability of $\bar{a}=a$ and $\bar{b}=b$ can be sustained in equilibrium as long as:

$$Q^{ab}\left(\overline{\phi}|\overline{\phi},b,X\right)=1 \text{ and } Q^{ab}\left(\overline{\phi}|\overline{\phi},b,Y\right)=1-\frac{u\left(0,b\right)-u\left(a,b\right)}{\delta\left(\overline{\omega}-\underline{\omega}\right)\left(p_0-p_a\right)} \tag{41}$$

where $\delta\geq\delta^{ab}\equiv\frac{u(0,b)-u(a,b)}{(\overline{\omega}-\underline{\omega})(p_0-p_a)}$. If $\delta<\delta^{ab}$ then only $\bar{a}=0$ and $\bar{b}=0$ can be enforced in equilibrium. Plugging Eq. (41) into constraint (i) we obtain the result.

Finally, we need to check the guess, by determining the conditions under which the most profitable deviation is $\left(\hat{a},\hat{b}\right)=\left(0,\bar{b}\right)$. Given that $\upsilon^{ab}_{\max}$ is not affected by $Q\left(\overline{\phi}|\overline{\phi},0,z_{t+1}\right)$, we impose the following restriction:

$$Q\left(\overline{\phi}|\overline{\phi},0,z_{t+1}\right)=0,\ \forall z_{t+1} \tag{42}$$

Clearly, under Eq. (42) $(\bar{a},0)$ cannot be the most profitable deviation. Indeed, agents by choosing $(0,0)$ can achieve higher payoff. However, if the best profitable deviation were $\left(\hat{a},\hat{b}\right)=(0,0)$ then in equilibrium only $\overline{a}=0$ and $\bar{b}=0$ can be enforced. Consequently, condition (42) is sufficient to state our result. ■

Lemma (3). Given $\Pi \equiv \upsilon_{\max}^{ab} - \upsilon_{\max}^{a}$, by using Eqs. (12), (15), (20) and (24) and rearranging, we obtain:

$$\begin{aligned}\Pi &= -\left(u\left(a,0\right)-u\left(a,b\right)\right)-\delta\left(1-p_a\right)\left(\omega\left(a,0\right)-\omega\left(a,b\right)\right) \\ &\quad +\delta p_a\left[\bar{\mu}^{ab}\left(\omega\left(a,b\right)-\omega\left(0,0\right)\right)-\bar{\mu}^{a}\left(\omega\left(a,0\right)-\omega\left(0,0\right)\right)\right]\end{aligned} \tag{43}$$

By contradiction, suppose $\bar{\mu}^{a} > \bar{\mu}^{ab}$ then the third term of Eq. (43) turns out to be negative, i.e. $\bar{\mu}^{ab}\left(\omega\left(a,b\right)-\omega\left(0,0\right)\right)-\bar{\mu}^{a}\left(\omega\left(a,0\right)-\omega\left(0,0\right)\right) < 0$, and consequently $\Pi < 0$. ■

Proposition (3). The conditions $\Pi \geq 0$, $\bar{\mu}^{a} \geq 0$ and $M \neq \varnothing$ require solving the following system of inequalities:

$$\begin{cases} p_a \geq \frac{\delta(\omega(a,0)-\omega(a,b))+(u(a,0)-u(a,b))}{\delta(\omega(a,0)-\omega(a,b))+(u(0,0)-u(0,b))}p_0 \\ p_a \leq p_0 - \frac{u(0,0)-u(a,0)}{\delta(\omega(a,0)-\omega(0,0))} \\ p_a \leq \frac{\delta(\omega(a,b)-\omega(0,0))-(u(0,0)-u(a,b))}{\delta(\omega(a,b)-\omega(0,0))-(u(0,0)-u(0,b))}p_0 \end{cases} \tag{44}$$

Let us denote $P \subseteq [0,1]^2$ the parametric space such that for each $(p_0, p_1) \in P$, the conditions reported in Eq. (44) are simultaneously satisfied. If:

$$\delta > \underline{\delta} \equiv \frac{u\left(0,0\right)-u\left(0,b\right)}{\left(\omega\left(a,b\right)-\omega\left(0,0\right)\right)-\left(\frac{u(0,b)-u(a,b)}{u(0,0)-u(a,0)}\right)\left(\omega\left(a,0\right)-\omega\left(0,0\right)\right)}$$

then $P \neq \varnothing$. ■

Corollario (1). To determine the set of equilibrium payoff Γ_1^a in the case of one period memory over public signals, we solve the linear programming problem reported in Proposition (1). The main difference is that in this case the transition probability maps into the next-period state by conditioning only on the realization of the last public signal, i.e. $Q^a\left(\phi_{t+1}|\cdot,\cdot,z_{t+1}\right)$. The worst sustainable payoff is equal to:

$$\upsilon_{\min}^{a} \equiv u\left(\underline{a},\underline{b}\right)+\delta\sum_{z_{t+1}\in Z}\sum_{\phi_{t+1}\in\Phi}\omega\left(\phi_{t+1}\right)Q^a\left(\phi_{t+1}|\cdot,\cdot,\ z_{t+1}\right)\Pr\left(z_{t+1}|\underline{a}\right)$$

