ΠΑΝΕΠΙΣΤΗΜΙΟ ΚΡΗΤΗΣ

ΣΧΟΛΗ ΚΟΙΝΩΝΙΚΩΝ ΕΠΙΣΤΗΜΩΝ

ΤΜΗΜΑ ΟΙΚΟΝΟΜΙΚΩΝ ΕΠΙΣΤΗΜΩΝ

Διδακτορικό Πρόγραμμα στην Οικονομική Επιστήμη

“Ρύθμιση Περιβαλλοντικών Εξωτερικοτήτων στον Αγροτικό Τομέα: Μια Εξελικτική Προσέγγιση”

Υποψήφια Διδάκτωρ: **Πασσά Π. Κωνσταντίνα**

Επιβλέπων Καθηγητής: **Ξεπαπαδέας Π. Αναστάσιος**

Ρέθυμνο

22 Δεκεμβρίου 2007

Διατριβή παραδοτέα για την εκπλήρωση των υποχρεώσεων για την απονομή του Διδακτορικού Διπλώματος.

ΣΥΝΟΨΗ ΔΙΔΑΚΤΟΡΙΚΗΣ ΔΙΑΤΡΙΒΗΣ

Στις 21/1/2004 εγκρίθηκε από την Γενική Συνέλευση Ειδικής Σύνθεσης (10/21-1-2004) του Τμήματος Οικονομικών Επιστημών, Πανεπιστημίου Κρήτης η εκπόνηση Διδακτορικής Διατριβής με τίτλο:

«Ρύθμιση Περιβαλλοντικών Εξωτερικοτήτων στον Αγροτικό Τομέα: Μια Εξελικτική Προσέγγιση»

Κινούμενη στο χώρο της Μικροοικονομικής Θεωρίας και Περιβαλλοντικής Πολιτικής, η εν λόγω Διατριβή *μελετά* την αποτελεσματικότητα των εθελοντικών μεθόδων (Voluntary Approaches) ως μέτρο πολιτικής παρέμβασης για την ρύθμιση προβλημάτων μη-σημειακής περιβαλλοντικής ρύπανσης (non-point-source) μέσα από ένα εξελικτικό, δυναμικό πλαίσιο ανάλυσης (evolutionary dynamic), χαρακτηριζόμενο από την υπόθεση της πεπερασμένης ορθολογικής ικανότητας επιλογής (bounded rationality) των υπό ρύθμιση οικονομικών μονάδων. Έμφαση δίδεται σε υπαρκτά μέτρα ρυθμιστικής πολιτικής που αφορούν καθαρά τον αγροτικό τομέα, τα οποία και έχουν απασχολήσει ευρέως τόσο την οικονομική βιβλιογραφία όσο και το πολιτικό γίγνεσθαι σε πανευρωπαϊκό επίπεδο αναφορικά με την αποτελεσματικότητα και την εν γένει χρηστικότητα τους.

Η **συνεισφορά** της εκπονηθείσας Διατριβής στην υπάρχουσα οικονομική βιβλιογραφία έγκειται στο γεγονός ότι υιοθετείται μια διαφορετική αναλυτική προσέγγιση όσον αφορά τον τρόπο δράσης των υπό εξέταση οικονομικών μονάδων. Η κλασική υπόθεση της πλήρους – απεριόριστης ορθολογικής ικανότητας επιλογής (full - unbounded rationality) αντικαθίσταται και υιοθετείται μια εναλλακτική και ενδεχομένως πιο ρεαλιστική υπόθεση, εκείνη της παθητικής, μιμητικής δυναμικής συμπεριφοράς, η οποία στηρίζεται σε μια συνεχή διαδικασία απόκτησης γνώσης μέσω της συνεχούς αλληλεπίδρασης (interaction) των οικονομικών μονάδων στο χρόνο και εκφράζεται μέσω μιμητικών δυναμικών μοντέλων (replicator dynamics equations).

Η εν λόγω Διδακτορική Διατριβή απαρτίζεται από τα κάτωθι τρία μέρη:

Μέρος Α: "Περιβαλλοντικές Πιέσεις και Ρύθμιση της Ευρωπαϊκής Αγροτικής Δραστηριότητας: Μια Βιβλιογραφική Ανασκόπηση σε Τρέχοντα Ζητήματα και Πολιτικές Παρέμβασης"

Μέρος Β: "Μοντελοποίηση της Αγροτικής Συμπεριφοράς και Αποτίμηση της Αποτελεσματικότητας Τρεχόντων Πολιτικών Μέσω ενός Εξελικτικού Πλαισίου"

Μέρος Γ: "Αποτελέσματα, Συνεισφορά στην Βιβλιογραφία και Πιθανές Προεκτάσεις της Διδακτορικής Διατριβής"

Συνοπτικά τα εν λόγω μέρη εξετάζουν:

Το **Μέρος Α** αποτελεί το εισαγωγικό μέρος της Διατριβής. Οι ευεργετικές και ιδίως οι δυσμενείς επιδράσεις της αγροτικής δραστηριότητας στο περιβάλλον παρουσιάζονται περιληπτικά. Δεδομένου ότι η πλειονότητα των προβλημάτων ρύπανσης αγροτικής προελεύσεως είναι μη-σημειακού τύπου, έμφαση δίδεται στην περιγραφή των ιδιαζόντων χαρακτηριστικών προβλημάτων τέτοιας φύσεως και στην επισήμανση των εμφανών διαφορών αυτών από τα συνήθη προβλήματα σημειακής ρύπανσης (point-source) (**Τμήμα 1**).

Αναφορά γίνεται στα βασικά γνωρίσματα των διαδεδομένων στην οικονομική βιβλιογραφία θεωρητικών μοντέλων μη-σημειακής ρύπανσης, τα οποία και αποδίδονται ιδίως μέσω βελτιστοποιητικών μοντέλων βασιζόμενων στην καθιερωμένη και εκτενώς χρησιμοποιούμενη υπόθεση της πλήρους ορθολογικής ικανότητας των υποεξέταση οικονομικών μονάδων. Δεδομένης της ιδιαίτερης φύσεως των αγρό-περιβαλλοντικών προβλημάτων, τα ιδιαίτερα χαρακτηριστικά των εν λόγω προβλημάτων βελτιστοποίησης προσδιορίζονται τόσο σε στατικό και δυναμικό πλαίσιο, όσο και υπό το καθεστώς βεβαιότητας και αβεβαιότητας, καθώς και υπό την παρουσία πληροφοριακών ασυμμετριών αναφορικά με τον τύπο των οικονομικών μονάδων (**Τμήμα 2**).

Υπογραμμίζονται οι πληροφοριακοί περιορισμοί που παρατηρούνται κατά την επιλογή των μέτρων πολιτικής ρύθμισης για την επαρκή αντιμετώπιση των προβλημάτων μη-σημειακής ρύπανσης, ενώ δε παρουσιάζεται επιγραμματικά το σύνολο των εφικτών μέτρων πολιτικής για την αντιμετώπιση αυτών (**Τμήμα 3**). Συγκεκριμένα, τα ρυθμιστικά πλαίσια που περιγράφονται συνοπτικά στην εν λόγω βιβλιογραφική επισκόπηση, είναι:

- ✓ Μέτρα βασιζόμενα στις ατομικές εκπομπές (Emission-based schemes).
- ✓ Μέτρα βασιζόμενα στις εισροές (Input-based schemes).
- ✓ Μέτρα βασιζόμενα στο παραγόμενο προϊόν (Output-based schemes).
- ✓ Μέτρα βασιζόμενα στις συλλογικές εκπομπές (Ambient-based schemes).
- ✓ Μεικτά μέτρα βασιζόμενα σε ένα συνδυασμό ατομικών και συλλογικών εκπομπών (Mixed-based schemes).
- ✓ Εθελοντικές Μέθοδοι.

Δεδομένων των πληροφοριακών απαιτήσεων και δυνατοτήτων, παρουσιάζονται οι εναλλακτικές μορφές που δύναται να λάβει το έκαστο μέτρο πολιτικής, ενώ όπου καθίσταται δυνατόν γίνονται αναφορές σε απτά παραδείγματα μέτρων πολιτικής παρέμβασης. Τέλος, εκτενής αναφορά γίνεται στις εθελοντικές μεθόδους, προτεινόμενες από την οικονομική βιβλιογραφία ως ένα νέο μέτρο περιβαλλοντικής πολιτικής για την ρύθμιση των εξωτερικοτήτων της μη-σημειακής οικονομικής δραστηριότητας (**Κεφάλαιο ΙΙ**).

