USING ENVIRONMENTAL KNOWLEDGE BROKERS TO PROMOTE DEEP GREEN AGRI-ENVIRONMENT MEASURES

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Using Environmental Knowledge Brokers to Promote Deep Green Agri-environment Measures

Paolo Melindi-Ghidi* Tom Dedeurwaerdere† Giorgio Fabbri‡

Abstract

Intermediary organisations have increasingly played a role in payments for agri-environment services across Europe over the last two decades. However, the economics literature has so far not examined the impact of this new governance mechanism on environmental protection and on individuals' behaviour. We develop a new theoretical economic framework to compare an incentive mechanism using intermediaries, such as environmental knowledge brokers and information providers, with a standard central governance mechanism, in terms of environmental impact. We show that the emergence of knowledge intermediaries is particularly effective where farmers initially have low environmental awareness, or when the public institution organising the scheme is insufficiently aware of individuals' characteristics. Our findings provide theoretical support for previous empirical results on payment schemes for agri-environment measures.

Key words: Knowledge Brokers, Intermediaries, Pro-environmental Culture, Agri-environment Measures, Cultural Transmission, Principal-agent.

JEL Classification: Q51, Q58, Z19.

1 Introduction

Agricultural policy is widely recognised as instrumental in preserving and enhancing sustainability and biodiversity. The EEC Agri-environment Council Regulation of 30 June 1992 on agricultural production methods strongly improved the Common Agricultural Policy (CAP) in the European Union (EU), introducing various targets to offset the loss of biodiversity and to improve environmental awareness among farmers. Since 1992, several policy tools have been developed to mitigate

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the environmental impact of agriculture. One of the main agricultural policy instruments to address environmental objectives within the CAP is represented by the Agri-environment schemes (AES). The main objective of AES is to provide financial support for Member States to implement policies able to encourage farmers to protect and enhance the environment on their farmland by paying them for the provision of environmental services. These payments, called agri-environment measures (AEMs), are provided by national or regional governments to farmers who subscribe to environmental commitments related to the preservation of the environment.[1]

The implementation of the Agri-environment schemes is done following the general subsidiarity principle governing the EU. Member States or Regions (as appropriate) allocate the EU funds to a selected set of national or regional measures, according to the rules specified in the applicable EU regulations (EU) 1305/2013 and (EU) No 1307/2013. In practice, two main governance mechanisms operate currently in Europe to incite farmers to adhere to the scheme (Chapman and Tripp, 2003). First, administrative agents from the public authority directly inform individual farmers on potential payments from applying environmentally-friendly farming practices, under a centralised governance mechanism. Second, the authority uses private non-profit organisations or individuals to create links with the farmers, delegating to these organisations the advisory services for implementing the agri-environmental services, under a knowledge broker governance mechanism. The latter practice has been accompanied by the proliferation of networks of support organisations for EU agri-environment policies. Often set up as service-oriented businesses by non-profit organisations, these knowledge brokers provide screening activities for public administrations as well as valuable social learning and knowledge for farmers.

The current system of advisory services, although effective, is still not sufficiently developed and deserves to be better targeted to actively contribute to meeting EU environmental and climate objectives (Meredith and Har, 2019). In this context, current discussion in the EU on the post-2020 CAP policy aims to strengthen this system of farm advisory services through a double mechanism (cf. the EC proposal COM(2018) 392 final). First, according to the EC's proposal, Members States or Regions should integrate advisors within the national Agricultural Knowledge and Innovation Systems. In particular, future CAP Strategic Plans should provide information on how advisory services, research and rural networks can work together, and each Member State or Region can fund actions to improve such collaborations. Second, the environmental sustain-

[1]See European Commission, Council Regulation (EC) No 1698/2005 of 20 September 2005.

ability purposes of the system is strengthened and emphasized throughout the Commission's proposal. The future policy therefore clearly aims to adopts a broader perspective on the support to knowledge brokers, by integrating farm advice in a broad network of advisory services, research organisations and rural networks with environmental purposes.

An empirical analysis of the emergence of networks of knowledge brokers was first undertaken by Dedeurwaerdere et al. (2015). Using a series of structured in-depth field interviews with farmers adhering to certain agri-environment schemes, they found that farmers involved in knowledge co-production and social learning processes organised by non-profit bridging organisations showed a strong improvement both in adoption of environmental practices and in adhesion to deep green (farther-reaching) AEMs. The analysis was conducted in the Walloon Region in Belgium, who selected 11 AEM for which farmers can receive payments and implemented a network of agri-environmental advisors across the Region (cf. more detail on the policy in Dedeurwaerdere et al., 2015). In this paper, we perform a dynamic theoretical analysis of this phenomenon, confirming the findings of Dedeurwaerdere et al. (2015) and suggesting policy implications for promoting environmentally-friendly behaviour in the farming population. We also characterize the economic conditions that encourage certain degrees of policy effectiveness of the proposed strengthening of the network of farm advisory services in the CAP beyond 2020.

To account for the important role of non-profit service providers in the knowledge networks, this paper uses an interdisciplinary approach. First, by building upon insights of evolutionary anthropology (Cavalli-Sforza and Feldman, 1981), sociology (Paley, 1996) and behavioural economics (Henrich et al., 2005), a certain persistence of acquired cultural traits - such as pro-environmental preferences - is supposed across different generations of farmers, the so-called hypothesis of imperfect empathy (cf. the discussion below and the overview in Bisin and Verdier, 2011). Second, by building upon insights from social economy (Anheier, 2006) and organizational sociology (Innes and Booher, 2010), the decision making of the non-profit service providers does not follow a logic of financial or organizational growth as the main incentive, but is also based on a preference for activities with the highest societal return as regards to its contribution to increasing environmental effectiveness of the AEM policy. By doing so, this paper aims to increase our understanding of the decision-making processes of non-profit knowledge service providers under the implementation cost constraints of the CAP.

In the specific context of the AES, two main payment schemes for environmental services can be distinguished:[2] *light green* AEMs (for instance, preserving hedge rows or isolated trees in the existing landscape) and *deep green* AEMs (such as preservation of local breeds or restoring natural grasslands). The former involve low ecological effects with low payments, while the latter are clearly important for the long-term environmental effectiveness of the policy but involve high payments. Deep green AEMs can greatly contribute to social-environmental returns, but they can be successfully carried out only if farmers actively participate by making a specific environmental effort (Vanslembrouck et al., 2002; Defrancesco et al., 2008; Burton et al., 2008; Poláková et al., 2011).

Bartolini and Vergamini (2019) survey the large theoretical and empirical literature on the different factors that are significant in determining the probability of participation to AEMs. Among the main mechanisms which can explain adoption of agri-environment schemes, both the level of transaction costs related to the expected mode of adoption (Wünscher et al., 2008, Mettepenningen et al., 2009) as well as the farmer's preferences and values (Espinosa-Goded et al., 2010) are important determinants. In particular, in a context where the possibility of ex-ante commitment is low, a key role is played by farmers' pro-environmental preferences. As the public authorities have only incomplete information on these preferences, they cannot determine ex-ante the optimal amount and form of knowledge brokering through a centralized support mechanism. In this paper, we argue for the advantage of adopting a decentralized and evolutionary perspective on the need for knowledge brokers, as farmers' pro-environmental preferences can co-evolve with the evolving network of non-profit advisory services. In particular, we aim to analyse to what extent cultural transmission processes between farmers can further amplify the impact of a decentralized network of knowledge brokers on the evolution of the farmers' preferences.

Real-world cultural transmission in the case of participation to AEM is complex and it includes amplification of new preferences through several social network and social learning mechanisms (Dedeurwaerdere et al., 2015; Bartolini and Vergamini, 2019). This paper analyses this reality using a variation of the model developed by Bisin and Verdier (2001). This mechanism is well established in the literature on economic models of evolution of other-regarding and pro-societal preferences (Francois and Zabojnik, 2005; Sáez-Martí and Sjögren, 2008; Olcina and Peñarrubia,

[2] The classification of AEMs in two main categories is a simplification for modelling purposes. However, a similar classification is also used by the European Commission (2005), distinguishing between broad brush (light green) versus deep and narrow (dark green) schemes. In reality, more complex combinations are financed even though these two categories already capture certain important features of the existing payment schemes made possible under the CAP.

2004). Differently from standard evolutionary models where the parent's values play no role in determining evolutionary selection, it allows for outcomes leading to lower pecuniary rewards, as can be the case for pro-environmental farming practices. It considers the transmission of new preferences from one generation of farmers to another through two channels: a *direct* (vertical) socialization, i.e. socialization within the family, and a *horizontal* (oblique) socialization, i.e. in society at large. This stylized form allows, at the same time, to consider a wide societal transmission process and to put the accent on the familiar context which is particularly appropriate given the characteristics of the farming system in the European Union, where (data from Eurostat, 2016) the vast majority of farms (96.2 % of 10.8 million farms in the EU-28 in 2013) are classified as family farms. In other words, in the structure of the model, the role of preference formation within the family is an important cultural mechanism that determines the probability of participation to AEM, even though other mechanisms and different channels, such us the society at large, play a fundamental role. In particular, the social norm that will play an important role in our theoretical setting is the *environmental consciousness*, a cultural value that the previous generation can choose to teach to the new one even though it leads to lower economic rewards.[3]

The model is dynamic and decisions about the cultural transmission take into account future context so that they are influenced by all the preferences and structural parameters of the economy and, this is one of the main point of the our argument, by the policy choices. The same learning mechanism gives very different outcomes depending on the situation. Of course the model remains stylized but it provides some precious insights on decision making by farmers and non-profit service providers under the CAP, within given cost implementation constraints. It has to be in any case understood as a part of an integrated and fully interdisciplinary approach which requires to account from other perspectives for the long term and society wide change processes that are determined by a broad set of motives such as social identity and ethical argumentation among others (Vatn, 2007).