It must satisfy with equality the following incentive compatible constraint:

$$\upsilon_{\min}^{a} \geq u\left(\bar{a},\bar{b}\right)+\delta\sum_{z_{t+1}\in Z}\sum_{\phi_{t+1}\in\Phi}\omega\left(\phi_{t+1}\right)Q^a\left(\phi_{t+1}|\cdot,\cdot,z_{t+1}\right)\Pr\left(z_{t+1}|\bar{a}\right) \tag{45}$$

At the same time the best sustainable payoff is equal to:

$$\upsilon_{\max}^{a} \equiv u\left(\bar{a},\bar{b}\right)+\delta\sum_{z_{t+1}\in Z}\sum_{\phi_{t+1}\in\Phi}\omega\left(\phi_{t+1}\right)Q^a\left(\phi_{t+1}|\cdot,\cdot,\ z_{t+1}\right)\Pr\left(z_{t+1}|\bar{a}\right)$$

It must satisfy with equality the following incentive compatible constraint:

$$\upsilon_{\max}^{a} \geq u\left(\underline{a},\underline{b}\right)+\delta\sum_{z_{t+1}\in Z}\sum_{\phi_{t+1}\in\Phi}\omega\left(\phi_{t+1}\right)Q^a\left(\phi_{t+1}|\cdot,\cdot,z_{t+1}\right)\Pr\left(z_{t+1}|\underline{a}\right) \tag{46}$$

Eqs. (45) and (46) imply that $\upsilon_{\max}^{a} = \upsilon_{\min}^{a}$, and therefore $\Gamma_1^a = \{\upsilon^{aut}\}$. ■

Corollary (2). To determine the set of equilibrium Γ_1^{ab} in the case of one period memory over public signals, we solve the linear programming problem reported in Proposition (2). The worst sustainable equilibrium payoff is $v^{ab}_{\min} = v^{aut}$ and, therefore, $(\underline{a}, \underline{b}) = (0, 0)$. Note that, equivalently to Proposition (2), as long as agents have at least two-period memory over the self-commitment action exerted by the previous generations, the transition probability maps the current state, the last self-commitment action and the realization of the last public signal into the next-period state, i.e. $Q^{ab}\left(\phi_{t+1}|\phi_t, b_t, z_{t+1}\right)$. Differing from Corollary (1), the expectational coordination over self-commitment actions enables to discriminate between two states. Consequently $Q^{ab}\left(\overline{\phi}|\overline{\phi}, 0, z_{t+1}\right) = 0\ \forall z_{t+1}$ can be sustained in equilibrium. Following steps of Proposition (2), self-enforceability of $\bar{a} = a$ and $\bar{b} = b$ can be sustained in equilibrium as long as $Q^{ab}\left(\overline{\phi}|\overline{\phi}, b, X\right) = 1$ and $Q^{ab}\left(\overline{\phi}|\overline{\phi}, b, Y\right) = 1 - \frac{u(0,b)-u(a,b)}{\delta(\overline{\omega}-\underline{\omega})(p_0-p_a)}\ \forall\ \delta \geq \delta^{ab} \equiv \frac{u(0,b)-u(a,b)}{(\overline{\omega}-\underline{\omega})(p_0-p_a)}$. ■

Proposition (4). To identify the conditions for $\gamma^S(b) > 0$. Given that $\gamma^S(0) = 0$, it is sufficient to find out the conditions under which $\frac{\partial \gamma^S(b)}{\partial b} > 0$, that implies $\frac{\partial \mathcal{C}(a,b)}{\partial b} < 0$.

$$\frac{\partial \mathcal{C}(a,b)}{\partial b} = \psi_b d(a,b)$$

where $d(a,b) \equiv u_c(\psi(b)) - (1-a)\, u_c(\psi(b)(1-a))$. Note that $d(0,b) = 0$ for each b, then to determine the sign of $d(a,b)$ we simply have to evaluate the relative impact of the a-decision:

$$\frac{\partial d(a,b)}{\partial a} = u_c(\psi(b)(1-a)) + \psi(b)(1-a)\, u_{cc}(\psi(b)(1-a)) \tag{47}$$

Eq. (47) can be rewritten as follows:

$$\frac{\partial d(a,b)}{\partial a} = 1 - \rho$$

It follows that, there are four possible economy configurations which depend on: i) Dynamic inefficiency (or efficiency), i.e. $\psi_b > (\leq) 0$, and ii) relative risk-aversion greater (or lower) than one, i.e. $\rho \geq (<) 1$, as follows:

1. If $\psi_b > 0$ and $\rho \geq 1$, then $\gamma^S(b) \geq 0$;
2. If $\psi_b \leq 0$ and $\rho \geq 1$, then $\gamma^S(b) \leq 0$;
3. If $\psi_b > 0$ and $\rho < 1$, then $\gamma^S(b) \leq 0$;
4. If $\psi_b \leq 0$ and $\rho < 1$, then $\gamma^S(b) \geq 0$.

■

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