Στόχος του Α Μέρους αποτελεί η διαμόρφωση μιας όσο το δυνατόν σαφέστερης εικόνας της ιδιαιτερότητας των προβλημάτων αγροτικής ρύπανσης και των εναλλακτικών δυνατοτήτων αντιμετώπισης αυτών, όπως αυτές διαφαίνονται από την συναφή οικονομική βιβλιογραφία. Το γεγονός ότι η μοντελοποίηση της αγροτικής συμπεριφοράς γίνεται ιδίως μέσω εκφράσεων, οι οποίες υποθέτουν ότι οι οικονομικές μονάδες (αγρότες) υιοθετούν μια βελτιστοποιητική συμπεριφορά (optimizing behavior), αναδεικνύει την μεγάλη στήριξη της τρέχουσας βιβλιογραφίας στην υπόθεση της πλήρους ορθολογικής ικανότητας παρά των ισχυρών ενδείξεων ότι οι οικονομικές μονάδες διακρίνονται στην πράξη από πεπερασμένη ορθολογική ικανότητα επιλογής. Την εν λόγω έλλειψη στην οικονομική βιβλιογραφίας καλείται να καλύψει εν μέρει η εν λόγω Διδακτορική Διατριβή στο Μέρος Β.

Το **Μέρος Β** αποτελεί το θεωρητικό μέρος της παρούσας Διατριβής, το οποίο απαρτίζεται από δύο τμήματα. Στο αρχικό, εισαγωγικό τμήμα παρατίθεται συνοπτικά η έννοια της πεπερασμένης ορθολογικής ικανότητας επιλογής καθώς και η καθιερωμένη θεωρητική έκφραση μέσω της οποίας μοντελοποιείται η δυναμική μιμητική συμπεριφορά των οικονομικών μονάδων (**Τμήμα Ι**). Το δε κύριο τμήμα (**Τμήμα ΙΙ**) του Β Μέρους συγκροτείται από τρεις ακόλουθες θεωρητικές εργασίες:

Κεφάλαιο Ι. **"Περιβαλλοντική Ρύθμιση των Αγροτικών Δραστηριοτήτων: Μια Εξελικτική Προσέγγιση"**

Κεφάλαιο ΙΙ. **"Μοντελοποίηση της Αγροτικής Συμπεριφοράς υπό το Καθεστώς των Παροχών της Κοινής Αγροτικής Πολιτικής (ΚΑΠ): Αποτίμηση των Περιβαλλοντικών Επιπτώσεων και της Αποτελεσματικότητας της Πολιτικής"**

Κεφάλαιο ΙΙΙ. **“Σχεδιασμός ενός Εθελοντικού Δημόσιου Περιβαλλοντικού Προγράμματος για την Αντιμετώπιση της Αγροτικής Νιτρορύπανσης: Μια Εξελικτική Προσέγγιση"**

Κύριο σημείο αναφοράς και δομικό λίθο των εν λόγω θεωρητικών εργασιών αποτελούν: (α) οι εθελοντικές μέθοδοι, ως το υιοθετούμενο ρυθμιστικό πλαίσιο των προβλημάτων της αγροτικής μη-σημειακής ρύπανσης, καθώς και (β) η υπόθεση της πεπερασμένης ορθολογικής ικανότητας των υπό εξέταση οικονομικών μονάδων, εκφραζόμενης μέσω της υπόθεση της δυναμικής μιμητικής συμπεριφοράς, ως το υιοθετούμενο αναλυτικό πλαίσιο των υπό διερεύνηση προβλημάτων μη-σημειακής ρύπανσης. Έκαστη των εργασιών εστιάζει στην μελέτη ενός διαφορετικού πεδίου της αγροτικής δραστηριότητας και πολιτικής παρέμβασης στο συγκεκριμένο πεδίο δραστηριοτήτων.

Ειδικότερα, το κάθε κεφάλαιο αποβλέπει στην:

Κεφάλαιο Ι: Αντιπαράθεση των κανόνων πλήρους και πεπερασμένης ορθολογικής ικανότητας επιλογής στη ρύθμιση προβλημάτων αγροτικής περιβαλλοντικής ρύπανσης, επικεντρώνοντας στο πρόβλημα της αγροτικής νιτρορύπανσης.

Το **πρώτο κεφάλαιο** εξετάζει την αγροτική δραστηριότητα και το πρόβλημα προσδιορισμού του επιπέδου ελέγχου (monitoring effort) υπό το καθεστώς των περιβαλλοντικών υποχρεώσεων της Κοινοτικής Οδηγίας για τον έλεγχο της νιτρορύπανσης (91/676/EEC) και των ενισχύσεων του δεύτερου πυλώνα της Κοινής Αγροτικής Πολιτικής για την ανάπτυξη της υπαίθρου. Μελετά την μακροχρόνια επίδραση των υιοθετούμενων, τόσο από πλευράς των υπό ρύθμιση οικονομικών μονάδων όσο και του ελεγκτικού φορέα, διαφορετικών κανόνων συμπεριφοράς, στα κίνητρα για συμμόρφωση με νομοθετικά υποδεικνυόμενες περιβαλλοντικές συμπεριφορές, ενός ευρύ πληθυσμού ομοιογενών οικονομικών μονάδων. Διατυπώνει τις προϋποθέσεις κάτω από τις οποίες καθίσταται επιτεύξιμη η πλήρης συμμόρφωση του πληθυσμού, στο σημείο της εξελικτικά ευσταθούς ισορροπίας. Τέλος, τόσο το πρόβλημα της αυθαίρετης (arbitrary) όσο και βέλτιστης επιλογής του επιπέδου ελέγχου προεκτείνεται και με την απόφαση για επένδυση σε κεφάλαιο ελέγχου (monitoring capital).

Κεφάλαιο ΙΙ: Ανάπτυξη (α) ενός ειδικού θεωρητικού πλαισίου αποτίμησης των περιβαλλοντικών επιπτώσεων των διαφόρων ρυθμιστικών εργαλείων καθώς και (β) του μηχανισμού προσδιορισμού του τύπου των κοινωνικά βέλτιστων (first best) μέτρων παρεμβατικής πολιτικής, επικεντρώνοντας στα κύρια είδη ενισχύσεων της Κοινοτικής Αγροτικής Πολιτικής (ΚΑΠ).

Το **δεύτερο κεφάλαιο** εστιάζει στην μοντελοποίηση της αγροτικής δραστηριότητας υπό το γενικευμένο καθεστώς ενισχύσεων και περιβαλλοντικών ρυθμίσεων της

Κοινής Αγροτικής Πολιτικής, όπως αυτό εκφράστηκε μέσω της μεταρρύθμισης "Ατζέντα 2000". Αποσκοπεί στην αποτίμηση των περιβαλλοντικών επιπτώσεων των διαφόρων καθεστώτων ενισχύσεων της εν λόγω κοινοτικής πολιτικής στην συμπεριφορά ενός πληθυσμού ομοειδών οικονομικών μονάδων, μέσω της σύγκρισης της επίδρασης των διαφόρων υποκαθεστώτων ενισχύσεων, παρεχομένων τόσο από τον πρώτο πυλώνα για τις οργανώσεις κοινής αγοράς (CMOS - Common Markets Organizations) όσο και τον δεύτερο πυλώνα για την ανάπτυξη της υπαίθρου (RD - Rural Development), στις παραγωγικές αποφάσεις μιας αντιπροσωπευτικής οικονομικής μονάδας ανεξαρτήτως από το υποτιθέμενο επίπεδο ορθολογικής ικανότητας. Επιπλέον στοχεύει στην αποτίμηση της αποτελεσματικότητας της μεταρρύθμισης Ατζέντας 2000, τόσο μέσω του προσδιορισμού των κοινωνικά βέλτιστων μέτρων της Κοινής Αγροτικής Πολιτικής υπό την υπόθεση τόσο της απεριόριστης όσο και πεπερασμένης ορθολογικής ικανότητας επιλογής των υπό εξέταση οικονομικών μονάδων. Συγκεκριμένα, υπό την υπόθεση της απεριόριστης ορθολογικής ικανότητας αποτιμούνται τόσο τα στατικά όσο και δυναμικά κοινωνικά βέλτιστα μέτρα της Κοινής Αγροτικής Πολιτικής, ενώ υπό την υπόθεση της πεπερασμένης ορθολογικής ικανότητας προσδιορίζονται ο τύπος των εξελικτικά δυναμικών κοινωνικά βέλτιστων ρυθμιστικών μέτρων. Τέλος, προβαίνει στην διατύπωση θέσεων για τη κοινωνικά βέλτιστη διάρθρωση της αγροτικής πολιτικής της Κοινότητας.