In this paper we propose a theoretical model which is an application of the theory of private provision of a public good *i.e.* environmental quality, in the agri-environmental context. We distinguishes between two basic observable farmer behaviours: making and not making an environmental effort, reflecting preferences for protecting or not the environment. Then, we assume

[3]The psychological literature has already analysed the role of pro-environmental individual behaviours (Stern, 2000). Following Zelezny and Schultz (2000) we refer to environmental awareness as a specific psychological factor related to the propensity to engage in pro-environmental behaviours.

that farmers' preferences in terms of the environment are acquired through a cultural transmission process across generations. We study two possible governance mechanisms enabling the public legislator to promote environmental awareness among farmers to ensure the environmental effectiveness of the policy. In the first (Section 2), it is possible to change the cost structure to promote the emergence of a network of environmental intermediaries such as knowledge brokers. In the second (Section 3), instead of financing intermediaries, the resources are transferred to local/regional institutions which use their budgets to identify how many farmers are likely to adopt deep green measures and provide the knowledge and advice themselves. The advantage of this latter policy is that the farmers fully know the level of knowledge support they will receive. Instead of depending upon an evolving population of knowledge brokers, this support is laid down in government policy.

Our objective is to compare the environmental effectiveness of those two governance mechanisms. We explore (Section 4) under which conditions the emergence of a network of knowledge brokers is more effective than a central governance mechanism in terms of diffusion of deep green agri-environment measures and of support for pro-environmental attitudes. We show that the process of socialisation between farmers and brokers may increase the proportion of pro-environmental farmers, thereby enhancing the impact of the environmental policy. This effect is particularly likely where there is limited knowledge of farmers' characteristics and preferences, and low initial environmental awareness. We also argue that developing the broker network can help escape the "low environmental awareness traps" that can arise with more traditional compensation schemes. Our results constitute a theoretical counterpart to the empirical findings of Dedeurwaerdere et al. (2015) both in farmers' behaviours and of policy effectiveness.

1.1 Contribution to Existing Literature

This work is the first to model the dynamic relationship between the emergence of environmental knowledge intermediaries and the evolution of farmers' willingness to change their management practices. It links the knowledge-brokering theory developed in the literature on environmental science with the process of individual preference formation developed in the economics literature. The former (see for instance Shapin, 1998, Sverrisson, 2001, Meyer, 2010 and, in a slightly different context, Klerkx et al., 2012, Dedeurwaerdere et al., 2016) has mainly concentrated on the rise of knowledge brokers as a means to connect researchers and their audiences, such as decision- and policy-makers. The main focus of the analysis in this literature is the existence of complementarities between different kind of knowledge providers and knowledge types, and the role of knowledge brokers in building collaborative networks between these providers. However, much less analysis has been made of the social learning effects of knowledge brokers, in a field characterized by a high level of scientific uncertainty and controversy over social values such as sustainability. The literature on preference formation in economics on the other hand is based on adapting models of evolutionary biology to the transmission of cultural traits as initiated by Cavalli-Sforza and Feldman (1981) and introduced into the economics literature, also in a dynamic context, by Bisin and Verdier (1998, 2001). Models of preference evolution have been applied to several contexts in the economics literature, such as for instance the evolution of ethnic traits (Bisin and Verdier, 2000, and Bisin et al., 2004), corruption (Hauk and Saez-Marti, 2002), social capital (Francois and Zabojnik, 2005), political ideology (Melindi-Ghidi, 2012), perceptions of pollution (Bezin, 2015), environmental preferences (Litina et al., 2016).

The governance mechanism through which agricultural payments are implemented in an economic context is modelled as an application of the theory of private provision of public good (Bergstrom et al., 1986). Several works in this literature have already analysed the importance of environmental groups in providing environmental public goods (Heyes, 1997, Sundberg, 2006, Grant and Langpap, 2019). However, the role of intermediary organisations in the context of payments for agri-environmental services in providing environmental amenities is still unsettled.

Our paper also contributes to the growing literature on the link between culture and institutional rules of organisations (Bisin and Verdier, 2017) applied to agri-environment issues. In particular, it allows co-determination of the equilibrium on non-profit organisation markets and the distribution of preferences showing how institutional rules affect farmer cultures. As such, our model also provides a theoretical approach to the literature on new modes of regulation based on more participatory and co-constructed modes of public intervention (Young, 2000; Gidron et al., 1992).

The paper proceeds as follows. Section 2 develops the theoretical model of the emergence of a network of knowledge brokers promoting deep green AEMs. Section 3 examines the standard governance model, in which local public institutions autonomously decide which AEMs to offer to farmers. Section 4 compares the two scenarios to reveal policy implications. Section 5 performs possible extensions. Section 6 concludes. Proofs of the results are contained in Appendix A.

2 The Economy with Environmental Intermediaries

We model a situation where the policy-maker decides to promote the emergence of a network of environmental intermediaries such as knowledge brokers, to which it partly delegates the implementation of agri-environment policy.

2.1 Farmers' Types

We consider an overlapping generation economy with discrete time where farmers live two period: in the childhood they are educated (and will be subject to the mechanism of cultural transmission that we will describe in detail below) while in the adulthood they make all economic choices. We suppose that there is no population growth and that the size of each generation is normalized to 1. Each farmer voluntarily subscribes to agri-environment measures (AEMs) and receives a monetary transfer for the provision of environmental services, such as protecting and enhancing their farmland environment. Farmers differ in their preferences: they can have pro-environmental preferences (and we will use in this case the terminology "e-type agent/farmer") or non pro-environmental preferences (n-type). We denote by $i \in \{e, n\}$ the farmer's type:

$$i = \begin{cases} \text{e} & \text{pro-environmental preferences} \\ \text{n} & \text{non pro-environmental preferences.} \end{cases}$$

We will assume that the farmers' characteristics are private: neither the state nor the intermediaries can observe them ex-ante.

2.2 Light and Deep Green Agri-environment Measures

At time t a unit of environmental intermediaries is born as well. They live only for one period. The intermediaries liaise between the public institution and the farming population.

We assume that the public legislator allocates an amount $x^b > 0$ of monetary resources to non-profit intermediaries for any project aimed at providing the knowledge support required to implement certain agri-environment measures. These intermediaries are able to choose autonomously whether to offer support to farmers for either a deep green AEM (Project 1) or a light green AEM (Project 2). Although a same organization can provide different types of knowledge support, in practice organisations or individuals within organisations specialize in certain fields of technical and administrative expertise (Meredith and Har, 2019). For modelling purposes we therefore consider two types of specialized knowledge advice services, respectively for deep green and light green measures, which can be provided by a same organization or different organsations.

We call *(environmental) knowledge brokers* all those social enterprises or intermediaries that ensure the availability of knowledge enabling deep green environmental actions to be put into practice and that thus (only) offer farmers projects of type 1. Conversely, we call *(environmental) information providers* those that specialise in information provision for light green measures and that (only) offer farmers projects of type 2. We denote by b_t the proportion of knowledge brokers in the economy. Summarising we have the following for Project r, with $r \in \{1, 2\}$:

$$\text{r} = \begin{cases} 1 \quad \text{deep green AEM} & \text{provided by knowledge brokers} \\ & \text{(proportion } b_t \text{ of intermediaries)} \\ 2 \quad \text{light green AEM} & \text{provided by information providers} \\ & \text{(proportion } 1 - b_t \text{ of intermediaries).} \end{cases}$$

2.3 Cost of the Measures

Realising a type r Project is costly. More precisely, we assume that the measure involves two different costs: a fixed cost $\bar{k}_r$ for some positive constants $\bar{k}_1 > \bar{k}_2$ (we assume that a deep green AEM requires higher fixed initial investments) and implementation costs. Since the costs of implementing deep green AEMs are higher, for the sake of analytical tractability we set the implementation costs of light green AEMs equal to zero. We assume that the implementation costs of a deep green AEM depend on the proportion b_t of knowledge brokers in the economy, therefore expressed as $s[b_t]$. Evidence suggests that intermediaries bear the costs of providing knowledge while farmers bear the cost of learning to efficiently realise the measure. We therefore denote by β (respectively $1 - \beta$) the exogenous share of total implementation costs of deep green AEMs borne by the intermediary (respectively farmer).

Since targeting a green deep AEM becomes more difficult the larger the number of knowledge brokers in the economy, with the obvious candidates already identified by other intermediaries, it is reasonable to assume that $s[\cdot]$ is an increasing function of b_t.[4] We assume that $s[b_t] \geq 0$,

[4] This assumption is in line with an extensive literature on the costs of agricultural extension services and is based on two main factors. First, only a small sub-group of specialist farmers voluntary invest time and money in working with the knowledge brokers. For the other categories of farmers, the added value is less direct, and

$s[0] = 0$, $s'[b_t] > 0$, $s''[b_t] \geq 0$. The total cost borne by a farmer properly implementing a deep green AEM is

$$k_1 \equiv k_1[b_t] = \bar{k}_1 + (1 - \beta)s[b_t] \quad (1)$$

while the cost to farmers properly implementing a light green AEM is simply

$$k_2 = \bar{k}_2 > 0. \quad (2)$$

2.4 Farmers' Preferences

At each time t, each broker liaises with a single farmer. Brokers support farmers with an initial direct payment $y_r > 0$. There is a probability b_t that a farmer will receive support from a knowledge broker for a deep green AEM. The probability is $(1-b_t)$ that the farmer will be matched with an information provider offering a light green AEM. The farmer can choose whether or not to properly implement the project. In the first case the cost to the farmer is given by (1) or (2), while in the second case the cost is equal to zero. Thus, a farmer's monetary payoff equals the difference between the direct payment y_r received for implementing an agri-environment measure and the cost of putting the measure into practice, that is $y_r - \chi k_r$, $r = 1, 2$, with $y_1 > y_2$ and χ taking the value of 1 (respectively, 0) if the farmer decides (respectively, not) to make the investment effort.