Κεφάλαιο ΙΙΙ: Διαμόρφωση ενός γενικού θεωρητικού πλαισίου ρύθμισης προβλημάτων αγροτικής περιβαλλοντικής ρύπανσης, επικεντρώνοντας στο πρόβλημα της αγροτικής νιτρορύπανσης.

Το **τρίτο κεφάλαιο** επικεντρώνεται στο σχεδιασμό ενός δημόσιου εθελοντικού περιβαλλοντικού προγράμματος (public voluntary program) που επιδιώκει την εθελοντική περικοπή τόσο των ατομικών όσο και συλλογικών νιτρικών εκπομπών. Εστιάζει στη μελέτη της συμπεριφοράς του υπό ρύθμιση ευρέως πληθυσμού των ομοιογενών οικονομικών μονάδων αναφορικά με (α) τα κίνητρα για συμμετοχή στο εν λόγω πρόγραμμα καθώς και (β) τα κίνητρα για συμμόρφωση στις περιβαλλοντικές υποδείξεις αυτού, υπό την παρουσία γρήγορων – αργών δυναμικών επιλογής (fast-slow selection dynamics) όσον αφορά την χρονική λήψη των εν λόγω αποφάσεων.

Προβαίνει στην επισήμανση των παραγόντων που δύνανται να συμβάλουν στη εξελικτική βιωσιμότητα (evolutionary sustainability) της εν λόγω περιβαλλοντικά φιλικής πολιτικής, καθώς και στην διατύπωση γενικών κανόνων αναφορικά με την διαμόρφωση του ελεγκτικού μηχανισμού (audit system) πού διασφαλίζουν την επίτευξη του επιθυμητού συλλογικού περιβαλλοντικού στόχου.

Στόχος του Μέρους Β αποτελεί η ανάδειξη των ουσιωδών εννοιολογικών και δομικών διαφορών ανάμεσα στον κανόνα πλήρους και μερικής ορθολογικής ικανότητας (**Κεφάλαιο Ι**), η αποτίμηση των επιπτώσεων αυτών στην μακροχρόνια συμπεριφορά ενός ευρέως πληθυσμού ομοιογενών οικονομικών μονάδων αναφορικά με την υιοθέτηση ή μη μιας υποδεικνυόμενης περιβαλλοντικά φιλικής συμπεριφοράς (**Κεφάλαιο Ι**) καθώς και στο μηχανισμό προσδιορισμού των ρυθμιστικών εργαλείων που διασφαλίζουν την επίτευξη κοινωνικά βέλτιστων συλλογικών περιβαλλοντικών στόχων (**Κεφάλαιο ΙΙ**), καθώς και στην διαμόρφωση ενός εξελικτικά βιώσιμου ρυθμιστικού και ελεγκτικού πλαισίου βασιζόμενου εξολοκλήρου στην υπόθεση της δυναμικά μιμητικής συμπεριφοράς (**Κεφάλαιο ΙΙΙ**).

Τέλος, στο **Μέρος Γ** παρουσιάζονται συνοπτικά τα συμπεράσματα της εν λόγω Διατριβής, η συνεισφορά αυτής στην τρέχουσα οικονομική βιβλιογραφία καθώς και οι πιθανές προεκτάσεις των αναπτυχθέντων θεωρητικών μοντέλων.

ΕΚΤΕΤΑΜΕΝΗ ΣΥΝΟΨΗ ΔΙΔΑΚΤΟΡΙΚΗΣ ΔΙΑΤΡΙΒΗΣ

Αναμφίβολα οι αγροτικές δραστηριότητες συνδράμουν αποφασιστικά στην διατήρηση της βιωσιμότητας και της ποικιλομορφίας της υπαίθρου, της τοπιογραφίας (landscape) και των χώρων διαβίωσης (habitants) των διαφόρων ειδών, καθώς δε συνεισφέρουν και στην προστασία του ευρύτερου περιβάλλοντος (ambient environment). Ωστόσο πέραν των καταγεγραμμένων ευεργετικών περιβαλλοντικών υπηρεσιών, ο Ευρωπαϊκός αγροτικός τομέας είναι συνδεδεμένος με μια σειρά από δυσμενείς περιβαλλοντικές επιδράσεις, οι οποίες συνοψίζονται ως εξής:

- *Απώλειες στη βιοποικιλότητα καθώς και στην* τοπιογραφία, *οριζόμενες σε όρους τόσο ποικιλομορφίας όσο και ποιότητας,, καθώς και συρρίκνωση των σημαντικών χώρων διαβίωσης των διαφόρων ειδών.*
- *Ασφυκτικές πιέσεις σε αγροτικά συστήματα υψηλής φυσικής αξίας καθώς και σε παραδοσιακές μορφές αγροτικής δραστηριότητας σε περιοχές χαρακτηριζόμενες ως οριακές (**marginal**).*
- *Ποιοτική υποβάθμιση των υδατικών πόρων, του εδάφους και αέρα.*

Τέτοιας φύσεως προβλήματα ρύπανσης, αγροτικής προελεύσεως, είναι άρρηκτα συνδεδεμένα με την παρατηρούμενη αβεβαιότητα, από πλευράς ενός τρίτου φορέα, αναφορικά με (α) την ταυτότητα των ρυπαντών και (β) την συνεισφορά έκαστου εξ αυτών στο συνολικό επίπεδο ρύπανσης. Η εν λόγω αβεβαιότητα απορρέει ιδίως από:

- Τις στοχαστικές διαδικασίες που ασκούν επιρροές στην παραγωγή, πορεία και μεταφορά των ρύπων.

Η μεταβλητότητα των φυσικών διαδικασιών (καιρικά φαινόμενα, τοπολογία) είτε και η τεχνολογική αβεβαιότητα (βλάβες στον εξοπλισμό, διακυμάνσεις στην ποιότητα των εισροών) προσδίδουν στοχαστικά χαρακτηριστικά στις εκπομπές ρύπων.

- Το πολλαπλό αριθμό των στατικών πηγών εκπομπής ρύπων και στην χωροταξική διάχυση της ατομικής ρύπανσης (diffuse).

Ο προσδιορισμός της εντοπιότητας της ρύπανσης δεν καθίσταται δυνατός με βεβαιότητα καθώς οι ρυπαντές είναι πολυάριθμοι και διασκορπισμένοι στο χώρο, ενώ οι δε ατομικές εκπομπές αυτών διαχέονται γρήγορα στο χώρο συντελώντας στην ρύπανση πολλαπλών γεωγραφικών ζωνών.

- Την αδυναμία του ρυθμιστή (regulator) να παρατηρήσει άμεσα τις ατομικές εκπομπές ρύπων είτε να αποτιμήσει αυτές έμμεσα μέσω του επίπεδου της συνολικής ρύπανσης ή των χρησιμοποιούμενων εισροών.

Η αδυναμία μέτρησης και ελέγχου των ατομικών εκπομπών αποδίδεται είτε σε νομικούς ή χρηματοδοτικούς περιορισμούς. Το κόστος της ελεγκτικής τεχνολογίας, το περιορισμένο ελεγκτικό προσωπικό καθώς και οι πληροφοριακές ασυμμετρίες συντελούν στην περιορισμένη πληροφόρηση του ρυθμιστή αναφορικά με το μικροοικονομικό στρατηγικό περιβάλλον των ατομικών ρυπαντών.

Βάσει των ανωτέρω οι ατομικές εκπομπές δεν δύναται να αποτιμηθούν και αναμφίβολα τα προβλήματα αγροτικής ρύπανσης κατατάσσονται στην κατηγορία των προβλημάτων μη-σημειακής ρύπανσης, γεγονός που θέτει αξιοσημείωτους περιορισμούς στο εύρος των δυνητικά διαθέσιμων αγρό-περιβαλλοντικών μέτρων πολιτικής ρύθμισης καθώς και στην αποτελεσματικότητα αρκετών εκ των εναπομεινουσών επιλογών.

Αν και η πολιτική παρέμβαση δικαιολογείται πλήρως από την αποτυχία της ανταγωνιστικής, μη-ρυθμιζόμενης (unregulated) αγοράς να επιφέρει την υιοθέτηση της κοινωνικά βέλτιστης συμπεριφοράς, καθιερωμένα εργαλεία πολιτικής - όπως οι Πιγουβιανοί (Pigouvian) φόροι, εμπορεύσιμες άδειες και τα όρια απόδοσης (performance standards) - κρίνονται ανεπαρκή να χειριστούν αποτελεσματικά τέτοιας φύσεως προβλήματα ρύπανσης. Συνεπώς, ο πολιτικός σχεδιασμός επικεντρώνεται σε εργαλεία που εστιάζουν σε άλλα γνωρίσματα των μη-σημειακών προβλημάτων, τα οποία και ενδέχεται να είναι παρατηρήσιμα, όπως είναι οι επιλογές των οικονομικών μονάδων (μέτρα βασιζόμενα στις εισροές) καθώς και οι συνέπειες αυτών (μέτρα βασιζόμενα στις συνολικές εκπομπές).

Στην συναφή οικονομική βιβλιογραφία εντοπίζεται πλειάδα εναλλακτικών μεθόδων πολιτικής ρύθμισης των προβλημάτων περιβαλλοντικής μη-σημειακής ρύπανσης, οι οποίες συνοψίζονται στις κατωτέρω κατηγορίες:

✓ Ρυθμίσεις βάσει των ατομικών εκπομπών.

Αν και μέτρα βασιζόμενα στις ατομικές εκπομπές ρύπων δεν είναι ευρέως διαδομένα στην πράξη, αποτελούν την βάση για τον σχεδιασμό εναλλακτικών εργαλείων πολιτικής. Η χρήση των εν λόγω εργαλείων πολιτικής καθίσταται δυνατή όποτε είναι εφικτή η άμεση παρατήρηση των ατομικών εκπομπών είτε όταν δύναται η έμμεση αποτίμηση αυτών με σχετική ακρίβεια.

✓ Ρυθμίσεις βάσει των εισροών.

Στην πράξη οι ατομικές εκπομπές ρύπων δεν είναι άμεσα παρατηρήσιμες, γεγονός που καθιστά πρακτικά ανέφικτα τα προαναφερθέντα ρυθμιστικά μέτρα. Στην προκείμενη περίπτωση η ρύθμιση των εκπομπών ρύπων επιτυγχάνεται έμμεσα μέσω του ελέγχου των παραγωγικών επιλογών, των εισροών που συμβάλουν είτε στην παραγωγή της αγροτικής μη-σημειακής ρύπανσης (productive / polluting inputs) είτε στην περικοπή αυτής (abating inputs).

✓ Ρυθμίσεις βάσει του παραγόμενου προϊόντος.

Την βάση για τον σχεδιασμό πολιτικών παρέμβασης αποτελεί το αποτέλεσμα της παραγωγικής διαδικασίας το οποίο και συνδράμει άμεσα στην παραγόμενη ρύπανση.

✓ Ρυθμίσεις βάσει των συλλογικών εκπομπών.

Στην απουσία πληροφόρησης αναφορικά τόσο με τις εκπομπές ρύπων όσο και με τις παραγωγικές επιλογές εκάστης οικονομικής μονάδας, οι ρυθμιστικές πολιτικές στηρίζονται στα επίπεδα των συνολικών εκπομπών ρύπων, τα οποία και είναι είτε ορατά ή δύναται να εκτιμηθούν σε συγκεκριμένα σημεία υποδοχής (receptor point) με λογικό κόστος.

✓ Ρυθμίσεις βάσει ενός συνδυασμού ατομικών και συλλογικών εκπομπών.

Στην προκείμενη κατηγορία, των μεικτών μέτρων πολιτικής, τη βάση για τον σχεδιασμό εναλλακτικών παρεμβατικών εργαλείων αποτελούν τόσο οι συλλογικές όσο και οι ατομικές εκπομπές ρύπων.

✔ Ρυθμίσεις μέσω εθελοντικών μεθόδων (Voluntary Approaches).

Αν και αρχικά η περιβαλλοντική πολιτική στηρίχθηκε σε μέτρα εντολής-και-ελέγχου (command-and-control), καθώς και σε κίνητρα βασιζόμενα στην αγορά (market-based incentives), τα μη-σημειακά χαρακτηριστικά της αγροτικής ρύπανσης κατέστησαν αναγκαία την διαμόρφωση νέων πολιτικών παρέμβασης. Την τελευταία δεκαετία παρατηρείται μια αξιοσημείωτη στροφή προς τις λεγόμενες εθελοντικές μεθόδους, ένα νέο εργαλείο πολιτικής, χρησιμοποιούμενο ευρέως στις Κοινοτικές αγροτικές πολιτικές. Το εν λόγω μέτρο πολιτικής θεωρείται συμπληρωματικό εργαλείο και όχι υποκατάστατο του συμβατικού συστήματος πολιτικών καθώς συνδυάζει τόσο εθελοντικά όσο και υποχρεωτικά στοιχεία (mandatory) – όπως όρια στην χρήση εισροών, φόρους στις συλλογικές εκπομπές κτλ. Βασίζεται σε ένα νέο είδος αλληλεπίδρασης ανάμεσα στην ρυθμιστική αρχή και τις υπό ρύθμιση οικονομικές μονάδες, όπου η εθελοντική συμφωνία ανάμεσα στα εμπλεκόμενα μέρη αποτελεί την βάση για την αντιμετώπιση προβλημάτων μη-σημειακής ρύπανσης, όπως είναι το πρόβλημα της αγροτικής νιτρορύπανσης. Κρίνεται ως σχετικά μια πιο “ήπια” μορφή ρύθμισης δεδομένων περιβαλλοντικών προβλημάτων, καθώς μπορεί να είναι πιο ευρεία και περιγραφική εν συγκρίσει με τις υποχρεωτικές ρυθμίσεις, ενώ παρέχει δε τη δυνατότητα για μειωμένα κόστη συμμόρφωσης.

Με τον όρο “Εθελοντικές Μέθοδοι” αναφερόμαστε σε μια σειρά από "*δεσμεύσεις από πλευράς των οικονομικών μονάδων ή βιομηχανικών τομέων (sectors) για την βελτίωση της περιβαλλοντικής επίδοσης αυτών*". Υπάρχουν ποικίλα κριτήρια βάσει των οποίων μπορούν να διαφοροποιηθούν τα εν λόγω μέτρα πολιτικής, ωστόσο η επικρατέστερη ταξινόμηση στηρίζεται στο βαθμό παρεμβατικότητας του δημοσίου φορέα. Στην προκείμενη περίπτωση οι εθελοντικές μέθοδοι διακρίνονται σε: (α) μονομερείς δεσμεύσεις (unilateral agreements), (β) δημόσια εθελοντικά προγράμματα (public voluntary programs) και (γ) διαπραγματεύσιμες συμφωνίες (negotiated agreements). Πέραν τούτου οι εθελοντικές μέθοδοι δύναται να διακριθούν περαιτέρω βάσει του υποκινητή της περιβαλλοντικής δράσης (initiator), του βαθμού εμβάθυνσης του προγράμματος σε λεπτομέρειες, την ύπαρξη ή μη νομικών δικλείδων, τον τύπο κυρώσεων κτλ.