Farmers' well-being does not only depend on pecuniary payments or monetary costs: we assume that farmers with pro-environmental preferences will experience a decrease in well-being from adopting non pro-environmental behaviour since they are endowed with "environmental awareness" and have a non-pecuniary psychological decrease in utility, $\gamma > 0$, when behaving non pro-environmentally at time t.[5] Utilities for e-type and n-type agents are given in Tables 1 and 2. As already observed, the preferences of the farmers are private, so the intermediaries do not know them before offering the project. Moreover, after a knowledge broker proposes a project

the knowledge brokers have to make additional efforts to convince them (Chapman and Tripp, 2003). Second, knowledge brokers might have an impact on a series of additional conditions, such as the existence of reputation networks (Sereke et al., 2016) and collective action networks to change practices in socio-technical agricultural production networks (Hellin, 2012).

[5]This intrinsic parameter is a fundamental component of many individuals' utility and it has already been recognised in the socio-psychological and socio-economic literature. See, for instance, Schlegelmilch et al. (1996), Mainieri et al. (1997), Lubell (2002), Ferrara and Serret (2008), Fourcade (2011), García-Valiñas et al. (2012).

to a farmer, she cannot control the farmer's actions, and of course cannot oblige the farmer to make the effort. The only incentive to make the effort will come from the farmer's potential pro-environmental preferences.

Table 1: Utility of an e-type farmer

e-type farmer	realises a Project 1	realises a Project 2
behaves pro-environmentally	$V_1^{ee} := y_1 - k_1[b_t]$	$V_2^{ee} := y_2 - \bar{k}_2$
behaves non pro-environmentally	$V_1^{en} := y_1 - \gamma$	$V_2^{en} := y_2 - \gamma$

Table 2: Utility of an n-type farmer

n-type farmer	realises a Project 1	realises a Project 2
behaves pro-environmentally	$V_1^{ne} := y_1 - k_1[b_t]$	$V_2^{ne} := y_2 - \bar{k}_2$
behaves non pro-environmentally	$V_1^{nn} := y_1$	$V_2^{nn} := y_2$

As can be observed from Table 2, an n-type farmer will never behave pro-environmentally.[6] However, incentive compatibility necessarily implies that farmers will make the necessary investment for the AEM if they are pro-environmental (e-type). We therefore introduce an assumption guaranteeing that the dominant strategy for e-type agents is to always act pro-environmentally.

Assumption 1. *The environmental awareness of the pro-environmental farmer is such that:* $\gamma > max\{k_1^u; \bar{k}_2\}$, *with* $k_1^u = \bar{k}_1 + (1-\beta)s[1]$.

2.5 Socialisation Choice and Cultural Evolution of Preferences

In this section we explain how the determination of individual traits works, drawing from the mechanism of cultural transmission developed in the economics literature by Bisin and Verdier (2001).[7] We assume that each farmer has one child that becomes active in the next period and participates in the implementation of some AEMs. Hence, the total farming population is stationary. As explained above, individuals differ in terms of preferences for the environment formed through a stochastic socialisation process across generations.

[6]Sanctions imposed by the institutions could be included in the current version of the model. As far as the observability of the effort, the level of the sanction and the probability of incurring it in the case of non-compliance with the commitment is such that the dominant strategy of the farmer is not altered, the main results of the paper are not affected. This seems to be a quite realistic situation if we look for instance at the results of Dedeurwaerdere et al. (2015) in Table 4.

[7]The selection of this specific mechanism aims to show the impact of cultural transmission on the amplification of the effect of knowledge brokers on the evolution of the preferences. As explained in the introduction, in the real world, stronger amplification occurs through more complex mechanisms of transmission.

We denote by q_t (respectively $(1-q_t)$) the proportion of pro-environmental (respectively non pro-environmental) farmers in the population. It is reasonable to assume that the preference distribution in the population, i.e. q_t, is common knowledge. Children are born naïve and are subject to a process of socialisation that influences their preferences. The socialisation process works as follows: parents socially condition their children to have the same preferences as themselves by making certain socialisation efforts (also equal to the probability of successfully transmitting their cultural traits) τ_t^i with $i \in \{e, n\}$: e pro-environmental and n non pro-environmental. If parents fail to condition their children to their trait, an indirect socialisation mechanism provides a probability of $1-\tau_t^i$ that the children's traits will be determined by imitating a random adult outside the family. If we denote by p_t^{ij} the probability that a child of parent i will adopt trait j, we can thus write the transition probabilities as follows:

$$p_t^{ee} = \tau_t^e + (1-\tau_t^e)q_t; \quad p_t^{en} = (1-\tau_t^e)(1-q_t); \tag{3}$$

$$p_t^{nn} = \tau_t^n + (1-\tau_t^n)(1-q_t); \quad p_t^{ne} = (1-\tau_t^n)q_t. \tag{4}$$

and then, in particular,

$$q_{t+1} = q_t p_t^{ee} + (1-q_t)p_t^{ne} = q_t(\tau_t^e + (1-\tau_t^e)q_t) + (1-q_t)(1-\tau_t^n)q_t = q_t + q_t(1-q_t)(\tau_t^e - \tau_t^n) \tag{5}$$

We follow the literature on cultural transmission by assuming that parents suffer from a particular form of myopia called *imperfect empathy* (see Bisin and Verdier, 1998). This implies that parents want children of the same type because they evaluate the future welfare of their children through the filter of their own preferences. This means, for instance, that e-type farmers will evaluate their child's welfare based on e-type preferences according to Table 1: if, for example, the child in the next period is type n (and will therefore behave non pro-environmentally), the parent will evaluate her utility at $y_1 - \gamma$ for Project 1 and $y_2 - \gamma$ for Project 2.

We denote the expected utility at time t of an i-type parent having a j-type child by W^{ij}. Parents' expected utility depends on both the type and the matching outcome of the child, but also on the probability b_t of matching up with a knowledge broker willing to implement a deep green AEM. Its formal expression is given by:

$$W^{ij}[b_t] = b_t V_1^{ij} + (1 - b_t) V_2^{ij} \tag{6}$$

with $(i, j) \in \{e, n\}$ and $(1, 2)$ the project offered by the intermediary. The values of V_1^{ij} and V_2^{ij} are given in Tables 1 and 2.

Socialisation effort τ_t^i is costly. We denote by $C(\tau^i)$ the socialisation cost functions and suppose that each individual chooses $\tau_t^i \in]0, 1]$ to solve the following maximisation problem:

$$max_{\tau^i} \left(p_t^{ii} W^{ii}[b_t] + p_t^{i\iota} W^{i\iota}[b_t] - C(\tau_t^i) \right). \tag{7}$$

being ι defined as follows: $\iota = 2$ if $i = 1$ and $\iota = 1$ if $i = 2$. Maximising (7) with respect to τ^i leads to a standard first-order condition of cultural transmission:

$$C'(\tau_t^i) = \frac{\partial p_t^{ii}}{\partial \tau_t^i} W^{ii}[b_t] + \frac{\partial p_t^{i\iota}}{\partial \tau_t^i} W^{i\iota}[b_t]. \tag{8}$$

We will concentrate on the case $C(\tau) = \frac{1}{2}\tau^2$, which is the simplest cost structure, often used as a benchmark in the literature on cultural transmission. Solving equation (8) for the e-type and n-type agent, we derive the following socialisation effort functions:

$$\begin{cases} \tau_t^e = (1 - q_t)(W^{ee}[b_t] - W^{en}[b_t]) \\ \tau_t^n = q_t(W^{nn}[b_t] - W^{ne}[b_t]), \end{cases} \tag{9}$$

Using the definition of W^{ij} given in (6) and the expressions of V_r^{ij} in Tables 1 and 2, we get $W^{ee}[b_t] - W^{en}[b_t] = \gamma - b_t(\bar{k}_1 + (1-\beta)s[b_t]) - (1-b_t)\bar{k}_2 > 0$ and $W^{nn}[b_t] - W^{ne}[b_t] = b_t(\bar{k}_1 + (1-\beta)s[b_t]) + (1-b_t)\bar{k}_2 > 0$ so that, using (9), we get $(\tau_t^e - \tau_t^n) = \gamma(1-q_t) - b_t(\bar{k}_1 + (1-\beta)s[b_t]) - (1-b_t)\bar{k}_2$ and then expression (5) becomes

$$q_{t+1} - q_t = q_t(1 - q_t)[\gamma(1 - q_t) - b_t(\bar{k}_1 + (1 - \beta)s[b_t]) - (1 - b_t)\bar{k}_2]. \tag{10}$$

As in standard evolutionary models, we will concentrate on the continuous time limit version of this dynamic, namely

$$\frac{dq_t}{dt} = q_t(1-q_t)[\gamma(1-q_t) - b_t(\bar{k}_1 + (1-\beta)s[b_t]) - (1-b_t)\bar{k}_2]. \tag{11}$$

The above differential equation describes the motion of q_t in the population. To study the full dynamics of the model, we introduce the dynamic behaviours of intermediaries.