Αν και εντοπίζεται πλειάδα ερευνητικών εργασιών στο πεδίο της ρύθμισης μη-σημειακής φύσεως περιβαλλοντικών προβλημάτων, η ανασκόπηση της συναφούς οικονομικής βιβλιογραφίας ανέδειξε ισχυρή εξάρτηση του αναλυτικού πλαισίου του εν λόγω τύπου προβλημάτων ρύπανσης στην υπόθεση της πλήρους - απεριόριστης ορθολογικότητας ικανότητας επιλογής και συνεπώς στην υπόθεση της βελτιστοποιητικής συμπεριφοράς των υπό εξέταση οικονομικών μονάδων. Συγκεκριμένα, οι υπό-ρύθμιση οικονομικές μονάδες μεταχειρίζονται "*σαν να*" κατέχουν συνειδητά όλη την απαραίτητη γνώση καθώς και τις ικανότητες εκείνες που τους επιτρέπουν να αποτιμήσουν όλες τις πιθανές εναλλακτικές επιλογές (στρατηγικές), να επιλύσουν ένα πολύπλοκο πρόβλημα από διαφορικές εξισώσεις για να εντοπίσουν την επιλογή εκείνη (στρατηγική) που βελτιστοποιεί την αντικειμενική τους συνάρτηση.

Στην πράξη όμως η ποσότητα της πληροφόρησης που δύναται να κατέχουν και να επεξεργαστούν οι ρυθμιζόμενες οικονομικές μονάδες είναι πεπερασμένη. Μέσω της αλληλεπίδρασης τους στο χρόνο οι μονάδες μαθαίνουν, μιμούνται και προσαρμόζουν την συμπεριφορά τους στις στρατηγικές των λοιπών μονάδων βάσει της πληροφόρησης που αποκαλύπτεται. Στρατηγικές που επιφέρουν υψηλότερες απολαβές διαδίδονται εντός του πληθυσμού των οικονομικών μονάδων εις βάρος των λιγότερο επιτυχημένων στρατηγικών. Τα δυναμικά συστήματα που χρησιμοποιούνται ευρέως για την περιγραφή τέτοιου είδους "μαζικών δράσεων", είναι τα μιμητικά δυναμικά μοντέλα. Ωστόσο, περιορισμένο είναι το εύρος των ερευνητικών εργασιών που βασίζεται στην υπόθεση της πεπερασμένης ορθολογικής ικανότητας και μεταχειρίζονται τις εν λόγω εκφράσεις.

Εν συντομία, η ανασκόπηση της οικονομικής βιβλιογραφίας στο πεδίο της ρύθμισης προβλημάτων περιβαλλοντικής μη-σημειακής ρύπανσης ανέδειξε ισχυρή εξάρτηση αυτής: (α) σε ένα αναλυτικό πλαίσιο που βασίζεται στην υπόθεση της πλήρους ορθολογικότητας ικανότητας και της βελτιστοποιητικής συμπεριφοράς των υπό εξέταση οικονομικών μονάδων, καθώς και (β) σε ένα ρυθμιστικό πλαίσιο που βασίζεται επί το πλείστον σε μέτρα εντολής-και-ελέγχου. Περιορισμένο είναι το εύρος της συναφούς βιβλιογραφίας, το οποίο προσεγγίζει το πρόβλημα της αγροτικής μη-σημειακής ρύπανσης μέσω του ρυθμιστικού πλαισίου των εθελοντικών μεθόδων σε συνδυασμό με το εναλλακτικό και λιγότερο διαδεδομένο αναλυτικό πλαίσιο της πεπερασμένη ορθολογική ικανότητα επιλογής.

Δεδομένης της ανωτέρω παρατήρησης η παρούσα Διδακτορική Διατριβή εστιάζει:

- Στις εθελοντικές μεθόδους, έως ένα εναλλακτικό ρυθμιστικό εργαλείο πολιτικής για την αντιμετώπιση των προβλημάτων αγροτικής μη-σημειακής ρύπανσης, σε συνδυασμό με ένα μιμητικά δυναμικό πλαίσιο, έως μια εναλλακτική μέθοδο ανάλυσης και προσέγγισης των προβλημάτων αγροτικής μη-σημειακής ρύπανσης.

Σκοπός της Διατριβής αποτελεί η ενασχόληση με τα ακολούθα ζητήματα:

- Αποτίμηση της αποτελεσματικότητας υπαρκτών δημοσίων εθελοντικών περιβαλλοντικών προγραμμάτων, αποκλειστικά σχεδιασμένων για τον αγροτικό τομέα, όπως αυτά περιγράφονται από την Κοινοτική Οδηγία (91/676/EEC) για την αντιμετώπιση της νιτρορύπανσης καθώς και τις κύριες μεταρρυθμίσεις της Κοινής Αγροτικής Πολιτικής, διαμορφωθείσες από την Ευρωπαϊκή Επιτροπή μέσω της μεταρρύθμισης Ατζέντα 2000.
- Αποτίμηση της δυναμικής περιβαλλοντικής συμπεριφοράς ενός ευρύ, υπό ρύθμιση πληθυσμού ομοιογενών οικονομικών μονάδων, μέσω της εξέτασης του προβλήματος του κοινωνικού ρυθμιστή για την επιλογή του επιπέδου ελέγχου και ελεγκτικού κεφαλαίου, όπου η διεξαγώμενη ανάλυση στηρίζεται στις αντιτιθέμενες υποθέσεις της πλήρους και πεπερασμένης ορθολογικής ικανότητας επιλογής των υπό εξέταση οικονομικών μονάδων.
- Περιγραφή του μηχανισμού επιλογής των βέλτιστων μέτρων πολιτικής ρύθμισης υπό το πλαίσιο της βελτιστοποιητικής και εξελικτικά μιμητικής συμπεριφοράς.

⇨ Διατύπωση προτάσεων για τον ορθό σχεδιασμό τόσο ενός δημόσιου εθελοντικού περιβαλλοντικού προγράμματος όσο και του ελεγκτικού μηχανισμού αυτού.

Συγκεκριμένα έκαστο εκ των κεφαλαίων του Β Μέρους της Διατριβής διαπραγματεύθηκε τα ακόλουθα ζητήματα:

Κεφάλαιο Ι:
“Περιβαλλοντική Ρύθμιση των Αγροτικών Δραστηριοτήτων: Μια Εξελικτική Προσέγγιση”

Το **Κεφάλαιο Ι** εστιάζει σε ένα δημόσιο εθελοντικό πρόγραμμα, το οποίο συνδυάζει στοιχεία από την Κοινοτική Οδηγία για την αντιμετώπιση της νιτρορύπανσης (91/676/EEC) καθώς και τα αγρό-περιβαλλοντικά προγράμματα του δεύτερο πυλώνα της Κοινής Αγροτικής πολιτικής (ΚΑΠ). Επικεντρώνεται στον εντοπισμό των πιθανών επιπτώσεων, που επιφέρει η εισαγωγή περιορισμών στο επίπεδο της ορθολογικής ικανότητας επιλογής των υπό εξέταση οικονομικών μονάδων (αγρότες), στα μακροχρόνια κίνητρα του πληθυσμού αυτών για συμμόρφωση με νομικά θεσπισμένες περιβαλλοντικές απαιτήσεις. Η αντιπαράθεση της περιβαλλοντικά φιλικής δυναμικής συμπεριφοράς ενός πληθυσμού ομοιογενών οικονομικών μονάδων υπό τις αντιτιθέμενες υπόθεσεις αναφορικά με την ορθολογική ικανότητα επιλογή των μελών αυτού, καθίσταται επιτεύξιμη μέσω του προβλήματος ενός κοινωνικού ρυθμιστή για την αυθαίρετη (arbitrary) και βέλτιστη επιλογής του επιπέδου ελέγχου (monitoring effort). Εν τέλει το εν λόγω πρόβλημα της αυθαίρετης και βέλτιστης επιλογής προεκτείνεται και με την απόφαση για επένδυση σε κεφάλαιο ελέγχου (monitoring capital).