2.6 Behaviour of Environmental Intermediaries

As previously noted, each intermediary receives the same monetary transfer x^b to support a particular AEM.[8] When a knowledge broker is able to offer a deep green AEM to a farmer who will provide the necessary investment effort to realise the measure, implementation is successful and generates a positive social-environmental return. This return, $\psi > 0$, is the 'environmental effectiveness' achieved by intermediaries and institutions when a deep green AEM is properly implemented. For the sake of simplicity, we fix the return at zero in the case of implementation of light green environmental measures. In our model, in fact, light green AEMs generate a much less significant social-environmental return since these measures are not able to provide substantial social-environmental benefit.

We then denote by π_1 and π_2 the intermediary's return on a single interaction with a farmer, respectively when a Project 1 and a Project 2 is offered. From the above, we have $\pi_1 = x^b - y_1 - \beta s[b_t] + \chi\psi$ and $\pi_2 = x^b - y_2$ where the parameter χ takes the value of 1 (respectively, 0) if the farmer decides (respectively, not) to make the investment effort.[9]

Intermediaries only know the preference distribution in the population, i.e. q_t. However, as noted above, since cultural traits and preferences are not observable, they do not know *a priori* the preference of any specific farmer. The expected return on a Project 1 to a knowledge broker is then given by $\Pi_1[b_t] = q_t(x^b - y_1 - \beta s[b_t] + \psi) + (1-q_t)(x^b - y_1 - \beta s[b_t])$. Conversely, the return on a Project 2 does not depend on agent type and is always $\Pi_2 = \pi_2 = x^b - y_2$.

Following Francois and Zabojnik (2005), we suppose that producers adjust instantaneously to changes in the economy. This is a reasonable assumption if we accept that socio-economic

[8] Note that monetary transfers cannot be lower than the expenditure on implementation by the knowledge brokers, since the pay-off of each intermediary can be interpreted as payments for knowledge or information activities.

[9] Observe that the described form of the return formalises our assumption that intermediaries are non-profit social enterprises. Intermediaries will try to maximise pay-off where a social utility term $\chi\psi$ appears: they are not profit-maximisers but they also aim to achieve environmental goals.

opportunities allow intermediaries to change their behaviour (i.e. their decision to specialise and become 'knowledge brokers' or 'information providers') relatively quickly compared to the speed at which inherent cultural traits change. When $\Pi^b[b_t] \equiv \Pi_1[b_t] - \Pi_2 = q_t\psi - (\beta s[b_t] + (y_1 - y_2)) > 0$, some intermediaries have an incentive to become 'knowledge brokers' and offer Project 1 rather than remaining 'information providers' and offering Project 2, and *vice versa* when $\Pi^b[b_t] < 0$. Only when $\Pi^b[b_t] = 0$ does no intermediary have any incentive to change strategy, so the proportion b_t adjusts as follows:

$$b_t = g[q_t] \equiv \begin{cases} 0 & \text{if } (q_t\psi - (y_1 - y_2))/\beta < s[0] \\ s^{-1}[(q_t\psi - (y_1 - y_2))/\beta] & \text{if } (q_t\psi - (y_1 - y_2))/\beta \in [s[0], s[1]] \\ 1 & \text{if } (q_t\psi - (y_1 - y_2))/\beta > s[1]. \end{cases} \quad (12)$$

Note that if any intermediary finds it profitable to offer Project 2, then the social network of knowledge brokers will not be formed. The highest value of q_t leading to non-formation of the social network of knowledge brokers (that is, the highest value of q_t that corresponds to $b_t = 0$ in (14)) is given by $q^0 = \frac{(y_1 - y_2) + \beta s[0]}{\psi}$. Conversely, the lowest value of q_t at which all intermediaries decide to offer Project 1 is given by $q^1 = \frac{(y_1 - y_2) + \beta s[1]}{\psi}$. To guarantee that both q^0 and q^1 belong to $]0, 1[$ we need a last assumption on parameter values.

Assumption 2. *The social return generated by the environmental effectiveness of successful implementation of a deep green AEM is sufficiently high:* $\psi > (y_1 - y_2) + \beta s[1]$.

Assumption 2 guarantees that deep green AEMs implemented by a farmer who makes the necessary investment effort yield higher expected returns for intermediaries than light green AEMs.

2.7 Dynamics

The dynamic properties of our economy can be analysed by using relation (11) together with (14). We get the following dynamic equation :

$$\frac{dq_t}{dt} = q_t(1 - q_t)[\gamma(1 - q_t) - g[q_t](\bar{k}_1 + (1 - \beta)s[g[q_t]]) - (1 - g[q_t])\bar{k}_2]. \quad (13)$$

The direction of the evolutionary dynamics will depend on both the role of knowledge brokers in the implementation processes of deep green AEMs and the socialisation effort of parents.

It is reasonable to concentrate only on the scenario in which one of the two traits is not always selected irrespective of the environment. In other words, in line with the theory developed in Bisin and Verdier (2001), we need to exclude parameter choices such that one trait culturally dominates. For this reason, we introduce the following assumption.

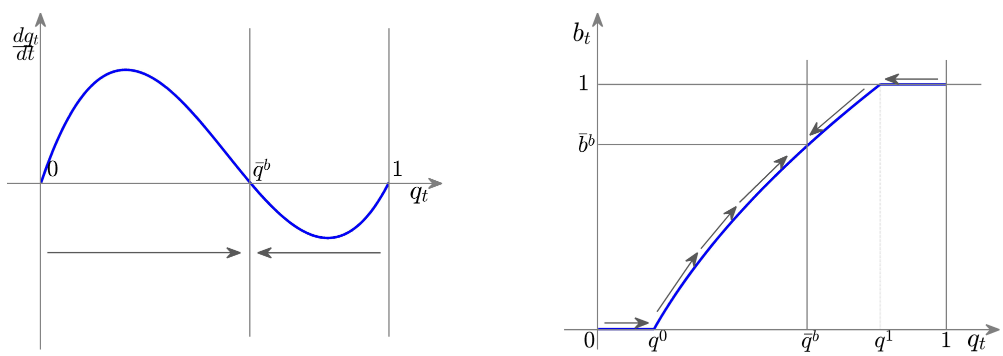
Assumption 3. *Evolutionary forces are such that no cultural trait is dominant:*

$$1 - \frac{(y_1 - y_2)}{\psi} > \frac{\bar{k}_2}{\gamma} \qquad \textit{and} \qquad 1 - \frac{(y_1 - y_2) + \beta s[1]}{\psi} < \frac{\bar{k}_1 + (1-\beta)s[1]}{\gamma}.$$

Proposition 1. *Suppose that Assumptions 1, 2 and 3, are satisfied. Then the system described by (13) admits three steady states:* 0, 1 *and a unique interior steady state* $\bar{q}^b$. *Moreover, for any initial condition* $q_0 \in]0,1[$, q_t *converges to* $\bar{q}^b$. *At the steady state* $\bar{q}^b$, *a network of knowledge brokers of size* $\bar{b}^b \in]0,1[$ *is formed.*

Proof. See Appendix A for the formal proof, and Figure 1 for the graphical representation of the dynamics. □

Figure 1: Phase diagram: internal solution



In Figure 1 we see the dynamics described in the Proposition 1. In the left part we have, on the horizontal axis, the value of q_t and, in y-axis, the derivative of q_t with respect to time. In correspondence of $\bar{b}^b$ the time derivative of the value of q_t is zero and in fact $\bar{b}^b$ is a steady state. On the other hand, we can see that for values of q_t smaller than $\bar{b}^b$ the derivative of q_t is positive and so its value increases with time until it reaches $\bar{b}^b$. Conversely, for levels of q_t above $\bar{b}^b$ its value decreases over time converging again to $\bar{b}^b$. Either for initial values of q_t above or below $\bar{b}^b$

the system tends, in the long run, to settle on the value $\bar{b}^b$. This is represented the right part of the figure where the dynamics of the variables q_t and b_t over time is is represented by the arrows.

As stated in the proposition, at the stable steady state $\bar{q}^b$, a network of knowledge brokers of size $\bar{b}^b \in]0,1[$ is formed. This network provides evolutionary incentives to have a proportion of pro-environmental agents equal to

$$\bar{q}^b = \frac{\gamma - \bar{b}^b((1-\beta)s[\bar{b}^b] + \bar{k}_1) - \bar{k}_2(1-\bar{b}^b)}{\gamma} \in]0,1[.$$

If, for instance, at time $t = 0$ the economy is characterised by a low proportion of knowledge brokers and b_0 is below its steady state level $\bar{b}^b$, then knowledge and learning costs are relatively low. Since the targeting of a pro-environmental farmer is more likely, we will observe an increase in the proportion of knowledge brokers that will promote an environmental culture in the next generation. Conversely, even when there is a high proportion of pro-environmental agents at time $t = 0$, if $b_0 > \bar{b}^b$, some intermediaries will find it profitable to avoid investment in the implementation of deep green AEMs. The reason is that with a high proportion of knowledge brokers it is harder to target a deep green measure and implementation costs will be high. Therefore, some intermediaries will offer Project 2 in the next period rather than Project 1. The decreasing presence of knowledge brokers in the economy will reduce the proportion of pro-environmental parents willing to make an effort to transmit this trait. Because of these two opposing trends, we observe an equilibrium position where the higher learning costs entailed in getting the remaining farmers on board exceeds the societal benefits that can be attained and claimed by the knowledge brokers.