Υπό το θεωρούμενο ρυθμιστικό πλαίσιο, αξιώνεται από έκαστη οικονομική μονάδα ο περιορισμός της χρήσης αζωτούχων λιπασμάτων έως ένα προκαθορισμένο επίπεδο, ενώ συνάμα προβλέπεται η παροχή επιδότησης ανά μονάδα εισροής αζώτου που περικόπτεται πέρα του προτεινόμενου ορίου. Αν και η συμμόρφωση με το ανωτέρω νομικά θεσπισμένο όριο απόδοσης ενέχει απώλειες σε όρους κέρδους, η εν λόγω ζημιά μπορεί να αποφευχθεί. Δεδομένου του μη-σημειακού χαρακτήρα της αγροτικής νιτρορύπανσης, οι ατομικές παραγωγικές αποφάσεις μεμονωμένων οικονομικών μονάδων μπορεί να παραμείνουν μη-παρατηρίσιμες για ένα τρίτο φορέα (ρυθμιστή). Στην προκειμένη περίπτωση είναι επικερδές για τις εν λόγω μονάδες να αποκλίνουν των περιβαλλοντικών υποχρεώσεων τους (μη-συμμόρφωση) και να λάβουν εν τέλει υψηλότερες απολαβές εν συγκρίσει των οικονομικών μονάδων που συμμορφώνονται. Ωστόσο, οι οικονομικές μονάδες είναι ενήμερες ότι αν μια τέτοιας φύσεως παραβατική συμπεριφορά (deviating) εντοπισθεί τότε προβλέπεται η επιβολή ενός συνόλου ποινών, ενέργεια που κατατάσσει τις αποκλίνουσες από το στόχο οικονομικές μονάδες σε μειονεκτική θέση, σε όρους απολαβών. Συνεπώς, έκαστη μονάδα οφείλει να λάβει υπόψη την επίπτωση του ελεγκτικού μηχανισμού στην δομή των απολαβών κατά την απόφαση αυτής να αποκλίνει ή όχι των θεσμοθετημένων περιβαλλοντικών υποχρεώσεων.

Τόσο το εύρος του υλοποιούμενου επιπέδου ελέγχου, όσο και η αντίληψη (perception) των υπό-ρύθμιση οικονομικών μονάδων αναφορικά με την επίδραση αυτού στην δομή των απολαβών, διαμορφώνει την τελική αποτελεσματικότητα του εξεταζόμενου ρυθμιστικού πλαισίου να υποκινήσει επαρκή κίνητρα για συμμόρφωση με την υποδεικνυόμενη περιβαλλοντική συμπεριφορά στον ευρύτερο, υπό ρύθμιση πληθυσμό. Ανάλογα με το υποτιθέμενο επίπεδο ορθολογικής ικανότητας επιλογής, οι οικονομικές μονάδες υιοθετούν είτε ένα βελτιστοποιητικό ή ένα μιμητικό, παθητικό κανόνα συμπεριφοράς προκειμένου να αποφανθούν κατά πόσον είναι επικερδές ή όχι να ενστερνισθούν την στρατηγική που συνεπάγεται συμμόρφωση με το προτεινόμενο περιορισμό στην χρήση εισροών αζώτου.

Αν θεωρηθεί ότι οι οικονομικές μονάδες διακρίνονται από πλήρη ορθολογική ικανότητα επιλογής, τότε αυτές συμπεριφέρονται "σαν να" κατέχουν τέλεια πληροφόρηση αναφορικά με την επίπτωση του ελεγκτικού μηχανισμού στην δομή των αποδοχών, γεγονός που τους επιτρέπει να επιλέξουν την ατομική τους στρατηγική με ένα βέλτιστο τρόπο. Αντιθέτως, εάν θεωρηθεί ότι οι οικονομικές μονάδες έχουν περιορισμένη πρόσβαση στην πληροφόρηση τότε η απόφαση, αναφορικά με την συμμόρφωση ή όχι με τις περιβαλλοντικές υποδείξεις του προγράμματος, στηρίζεται στην προσωπική τους αντίληψη για την επίδραση του ελεγκτικού μηχανισμού στην δομή των απολαβών. Δεδομένου, ωστόσο, ότι οι οικονομικές μονάδες αλληλεπιδρούν κατά την διάρκεια του χρόνου, η εν λόγω απόφαση δύναται να αναπροσαρμοσθεί ανάλογα με το είδος της πληροφόρησης που αποκαλύπτεται. Ένας τέτοιος παθητικός τρόπος λήψης αποφάσεων, βασίζεται στην μίμηση της στρατηγικής εκείνης που επιφέρει την υψηλότερη απόδοση και μοντελοποιείται μέσω του δυναμικά μιμητικού κανόνα. Σύμφωνα με τον προαναφερθέντα κανόνα, το μερίδιο (share) των πιο επιτυχών, σε όρους απολαβών, δραστηριοτήτων σταδιακά αυξάνει στο πληθυσμό εις βάρος των λιγότερο επιτυχημένων οικονομικών μονάδων, το μερίδιο των οποίων συρρικνώνεται σταδιακά.

Το μέγεθος (magnitude) του υλοποιούμενου επιπέδου ελέγχου (καθώς και της επένδυσης σε ελεγκτικό κεφάλαιο) επιλέγεται είτε (α) με αυθαίρετο τρόπο βάσει των υιοθετούμενων από τις οικονομικές μονάδες εναλλακτικών και αντικρουόμενων κανόνων ορθολογικής συμπεριφοράς, είτε (β) με ένα βέλτιστο τρόπο μέσω της ελαχιστοποίησης ενός κριτηρίου κοινωνικού κόστους υπό τον περιορισμό των κανόνων πλήρους ή πεπερασμένης ορθολογικής ικανότητας επιλογής. Μέσω του προαναφερθέντος αναλυτικού πλαισίου διαπραγματεύονται τα κριτήρια επιλογής εκείνου του επιπέδου ελέγχου (καθώς και του επιπέδου επένδυσης σε ελεγκτικό κεφάλαιο) που παρακινεί ένα ευρύ πληθυσμό ομοειδών οικονομικών μονάδων να συμμόρφωρθεί στην μακροχρόνια περίοδο με την υποδεικνυόμενη περιβαλλοντική συμπεριφορά. Συνάμα καθίσταται δυνατή η σύγκριση του μεριδίου των συμμορφωθέντων (compliant) οικονομικών μονάδων, όπως αυτό ανακύπτει στο σημείο της μακροχρόνιας ισορροπίας, υπό τις εναλλακτικές υποθέσεις αναφορικά με (α) τον βαθμό ορθολογικότητας και (β) τον μηχανισμό επιλογής των διεξαγομένων ελέγχων.

Από την ανάλυση ανέκυψε ότι ανεξαρτήτως από θεωρούμενο επίπεδο ορθολογικής ικανότητας επιλογής, εάν το επίπεδο ελέγχου επιλεχθεί με αυθαίρετο τρόπο τότε ο πληθυσμός των υπό-ρύθμιση οικονομικών μονάδων υιοθετεί μια μονομορφική συμπεριφορά, η οποία και συνεπάγεται είτε πλήρη συμμόρφωση (full compliance) ή μηδενική συμμόρφωση (non compliance) με τις νομικά θεσμοθετημένες περιβαλλοντικές υποχρεώσεις. Για την επίτευξη του στόχου της πλήρους συμμόρφωσης, τόσο υπό τον βελτιστοποιητικό όσο και τον μιμητικό κανόνα συμπεριφοράς, το υλοποιούμενο επίπεδο ελέγχου πρέπει να διατηρείται αμετάβλητο (fixed) στο χρόνο καθώς και να τεθεί μεγαλύτερο από την κριτική τιμή που θέτει τις οικονομικές μονάδες αδιάφορες ανάμεσα στην στρατηγική συμμόρφωσης και απόκλισης (παραβατική στρατηγική). Η μόνη διαφοροποίηση ανάμεσα στους δύο κανόνες ορθολογικής ικανότητας είναι η χρονική επίτευξη της επιθυμούμενης μακροχρόνιας συμπεριφοράς. Στην μεν περίπτωση της πλήρους ορθολογικότητας επιτυγχάνεται άμεση σύγκλιση στο επιθυμητό σημείο ισορροπίας, ενώ στην δε περίπτωση της πεπερασμένης ορθολογικότητας υπάρχει σταδιακή σύγκλισή στο σημείο πλήρους συμμόρφωσης.

Διαφοροποίηση παρατηρείται στην μακροχρόνια συμπεριφορά του υπό-εξέταση πληθυσμού, στην περίπτωση που το υλοποιούμενο επίπεδο ελέγχου επιλέγεται με βέλτιστο τρόπο. Η λύση του συμβατικού προβλήματος βελτιστοποίησης υπό το καθιερωμένο περιορισμό του κανόνα της πλήρους ορθολογικής ικανότητας επιλογής, συνεπάγεται όπως και ανωτέρω την υιοθέτηση μιας ξεκάθαρα μονομορφικής συμπεριφοράς από πλευράς του ρυθμιζόμενου πληθυσμού. Ωστόσο όταν το κριτήριο κοινωνικής ευημερίας ελαχιστοποιείται υπό τον περιορισμό του δυναμικά μιμητικού κανόνα συμπεριφοράς, τότε το εξελικτικά ευσταθές σημείο ισορροπίας διέπεται είτε από μια μονομορφική ή πολυμορφική συμπεριφορά του πληθυσμού. Στην προκειμένη περίπτωση η πολυμορφική συμπεριφορά συνεπάγεται μερική συμμόρφωση (partial compliance) του πληθυσμού με τις περιβαλλοντικές υποχρεώσεις και η σύγκλιση στο εν λόγω σημείο ισορροπίας εξαρτάται ιδιαίτερα από τις αρχικές συνθήκες του προβλήματος.

Τέλος, το πρόβλημα επιλογής ελέγχου εμπλουτίσθηκε και με την απόφαση για επένδυση σε κεφάλαιο ελέγχου, όπου ανάλυση δεν ανέδειξε ιδιαίτερες τροποποιήσεις στη δυναμική συμπεριφορά του υπό εξέταση πληθυσμού εν συγκρίσει με τα προαναφερθέντα αποτελέσματα. Τα ανωτέρω οδηγούν στο ασφαλές συμπέρασμα ότι τα κίνητρα για συμμόρφωση με νομικά υποδεικνυόμενες περιβαλλοντικές συμπεριφορές ενός υπό ρύθμιση πληθυσμού που απαρτίζεται από ομοιογενείς οικονομικές μονάδες, επηρεάζονται τόσο (α) από τον κανόνα επιλογής του επιπέδου ελέγχου καθώς και επένδυσης σε ελεγκτικό κεφάλαιο, όσο και (β) από τον υιοθετούμενο εναλλακτικό και αντικρουόμενο κανόνα συμπεριφοράς αναφορικά με το θεωρούμενο επίπεδο ορθολογικής ικανότητας επιλογής των υπό-εξέταση οικονομικών μονάδων.

Η συνεισφορά της εν λόγω ερευνητικής εργασίας έγκειται στο γεγονός ότι:

- ✓ Αντιπαραβάλλει την καθιερωμένη υπόθεση της πλήρους ορθολογικότητας και την σχετικά πιο ρεαλιστική υπόθεση της πεπερασμένης ορθολογικής ικανότητας επιλογής, όπως αυτή εκφράζεται μέσω των δυναμικά μιμητικών μοντέλων, μέσω της αποτίμησης της επίδρασης αυτών στην μακροχρόνια συμπεριφορά ενός πληθυσμού ομοιογενών οικονομικών μονάδων αναφορικά με την συμμόρφωση ή όχι αυτού με υπάρχουσες, νομικά θεσμοθετημένες περιβαλλοντικές ρυθμίσεις.
- ✓ Συνδυάζει ένα πρόβλημα δυναμικού βέλτιστου ελέγχου με ένα εξελικτικά μιμητικά κανόνα συμπεριφοράς αντί για τον συμβατικό βελτιστοποιητικό κανόνα.

Η παρούσα ερευνητική εργασία διαμορφώνει ένα γενικευμένο πλαίσιο που επιτρέπει την ανάλυση της δυναμικής συμπεριφοράς ενός υπό-ρύθμιση πληθυσμού ομοιογενών οικονομικών μονάδων, ο οποίος και δραστηριοποιείται σε ένα περιβάλλον με έντονα μη-σημειακά χαρακτηριστικά γνωρίσματα, υπό την παρουσία ενός μηχανισμού ελέγχων και κυρώσεων. Μέσω του εν λόγω πλαισίου καθίσταται εφικτή η διατύπωση προτάσεων για τον ορθό σχεδιασμό του μηχανισμού ελέγχων και κυρώσεων, προκειμένου να διασφαλίζεται τουλάχιστον η μερική συμμόρφωση ενός δεδομένου ρυθμιζόμενου πληθυσμού με υποδεικνυόμενες περιβαλλοντικά φιλικές συμπεριφορές. Δεδομένου δε ότι το εξεταζόμενο δημόσιο εθελοντικό περιβαλλοντικό πρόγραμμα παρουσιάζει αρκετές ομοιότητες με διάφορα κοινοτικά προγράμματα ανάπτυξης της υπαίθρου, το αναπτυχθέν αναλυτικό πλαίσιο μπορεί να αναπροσαρμοστεί καταλλήλως στα δεδομένα έκαστης περίπτωσης ούτως ώστε να εξαχθούν χρήσιμα συμπεράσματα αναφορικά με το σωστό σχεδιασμό του ελεγκτικού σχεδιασμού.

Το συγκεκριμένο αναλυτικό πλαίσιο μπορεί να εφαρμοστεί περαιτέρω για την αποτίμηση των κινήτρων για συμμόρφωση με δεδομένες περιβαλλοντικές ρυθμίσεις ενός πληθυσμού οικονομικών μονάδων υπό την παρουσία ενός μηχανισμού ατελών ελέγχων (imperfect monitoring), υπό την έννοια ότι οι ατομικές αποφάσεις (εκπομπές ρύπων, χρησιμοποιούμενες εισροές) μπορεί να μην αποτιμηθούν σωστά από ένα τρίτο φορέα (ρυθμιστή), με συνέπεια να επιβληθούν εσφαλμένα κυρώσεις σε οικονομικές μονάδες οι οποίες συμμορφώνονται με τις υποδείξεις του εθελοντικού περιβαλλοντικού προγράμματος. [1] Επιπλέον, η μακροχρόνια συμπεριφορά ενός πληθυσμού οικονομικών μονάδων μπορεί να αναλυθεί υπό το πρίσμα εναλλακτικών κανόνων μιμητικής συμπεριφοράς, όπως είναι ο κανόνας των μέσων απολαβών (average profit principle) και ο κανόνας της αποτελεσματικής ποινής (effective punishment principle), προκειμένου να εντοπισθεί πιθανές μεταβολές στα ποιοτικά χαρακτηριστικά των εξαγομένων, σε έκαστη περίπτωση, σημείων ευστάθειας.[2] Τέλος, ενδιαφέρον παρουσιάζει ο συνδυασμός σε ένα πρόβλημα βέλτιστου ελέγχου τόσο του βελτιστοποιητικού όσο και του δυναμικά μιμητικού κανόνα συμπεριφοράς, υπό την έννοια ότι ένα μερίδιο του εξεταζόμενου πληθυσμού χαρακτηρίζεται από πλήρη ορθολογική ικανότητα επιλογής ενώ το υπολειπόμενο μερίδιο διακρίνεται από πεπερασμένη ορθολογική ικανότητα επιλογής.

[1]Για περαιτέρω λεπτομέρειες όρα Malik (1993).

[2]Για περαιτέρω λεπτομέρειες όρα Lipatov (2005).