Two more (non-interior) steady states appear in the dynamics: the two boundary points $q = 0$ and $q = 1$ corresponding to the two trivial situations where, respectively, the whole farming population is of type n or of type e.[10] Still, neither of these two steady states is stable, and once the initial state of the system is perturbed, the dynamics will converge to the unique stable steady state $\bar{q}^b$.

A natural question, already raised for example by Bisin and Verdier (2001) in their seminal contribution, is the relation between the direct parents (or *vertical*) transmission and the indirect (or *oblique*) transmission. Bisin and Verdier (2001) observe that, in their model, a convergence

[10] Of course, when all farmers are the same type neither the direct nor the indirect socialisation mechanism can cause deviation from the norm and we have a steady state.

toward an internal steady state, *i.e.* a long-run heterogeneous distribution of cultural traits, arises when vertical transmission acts as a cultural substitute to oblique transmission. We argue here that the result of Proposition 1 is in the line with this claim. In terms of our model the mentioned substitutability reads as a negative impact of an increase of q_t on the value of τ^e that is a negative sign in the derivative (see (9)) $\frac{d\tau^e}{dq_t} = \left[(1-q_t)\frac{d(W^{ee}[b_t]-W^{en}[b_t])}{dq_t}\right] - [W^{ee}[b_t] - W^{en}[b_t]]$. There are two opposite forces at play. First, a complementarity effect (which corresponds to the the first addendum in the derivative expression) since an increase of b_t directly increases q_t by increasing the probability that the child will meet a knowledge broker. Second, a substitutability effect (the second addendum) because implementation costs are increasing in the fraction of knowledge brokers b_t. Due to the model structure, we observe that substitutability always dominates complementarity. Indeed τ^e as a function of q_t and of the parameters can be written (using (9), Tables 1 and 2 and (14)) as $(1-q_t)(\gamma - g[q_t](\bar{k}_1 - \bar{k}_2) - (1-\beta)s[g[q_t]] - \bar{k}_2)$ and both the terms $(1-q_t)$ and $(\gamma - g[q_t](\bar{k}_1 - \bar{k}_2) - (1-\beta)s[g[q_t]] - \bar{k}_2)$ are positive (the latter thanks to Assumption 1) for $q_t \in (0,1)$ and decreasing in q_t and so it is their product. This means that the complementarity effect is always outweighed by the substitutability effect. In line with the result of Bisin and Verdier (2001) Proposition 1 shows that in the model we have a long-rung convergence toward an internal steady state.

3 Central Governance Policy

The emergence of knowledge brokers within the process of implementation of deep green AEMs could strongly impact both the policy choices of the public authorities and the long-run evolution of pro-environmental preferences among farmers. The standard alternative to giving intermediaries an active role is to transfer resources to local public authorities who then directly pay farmers for implementing AEMs, without knowledge support. We assume that in a central governance policy scenario, the local public institution receives from the public legislator (e.g. European Union) a fixed amount of resources equal to x^c for the implementation of any project.[11]

Our framework with a central governance mechanism is very close to the model of Hauk and Saez-Marti (2002) as well as to the standard principal-agent model of Tirole (1996). Similarly, we assume that, even if the preferences of all farmers are not common knowledge, the local institution

[11] The local public authorities provide direct payments y_r to develop projects of type r. Hypotheses on the structure of $s[\cdot]$ and Assumption 1 still hold.

knows whether the farmer being offered a project is non pro-environmental with an exogenous positive probability of $\phi > 0$. We also assume that the institutions know the distribution of traits in the population, q_t. As in the previous section, Project 1 yields a higher return than Project 2 if the former project is offered to a pro-environmental agent due to the production of environmental effectiveness, $\psi > (y_1 - y_2)$. However, in this scenario it is the local public institution that directly manages the agri-environment measure payments. Thus, the social returns defined in the previous section are obtained by the public institution if the match is successful.

Public authorities can adopt either a pooling strategy or a separating strategy. A pooling strategy consists in offering either Project 1 or Project 2 to all the farmers. A separating strategy consists in offering a deep green AEM to seemingly pro-environmental farmers, and a light green AEM to farmers who are found (probability ϕ) to be non pro-environmental, assuming that the dominant strategy of potentially non pro-environmental farmers is to behave non pro-environmentally, that is $0 < \phi < \frac{\bar{k}_1}{(y_1 - y_2)}$. For Project 1, the public institution's return from a single successful match is $\pi_1 = x^c - y_1 + \chi\psi$, where χ takes the value of 1 (respectively, 0) if the farmer decides (respectively, not) to make the investment effort while, for Project 2, $\pi_2 = x^c - y_2$. We denote by $\pi_1^e = x^c - y_1 + \psi$ and $\pi_1^n = x^c - y_1$ the return under Project 1 if the farmer targeted is respectively pro-environmental or non pro-environmental. The expected aggregate returns from the pooling strategy of offering Project 1 and Project 2 are, respectively, $\Pi_1^p = q_t\pi_1^e + (1 - q_t)\pi_1^n$ and $\Pi_2^p = \pi_2$ while the expected aggregate return from the separating strategy is $\Pi^s = q_t\pi_1^e + \phi(1 - q_t)\pi_2 + (1 - \phi)(1 - q_t)\pi_1^n$. Clearly, the pooling strategy of offering Project 1 will never be chosen by rational institutions seeking to maximise the aggregate expected return, since $\Pi^s > \Pi_1^p$ for all $q \in]0, 1[$.

Comparing Π^s with Π_2^p we can derive the threshold that determines the optimal strategy of the principal in each period of time t. Indeed, the institution will implement a separating strategy if the share of pro-environmental farmers at time t is sufficiently high: $\frac{(1-\phi)(y_1-y_2)}{\psi-\phi(y_1-y_2)} < q_t < 1$. Define $\tilde{q}[\phi] \equiv \frac{(1-\phi)(y_1-y_2)}{\psi-\phi(y_1-y_2)}$. The institution can change strategy over time, depending on the evolution of cultural traits in the population. More precisely, if at time t the proportion of pro-environmental agents is sufficiently high, $q_t > \tilde{q}[\phi]$, it will offer a separating strategy. Otherwise, that is $\tilde{q}[\phi] > q_t$, the public institution will find it optimal to offer a light green AEM to all the agents.

To characterise the steady state of this economy, we need to take into account the fact that the parents' behaviour in the socialisation process depends on the decision taken by the public institution. As in the previous section, we assume that imperfect empathy holds, socialisation effort τ_t^i is costly, and socialisation costs are given by $C(\tau^i) = \frac{1}{2}{\tau^i}^2$. Adapting equations (8)-(9) and (11) to this standard principal-agent scenario, after some algebraical manipulation (see the proof of Proposition 2 for details), we derive the usual corner steady states $\bar{q} = 0$, $\bar{q} = 1$ and two new non-corner steady states: the first, $\bar{q}^s = 1 - \frac{\bar{k}_1 - \phi(y_1 - y_2)}{\gamma}$, arises if a separating strategy is implemented in the long run while the second, $\bar{q}^p = 1 - \frac{\bar{k}_2}{\gamma}$, is the result of a strategy of long-run pooling of Project 2.

We summarise the parameter restrictions introduced and discussed in previous paragraphs in this section in the following assumption.

Assumption 4. *The probability of recognising a non pro-environmental farmer is such that* $0 < \phi < \frac{\bar{k}_1}{(y_1 - y_2)}$. *Moreover* $\psi > y_1 - y_2$.

Proposition 2. *Under Assumption 4, a central governance policy exhibits the following dynamic properties:*

(i) if $\tilde{q}[\phi] < \min(\bar{q}^p, \bar{q}^s)$ *then* q_t *converges to* $\max(\bar{q}^p, \bar{q}^s)$*;*

(ii) if $\tilde{q}[\phi] > \max(\bar{q}^p, \bar{q}^s)$ *then* q_t *converges to* $\min(\bar{q}^p, \bar{q}^s)$*;*

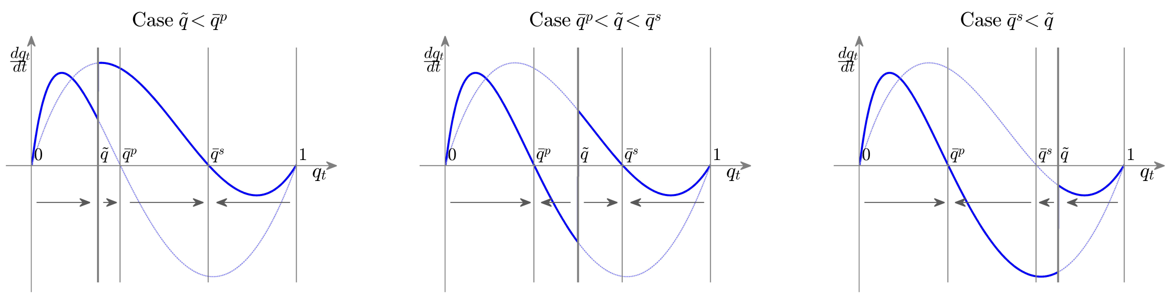
(iii) if $\min(\bar{q}^p, \bar{q}^s) < \tilde{q}[\phi] < \max(\bar{q}^p, \bar{q}^s)$*, expectations are stationary and the long-run equilibrium depends on initial conditions: (iii.a)* q_t *converges to* $\max(\bar{q}^p, \bar{q}^s)$ *when* $q_0 > \tilde{q}[\phi]$*; (iii.b)* q_t *converges to* $\min(\bar{q}^p, \bar{q}^s)$ *when* $q_0 < \tilde{q}[\phi]$.

Proof. See Appendix A for the formal proof, and Figure 2 for a graphical representation of the dynamics in the case $\bar{q}^s > \bar{q}^p$. □

In Figure 2 we see the dynamics described in the Proposition 2 in the case $\bar{q}^s > \bar{q}^p$ (a completely similar representation is obtained in case $\bar{q}^s < \bar{q}^p$). It is divided into three parts depending on the relative values of $\bar{q}^p$, $\bar{q}^s$ and $\tilde{q}$. In each part we have, on the horizontal axis, the value of q_t and, in y-axis, the derivative of q_t with respect to time. In each both the separating and the pooling strategies are represented in blue and we highlighted with a thicker line the chart corresponding to the strategy chosen by the public institution: for $q_t < \tilde{q}[\phi]$ the separating strategy, for $q_t > \tilde{q}[\phi]$ the pooling strategy where the public institution only offer light green AEM.

The left image correspond to part (i) of Proposition 2: if $\tilde{q}[\phi] < \bar{q}^p < \bar{q}^s$) then the unique internal value for which the value of the time-derivative is zero (i.e. the unique internal steady

Figure 2: Dynamics: The Central Governance Policy



state) is $\bar{q}^s$; the derivative is positive for values smaller than $\bar{q}^s$ and negative for values higher than $\bar{q}^s$ so, for initial conditions lower than $\bar{q}^s$ the value of q_t increases with time until it reaches $\bar{q}^s$; conversely, for levels of q_t above $\bar{q}^s$ its value decreases over time converging again to $\bar{q}^s$ (this behaviour is emphasized by the arrows which in the lower part of the picture). The right image, which corresponds to point (ii) of of Proposition 2 describes the situation where $\bar{q}^p < \bar{q}^s < \tilde{q}[\phi]$. Also in this case there is only an internal steady state but it corresponds now to $\bar{q}^b$. Similarly to what happens in the first image the value of q_t tends to converge in the long-run to the internal steady state. The situation is a little more elaborated in the middle image (which is the case $\bar{q}^p < \tilde{q}[\phi] < \bar{q}^s$ and corresponds to point (iii) of Proposition 2) where there are two distinct possible internal steady states. The value of q_t tends to increases when q_t is in the intervals $(0, \bar{q}^p)$ and $(\tilde{q}[\phi], \bar{q}^s)$ while it is decreasing on $(\bar{q}^p, \tilde{q}[\phi])$ and $(\bar{q}^s), 1)$ so that, in the long-run, the value o q_t converges to $\bar{q}^p$ if its initial value is in $(0, \tilde{q}[\phi])$ and to $\bar{q}^s$ if its initial value is in $(\tilde{q}[\phi], 1)$.

Note that the threshold that determines the principal's behaviour negatively depends on the probability of identifying a non pro-environmental farmer in the population, ϕ. When ϕ is low, the threshold $\tilde{q}[\phi]$ for the separating strategy is high. This scenario can be characterised by a situation in which, even when there is a high initial proportion of pro-environmental farmers, the dynamics converges to the low pro-environmental steady state with pooling $\min(\bar{q}^p, \bar{q}^s)$. The reason is quite intuitive: pro-environmental parents do not try hard to condition their children to their preference, because the lower the probability of identifying pro-environmental farmers, the more profitable it becomes to be non pro-environmental. Note also that the central governance policy implies a different long-run equilibrium distribution of environmental preferences compared to policy of using knowledge brokers described in Proposition 1.

4 Discussion: Emergence of Brokers' Networks *versus* Institutional Governance

The decision by the public legislator to stimulate the emergence of intermediaries rather than to use a more traditional direct subsidy scheme is a matter of controversy. One of the main debates is over these different policies' benefits and costs. The presence of intermediaries could require larger investments by the legislator, such as payments for the organisation of learning. However, the public institution might find it profitable to promote this governance mechanism if one of its main objectives is to seek the social benefits of environmental effectiveness and the promotion of a pro-environmental culture.

To compare the two policies, we look at what happens when the two per-project transfers x^b and x^c, and thus the costs of the two policies, are the same. In this case, the public legislator's decision to adopt a central governance policy rather than investing extra resources to finance intermediaries depends on the level of benefits generated by the environmental effectiveness of the implementation of deep green AEMs. We concentrate on the long-run proportion of pro-environmental farmers and the long-run number of (per-period) successfully implemented deep green AEMs as measures of the total environmental effectiveness generated by different policies. We have the following result.

Proposition 3. *Suppose that Assumptions 1, 2, 3 and 4 are verified. Then*

(i) There exists a threshold value for ϕ, denoted by Ψ, such that the emergence of a network of knowledge brokers generates more environmental effectiveness in the long run compared to the institutional governance policy if and only if ϕ is smaller than Ψ. Moreover a change in the parameters that increases the level of $\bar{b}^b$ without affecting other fundamental values increases Ψ.

(ii) The lower the initial share q_0 of pro-environmental agents, the larger the set of parameters ensuring that the emergence of a network of knowledge brokers generates more environmental effectiveness in the long run compared to institutional governance.

Proof. See Appendix A. □

The first point of the proposition compares the efficiency of the two systems in terms of their capacity to promote a pro-environmental culture and a greater number of successfully implemented deep green AEMs. The parameter ϕ measures the probability, in the central governance context, of correctly matching a non pro-environmental farmer with a light green project, and therefore it measures how well the policy maker knows the farmers' preferences. The more capable the local public institution is of correctly analysing the context, the less need there is for external skills and for experts like brokers. On the other hand, the system of intermediaries is more valuable if it is more extensive and diffuse. In that situation, the number (or, equivalently, the share $\bar{b}^b$) of knowledge brokers working in the economy at equilibrium will be higher as well. In other words, the larger (long run) the network size $\bar{b}^b$ of knowledge brokers, the higher the threshold Ψ, so the easier it is for the network of knowledge brokers to generate more environmental effectiveness in the long run compared to a central governance policy. These results are consistent with (and support) the empirical finding of Dedeurwaerdere et al. (2015) (Table 4) which shows that (i) governmental monitoring and (ii) bridging organisations have a positive impact on the decisions of farmers to comply with deep/light green measures.

The second part of the proposition shows that it is even more important to promote a broker network when farmers' initial environmental awareness is low, making the presence of intermediaries even more effective in "unblocking" the system. This can lead to further benefits: in certain situations, the network of knowledge brokers can provide an escape route from a certain low-equilibrium trap. This is the case for instance when $\min(\bar{q}^p, \bar{q}^s) < \tilde{q}[\phi] < \max(\bar{q}^p, \bar{q}^s)$ and $q_0 < \tilde{q}$. Again, our findings offer theoretical support for the empirical results of Dedeurwaerdere et al. (2015), highlighting the effectiveness of intermediaries in convincing farmers to change their agri-environment choices.

5 Possible Extensions of the Model

While we kept the model in its simplest form to clearly present and discuss the mechanisms at work, a series of extensions are possible. We present here some of them describing how to adapt the arguments we used in the text and if and how they impact the results.

5.1 Including Implementation Costs for Light Green Projects

In Subsection 2.3 we supposed that implementation costs for light green projects are zero. This is a simplifying assumption which is justified by the fact that, in the proposed setting, the costs of implementing light green measures are very low compared to deep green measures. Nevertheless we can see how to change the study if we introduce an additional implementation cost of $k_2^I > 0$ for light green measures.

Consistently with the hypothesis we made in Subsection 2.3 for the implementation costs between farmer and intermediary in the case of deep green measures, we suppose that a part β (respectively $(1-\beta)$) of this new cost is borne by the intermediary (respectively the farmer) and we define k_2 (previously defined as in (2)), similarly to (1):

$$k_2 = \bar{k}_2 + (1-\beta)k_2^I.$$

The solution of the model with implementation costs for light green measures follows the same lines of the solution of the version we have in Sections 2, 3 and 4 with a few modifications:

(i) k_2 appears in Tables 1 and 2 instead of $\bar{k}_2$ and in Assumption 1.

(ii) The quantity $\tilde{y}_2 := y_2 - \beta k_2^I$ appears, instead of y_2, in Subsections 2.4, 2.6 and 2.7 (notably in in Assumptions 2 and 3) and in Sections 3 and 4.[12]

Once this is done the model is formally identical to the model we have studied in Sections 2, 3 and 4 and, given the continuity of the problem, the qualitative results are robust for sufficiently small values of $k_2^I > 0$, as it is rational to assume.

5.2 Including Environmental Return for Light Green Projects

In the version of the model we solved in Sections 2, 3 and 4, unlike deep green projects that have an potential environmental return of ψ, light green projects does not give any environmental returns, even when implemented by a farmer with pro-environmental preferences.

In reality it is possible to include the environmental return for light green projects too. We can indeed add, in the expression of π_2 in Subsection 2.6 a term $\chi\psi_2$ being $\psi_2 < \psi$ the environmental return for a light green project. In this case we have $\pi_2 = x^b - y_2 + \chi\psi_2$. The term appears consequently in the expression of $\Pi^b[b_t]$ which becomes

$$\Pi^b[b_t] \equiv \Pi_1[b_t] - \Pi_2 = q_t(\psi - \psi_2) - (\beta s[b_t] + (y_1 - y_2)) > 0.$$

[12]In Subsection 2.4 in principle one has to keep the value y_2 but observe that in that section all that matters are the differences between the utilities in the tables. Indeed changing y_2 with $\tilde{y}_2$ wouldn't make any difference to farmers' behaviour there and everywhere in the paper).

From that point on, starting from (14) and then in Subsection 2.7 and Sections 3 and 4 the arguments for the model integrating the two returns remains exactly the same just changing at each recurrence ψ with $\tilde{\psi} := \psi - \psi_2$. In particular, as far as $\tilde{\psi}$ continue to satisfy Assumptions 2, 3 and 4, the qualitative behaviours of the system remain the same.

5.3 Complementarity of Environmental Returns and Pure Public Good

In the model (in the version of Sections 2, 3 and 4 not including the ψ_2 introduced in Subsection 5.2) the total provision of the environmental quality is measured by

$$\Psi := q_t \psi$$

that is the sum of the private provisions of the farmers. This public good does not enter in the utility of the agents. A first way to include the welfare gain due to the services of the environmental quantity is to introduce an additional utility term $u(\Psi)$ in the expressions of the utilities of the agents (think for instant to the simplest linear case $u(\Psi) = \theta\Psi$). This first possibility does not change much the behaviour of the agents (it has the effect of a variation in the parameters that is smaller the higher the number of the agents and zero in the infinitely many agents case).

A second possibility is to suppose (this is rather common in the literature) that there exists some form of utility-complementarity in the provisions of agents. One could think for instance to change the utility term $\chi\psi$ appearing in the brokers' utility with $\chi h(q_t)\psi$ for some increasing function $h(\cdot)$. As a staring point one could think to the identity function $h(q_t) = q_t$ and to the infinitely many agents case. In this very specific case (and similarly for a family of specification indeed) our results are pretty robust:

- Nothing changes in the behaviour of the farmers (both if we add or not add an equal term to each possibility of Tables 1 and 2).

- The expression of $\Pi_1[b_t]$ (Subsection 2.6) becomes $\Pi_1[b_t] = q_t(x^b - y_1 - \beta s[b_t] + q_t\psi) + (1 - q_t)(x^b - y_1 - \beta s[b_t])$ so that $\Pi^b[b_t]$ becomes $q_t^2\psi - (\beta s[b_t] + (y_1 - y_2))$ and

$$b_t = g[q_t] \equiv \begin{cases} 0 & \text{if } (q_t^2\psi - (y_1 - y_2))/\beta < s[0] \\ s^{-1}[(q_t^2\psi - (y_1 - y_2))/\beta] & \text{if } (q_t^2\psi - (y_1 - y_2))/\beta \in [s[0], s[1]] \\ 1 & \text{if } (q_t^2\psi - (y_1 - y_2))/\beta > s[1]. \end{cases} \quad (14)$$

- The values of q_0 and q^1 (see again Subsection 2.6) become $q^0 = \sqrt{\frac{(y_1-y_2)+\beta s[0]}{\psi}}$ and $q_1 = \sqrt{\frac{(y_1-y_2)+\beta s[1]}{\psi}}$ (the square roots of the values we have in Subsection 2.6) so that the Assumption 1 is again the right condition to ensure them to be in $(0, 1)$.

- The qualitative behaviour of g does not change because both $q_t \mapsto q_t\psi$ and $q_t \mapsto q_t^2\psi$ are increasing functions so all the subsequent arguments remain the same with the same set of assumption and the same propositions continue to hold.

Something might change. More precisely:

- The values of the various thresholds ($\bar{q}^b$, $\bar{q}^s$, $\tilde{q}$) change in value and possibly also in relative value (so we could switch in the regime in Proposition 3).

- The speeds of convergence of the system (both in the brokers' and in the institutional governance specification) change.

When the specification of $h(\cdot)$ is more complex the things can change substantially, for instance Assumption 1 could not be anymore sufficient to assure the system to remain in the interval $(0, 1)$ and the value of $\bar{q}^b$ could not be anymore internal and then we could loose the heterogeneous long-run equilibrium situation.

6 Conclusion

The network of knowledge intermediaries is a vital component of many implementation mechanisms for the agri-environment measures conceived under the EU Common Agricultural Policy. The objective of these mechanisms is to better reallocate monetary resources to farmers implementing deep green agri-environment measures. In this paper we study the emergence of the intermediaries' network, its interaction with the dynamics of farmers' environmental preferences, and its impact on policy effectiveness. Ours is the first theoretical analysis connecting the knowledge-brokering theory developed in environmental science with the process of transmission of individual preferences developed in the economics literature. By introducing pro-environmental motives at the level of the farmers and the knowledge brokers decision making, the paper highlights the contribution of non-profit knowledge service providers to increasing the environmental effectiveness of the AEM measures under the CAP.

In particular, we compare the effect of a policy of promoting a decentralized network of non-profit knowledge brokers with that of a more traditional subsidy scheme where the local public institutions autonomously decide which kind of knowledge support to allocate to each farmer. We show that the emergence of intermediaries is particularly effective, as compared to a centralized governmental criteria based subsidy scheme, where knowledge of the farmers' characteristics and preferences is limited, and where there is low initial environmental awareness.

Our results have important implications for implementation policies. They suggest that relying on intermediaries will provide higher environmental quality when knowledge of the farmers' characteristics is poor. The lower the probability of the public institution being able to correctly match environmental projects with farmers' profiles, the more desirable the network of environmental intermediaries. Developing the broker network can be a way to escape a "low environmental awareness traps" in which too few deep green projects are run, as can arise under more traditional compensation schemes. These results clearly indicate that the emergence of intermediaries is a particularly effective policy option where initial farmers' preferences are not very eco-friendly.

As stated above, this paper studies a model of cultural transmission of pro-environmental traits among farmers from one generation to another. Possible extensions of the analysis could include models with stronger amplifications which are likely to occur through more complex mechanisms of cultural transmission, especially in the context of the proposed measures under the CAP post 2020, where increased support for integrating rural networks, research and farm advisory services is foreseen. However, the insights gained from our model help us to ameliorate our understanding of the decision making process of non-profit knowledge service providers under the implementation cost constraints of the CAP.

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A Proofs

Proof of Proposition 1. Define the function $F\colon [0,1] \to [0,1]$ which is given by

$$F(q) = q(1-q)\left(\gamma(1-q) - g[q](\bar{k}_1 + (1-\beta)s[g[q]]) - (1-g[q])\bar{k}_2\right).$$

The steady states of (13) are the values of q that satisfy the condition $F(q) = 0$. Two of these steady states are given by $q = 0$ and $q = 1$. Moreover, if we look at the expression

$$G(q) \equiv \left(\gamma(1-q) - g[q](\bar{k}_1 + (1-\beta)s[g[q]]) - (1-g[q])\bar{k}_2\right)$$

, we can easily see that:

(i) Its value is strictly positive in 0 (thanks to Assumption 1 and the fact that $g[0] = 0$)

(ii) Its value is strictly negative in 1 (recall that $g[1] = 1$)

(iii) It is strictly decreasing in the interval $[0,1]$. To see this we can rewrite the expression as

$$\left(\gamma(1-q) - g[q](\bar{k}_1 - \bar{k}_2) - (1-\beta)g[q]s[g[q]] - \bar{k}_2\right).$$

Since g and s are increasing functions and $\bar{k}_1 > \bar{k}_2$ by hypothesis, each term of the previous expression is decreasing (and the first one strictly decreasing).

Since the expression is continuous we have a third steady state that is interior (and unique due to (iii)). We call this $\bar{q}^b$. Since $q(1-q)$ is always positive in $]0,1[$ the sign of the $F(q)$ only depends on the sign of $G(q)$ which due to (i), (ii) and (iii) above, is strictly positive on $]0, \bar{q}^b[$ and strictly negative on $]\bar{q}^b, 1[$ so for any initial condition $q_0 \in]0,1[$ q_t converges to $\bar{q}^b$ when $t \to \infty$.

It only remains to prove that in the steady state $\bar{q}^b$ a network of knowledge brokers is formed, i.e. that $g[\bar{q}^b] > 0$. We will actually show that $g[\bar{q}^b] \in]0,1[$. To see this it is enough to check that $G(q^0) > 0$ and $G(q^1) < 0$, i.e. that $\gamma\left(1 - \frac{(y_1-y_2)}{\psi}\right) - \bar{k}_2 > 0$ and $\gamma\left(1 - \frac{(y_1-y_2)+\beta s[1]}{\psi}\right) - (\bar{k}_1 + (1-\beta)s[1]) < 0$. These conditions are verified thanks to Assumption 3. $\square$

Proof of Proposition 2. As in the case of the economy with knowledge brokers (Section 2), the dynamics of the system is given by

$$\frac{dq_t}{dt} = q_t(1-q_t)(\tau_t^e - \tau_t^n)$$

and we can argue as we did to get (11). Since the cost function is given once more by $C(\tau) = \frac{1}{2}\tau^2$, we can get, as in (9),

$$\tau_t^e = (1 - q_t)(W_t^{ee} - W_t^{en}) \qquad \text{and} \qquad \tau_t^n = q_t(W_t^{nn} - W_t^{ne}). \tag{15}$$

where the coefficients W_t^{ij} are defined similarly to those appearing in (6) but now, instead of being $(1-b_t)$, the probability of a Project 2 being proposed is now 1 for all agents in the pooling case and 0 for e-type farmers (respectively ϕ for n-type farmers) in the separating case.

Using the utilities described in Tables 1 and 2, we can then specify the previous expressions respectively as the pooling strategy of offering Project 2 to all the agents and the separating case.

The pooling case. In this case, using the second column of Tables 1 and 2 (and given that the probability of Project 2 being proposed is 1 we have $W_t^{en} = V_2^{en}$, $W_t^{ee} = V_2^{ee}$, $W_t^{ne} = V_2^{ne}$, $W_t^{nn} = V_2^{nn}$ and so, using (15), we have $\tau_t^e = (1 - q_t)((y_2 - \bar{k}_2) - (y_2 - \gamma))$ and $\tau_t^n = q_t(y_2 - (y_2 - \bar{k}_2))$ and then

$$\frac{dq_t}{dt} = q_t(1 - q_t)((\gamma - \bar{k}_2) - \gamma q_t).$$

If we set the right hand side equal to zero, we find the steady states of the system: the two corner steady states 0 and 1 and $\bar{q}^p = 1 - \frac{\bar{k}_2}{\gamma}$ that is in $]0, 1[$ thanks to Assumption 1. The sign of the right hand side is positive for $q_t \in]0, \bar{q}^p[$ and negative for $q_t \in]\bar{q}^p, 1[$ so, if we consider the pure pooling case, q^p is an attractor for any initial datum $q_0 \in]0, 1[$.

The separating case. In this case we have $W_t^{ee} = V_1^{ee}$, $W_t^{en} = \phi V_2^{en} + (1 - \phi)V_1^{en}$, $W_t^{nn} = \phi V_2^{nn} + (1 - \phi)V_1^{nn}$, and $W_t^{ne} = V_1^{ne}$. Using the utility matrix in Tables 1 and 2 and (15), we have $\tau_t^e = (1 - q_t)((y_1 - \bar{k}_1) - (\phi(y_2 - \gamma) + (1 - \phi)(y_1 - \gamma)))$ and $\tau_t^n = q_t((\phi y_2 + (1 - \phi)y_1) - (y_1 - \bar{k}_1))$ and then, after some computations,

$$\frac{dq_t}{dt} = q_t(1 - q_t)((\gamma - \bar{k}_1 + \phi(y_1 - y_2)) - \gamma q_t).$$

So we again find the two corner steady states 0 and 1, and the third steady state $\bar{q}^s = 1 - \frac{\bar{k}_1 - \phi(y_1 - y_2)}{\gamma}$ which is smaller than 1 thanks to Assumption 4. Similar to what we had before, the sign of the right hand side of the previous equation is positive for $q_t \in]0, \bar{q}^s[$ and negative for $q_t \in]\bar{q}^s, 1[$ so, if we consider the pure separating case, $\bar{q}^s$ is an attractor for any initial datum $q_0 \in]0, 1[$.

In the following we discuss the situation where $\bar{q}^s > \bar{q}^p$. Exactly the same arguments can be employed for the reverse case.

The whole system. The entirety of the central governance policy dynamic is described by the following equation

$$\frac{dq_t}{dt} = h(q_t) := \begin{cases} q_t(1-q_t)((\gamma - \bar{k}_2) - \gamma q_t) & \text{if } q_t < \tilde{q} \\ q_t(1-q_t)((\gamma - \bar{k}_1 + \phi(y_1 - y_2)) - \gamma q_t) & \text{if } q_t \geq \tilde{q}. \end{cases}$$

There are three possible configurations of the system depending on the relative positions of $\bar{q}^p$, $\bar{q}^s$ and $\tilde{q}$ (see also Figure 2):

(i) $\tilde{q} < \bar{q}^p < \bar{q}^s$: in this case $h(q_t) > 0$ for any $q_t \in]0, \bar{q}^s[$ and $h(q_t) < 0$ for any $q_t \in]\bar{q}^s, 1[$ so that $\bar{q}^s$ is an attractor for initial datum $q_0 \in]0, 1[$.

(ii) $\bar{q}^p < \tilde{q} < \bar{q}^s$: in this case $h(q_t) > 0$ for $q_t \in]0, \bar{q}^b[$ and $q_t \in]\tilde{q}, \bar{q}^s[$ while $h(q_t) < 0$ for $q_t \in]\bar{q}^p, \tilde{q}[$ and $q_t \in]\bar{q}^s, 1[$ so that $\bar{q}^b$ is an attractor for the trajectories originating from an initial datum $q_0 \in]0, \tilde{q}[$ while $\bar{q}^s$ is an attractor for the trajectories originating from $q_0 \in]\tilde{q}, 1[$.

(iii) $\bar{q}^p < \bar{q}^s < \tilde{q}$: in this case $h(q_t) > 0$ for any $q_t \in]0, \bar{q}^p[$ and $h(q_t) < 0$ for any $q_t \in]\bar{q}^p, 1[$ so that $\bar{q}^p$ is an attractor for initial datum $q_0 \in]0, 1[$.

This concludes the proof. □

Proof of Proposition 3. As in the proof of Proposition 2, we focus on the situation where $\bar{q}^s > \bar{q}^p$. The same arguments apply to the reverse case.

We start by looking at the effects on the long-run value of q_t. We need to compare the long-run values of q_t in the two situations: creation of the brokers' network (BN) and the central governance policy (CG). In the BN case the long-run value of q_t is always $\bar{q}^b$ as shown in Proposition 1. In the case of CG it is $\bar{q}^p$ or $\bar{q}^s$ depending on the values of q_0 and $\tilde{q}$ (see Proposition 2 for details). We write $BN \succ CG$ (respectively $BN \prec CG$) if the long-run value of q_t under the BN policy is greater (respectively smaller) than the long-run value of q_t under the CG policy. We have the following eight cases:

Condition(s)	Comparison
$\bar{q}^b < \bar{q}^p$	$BN \prec CG$
$\bar{q}^p < \bar{q}^b < \tilde{q} < \bar{q}^s$ and $q_0 < \tilde{q}$	$BN \succ CG$
$\bar{q}^p < \bar{q}^b < \tilde{q} < \bar{q}^s$ and $q_0 > \tilde{q}$	$BN \prec CG$
$\bar{q}^p < \bar{q}^b < \bar{q}^s < \tilde{q}$	$BN \succ CG$
$\bar{q}^p < \tilde{q} < \bar{q}^b < \bar{q}^s$ and $q_0 < \tilde{q}$	$BN \succ CG$
$\bar{q}^p < \tilde{q} < \bar{q}^b < \bar{q}^s$ and $q_0 > \tilde{q}$	$BN \prec CG$
$\tilde{q} < \bar{q}^p < \bar{q}^b < \bar{q}^s$	$BN \prec CG$
$\bar{q}^s < \bar{q}^b$	$BN \succ CG$

We use this fact to prove part (i) of the proposition. First observe that $\bar{q}^b$ and $\bar{q}^p$ do not depend on ϕ, that $\bar{q}^s = 1 - \frac{\bar{k}_1 - \phi(y_1 - y_2)}{\gamma}$ is increasing as a function of ϕ (since $y_1 > y_2$ by hypothesis) and that

$\tilde{q} = \frac{(1-\phi)(y_1-y_2)}{\psi-\phi(y_1-y_2)}$ is decreasing as a function of ϕ (recall that $\psi > y_1 - y_2$ thanks to Assumption 2). Using these facts, it is easy to verify that, if for a certain choice of the parameters and of the initial condition the system is in one of the cases where $BN \succ CG$, it remains in one of these cases even when (keeping the same value for all other parameters and for the initial datum) we decrease the value of ϕ. Conversely, it can easily be seen that, if a certain configuration implies that $BN \prec CG$, *ceteris paribus* increasing the value of ϕ again gives a configuration where $BN \prec CG$. So there exists a threshold $\Psi \in [0, 1]$, depending on the choice of q_0 and of all the parameters except ϕ, such that $BN \succ CG$ for any $\phi < \Psi$ and $BN \prec CG$ for any $\phi > \Psi$ (observe that, if $\Phi = 0$ or $\Phi = 1$ one of these two sets is void).

Similarly, to prove the second claim of part (i), it can observed that, if changing the set of the parameters the value of $\bar{q}^b$ (or equivalently $\bar{b}^b$, since they are linked by the strictly increasing relation described in (14)) and maintaining the levels of $\bar{q}^p$, $\tilde{q}$ and $\bar{q}^s$ we can only switch from configurations where $BN \prec CG$ toward configurations where $BN \succ CG$, while the opposite never happens.

We can verify part (ii) of the proposition with a similar argument: actually, looking at the table of the cases above, we see that in the cases (i.e. in the parameter choices) where the choice of q_0 is relevant, decreasing *ceteris paribus* the value of q_0 can only allow the system to switch from configurations where $BN \prec CG$ toward configurations where $BN \succ CG$, while the opposite never happens.

When, instead of looking at the long-run level of q_t, we look at the long-run number of (per-period) successfully implemented deep green AEMs, the situation is the same. Indeed in the CG case a deep green AEM is proposed to all the e-type farmers, so the number of successfully implemented deep green AEMs is equal to the long-run level of q_t while in the BN case the number of successfully implemented deep green AEMs is given by $\bar{q}\bar{b} = \bar{q}g[\bar{q}]$. Since $g[\cdot]$ is an increasing function, all the previous considerations can be repeated. □

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