Κεφάλαιο ΙΙ:

"Μοντελοποίηση της Αγροτικής Συμπεριφοράς υπό το Καθεστώς Παροχών της Κοινής Αγροτικής Πολιτικής: Αποτίμηση των Περιβαλλοντικών Επιπτώσεων και της Αποτελεσματικότητας της Πολιτικής"

Το **Κεφάλαιο ΙΙ** εστιάζει σε ένα ρυθμιστικό πλαίσιο, στο οποίο ενσωματώνονται οι βασικές μεταρρυθμίσεις της Κοινής Αγροτικής Πολιτικής (ΚΑΠ) για τις οργανώσεις κοινών αγορών (CMOs) καθώς και για την ανάπτυξη της υπαίθρου (RD), όπως αυτές περιγράφονται από το πρώτο και δεύτερο πυλώνα της μεταρρύθμισης "Ατζέντα 2000". Αναπτύσσει ένα γενικευμένο θεωρητικό μοντέλο για την περιγραφή της αγροτικής δραστηριότητας υπό το προαναφερθέντα ρυθμιστικό πλαίσιο, μέσω του οποίου αποτιμούνται οι επιπτώσεις των διαφόρων τύπου ενισχύσεων της εν λόγω κοινοτικής πολιτικής στην περιβαλλοντική επίδοση ενός πληθυσμού ομοειδών οικονομικών μονάδων. Η εν λόγω αποτίμηση καθίσταται επιτεύξιμη μέσω της εκτίμησης της επίδρασης των διαφόρων υποκαθεστώτων ενισχύσεων του πρώτου και δεύτερου πυλώνα στις παραγωγικές αποφάσεις μιας αντιπροσωπευτικής οικονομικής μονάδας, ανεξαρτήτως από το θεωρούμενο επίπεδο ορθολογικής ικανότητας επιλογής. Επίσης, εκτιμά την αποτελεσματικότητα της μεταρρύθμισης "Ατζέντας 2000" να υποκινήσει την συμμόρφωση ολόκληρου του πληθυσμού (πλήρης συμμόρφωση) με ένα κοινωνικά προκαθορισμένο περιβαλλοντικό στόχο, μέσω της θεώρησης του μηχανισμού που προσδιορίζει το τύπο των κοινωνικά βέλτιστων ρυθμιστικών μέτρων της εν λόγω κοινοτικής πολιτικής. Συγκεκριμένα, προσδιορίζεται ο τύπος: (α) των στατικών και δυναμικών κοινωνικά βέλτιστων ρυθμιστικών μέτρων υπό την υπόθεση της απεριόριστης ορθολογικής ικανότητας επιλογής, καθώς και (β) των εξελικτικά δυναμικών κοινωνικά βέλτιστων ρυθμιστικών μέτρων υπό την υπόθεση της πεπερασμένης ορθολογικής ικανότητας.

Στο υπό το εξέταση επίσημο δημόσιο εθελοντικό πρόγραμμα, παρέχεται σε έκαστη οικονομική μονάδα (αγρότης της Ευρωπαϊκής Ένωσης) μια επιδότηση συνδεδεμένη με το επίπεδο του παραγομένου προϊόντος (coupled payment), καθώς και δύο ειδών άμεσων ενισχύσεων (direct payments), χορηγούμενες βάσει της έκτασης γης που τίθεται σε (α) καλλιέργεια και (β) αγρανάπαυση. Σύμφωνα με της αρχή της οριζόντιας ρύθμισης (horizontal regulation) το ποσό των εν λόγω άμεσων ενισχύσεων παρέχεται στο ακέραιο υπό την προϋπόθεση ότι τηρούνται συγκεκριμένες περιβαλλοντικές ρήτρες, αναφορικά με (α) την ποιοτική κατάσταση της καλλιεργούμενης αγροτικής έκτασης (land quality standard), καθώς και με (β) την έκταση της αγροτικής γης που επιτρέπεται να τεθεί σε καλλιέργεια (land usage standard). Οι εν λόγω περιβαλλοντικοί στόχοι δύναται να επιτευχθούν είτε μέσω της (α) περικοπής των πρωτογενών παραγωγικών επιλογών (primary production choices) (πχ καλλιεργούμενη γη) ή μέσω της (β) εισαγωγής δευτερογενών παραγωγικών επιλογών (secondary production choices), οι οποίες συνδράμουν στην περιβαλλοντικά φιλική μεταχείριση (treatment) των πρωτογενών επιλογών (πχ φράκτες, αναβαθμίδες). Οι συγκεκριμένες περιβαλλοντικά φιλικές παραγωγικές επιλογές χρηματοδοτούνται εν μέρει από κοινοτικά αναπτυξιακά προγράμματα (rural development programs), προσφερόμενα από τον δεύτερο πυλώνα της κοινοτικής αγροτικής πολιτικής για την ανάπτυξη της υπαίθρου, τα οποία και προβλέπουν την παροχή μιας σειράς επιδοτήσεων ανά μονάδα υλοποιούμενων περιβαλλοντικά φιλικών δράσεων (per unit subsidy).

Δεδομένου του μη-σημειακού χαρακτήρα των αγροτικών δραστηριοτήτων και των έμφυτων κινήτρων για παρέκκλιση από τις προαναφερθείσες περιβαλλοντικές υποχρεώσεις (free-riding incentive), τόσο οι άμεσες ενισχύσεις όσο και οι επιδοτήσεις για την ανάπτυξη της υπαίθρου (rural development subsidies) υπόκεινται στην αρχή της διασταυρωμένης συμμόρφωσης (cross-compliance principle). Πρόκειται για μια διαδικασία κυρώσεων, ενσωματωμένη στην αρχή της οριζόντιας ρύθμισης, η οποία και συνεπάγεται την επιβολή αναλογικών ποινών στην περίπτωση που επαληθεύεται η παράβαση των περιβαλλοντικών ρητρών. Συγκεκριμένα, προβλέπεται η μερική ή πλήρη αφαίρεση των παρεχομένων οικονομικών ενισχύσεων σε εκείνες τις οικονομικές μονάδες, που έπειτα από ένα τυχαίο έλεγχο, εντοπίζονται να αποκλίνουν από τα καθορισμένα ποιοτικά και ποσοτικά όρια δράσης.

Η γενικευμένη φύση του αναπτυχθέντος αναλυτικού πλαισίου καθιστά δυνατή την αποτίμηση και σύγκριση των επιδράσεων στην περιβαλλοντική συμπεριφορά ενός πληθυσμού ομοειδών οικονομικών μονάδων, των διαφόρων καθεστώτων ενισχύσεων της κοινοτικής αγροτικής πολιτικής, όπως αυτά καθορίζονται από την μεταρρύθμιση του 1999. Η εν λόγω συμπεριφορά ορίζεται σε όρους πρωτογενών ή / και δευτερογενών παραγωγικών επιλογών και μελετάται μέσω της εκτίμησης της επίδρασης των διαφόρων υποκαθεστώτων ενισχύσεων του πρώτου και δεύτερου πυλώνα στις παραγωγικές αποφάσεις μιας αντιπροσωπευτικής οικονομικής μονάδας, ανεξαρτήτως από το θεωρούμενο επίπεδο ορθολογικής ικανότητας επιλογής. Η προαναφερθείσα σύγκριση διεξάγεται μέσω της αποτίμησης των συνθηκών βελτιστοποίησης (optimality conditions) ενός δεδομένου υποκαθεστώτος ενισχύσεων της εν λόγω κοινοτικής πολιτικής στις βέλτιστες παραγωγικές επιλογές ενός εναλλακτικού υποκαθεστώτος ενισχύσεων (profit maximizing equilibrium choices).

Τα συγκρινόμενα υποκαθεστώτα της κοινοτικής αγροτικής πολιτικής, όπως αυτή διαμορφώνεται από την μεταρρύθμιση "Ατζέντας 2000", διακρίνονται σε τρεις γενικευμένες κατηγορίες. Πρόκειται για υποκαθεστώτα που προβλέπουν: (α) την χορήγηση ενισχύσεων μονάχα από το πρώτο πυλώνα για τις οργανώσεις κοινών αγορών, (β) την παροχή επιδοτήσεων από το δεύτερο πυλώνα για την ανάπτυξη της υπαίθρου, καθώς και (γ) την παροχή ενός συνδυασμού από ενισχύσεις προερχόμενες τόσο από το πρώτο όσο και τον δεύτερο πυλώνα. Εντός των εξεταζόμενων υποκαθεστώτων παρεμβατικής πολιτικής υπάγονται: (α) το καθεστώς πλήρους σύνδεσης των ενισχύσεων με το επίπεδο του παραγομένου προϊόντος (full coupling regime), (β) το καθεστώς μερικής καθώς και πλήρους αποσύνδεσης των ενισχύσεων από το παραγόμενο προϊόν (partial and full decoupling regime), (γ) το καθεστώς ενισχύσεων ανά μονάδα υλοποιούμενων περιβαλλοντικά φιλικών δράσεων (rural development regime), καθώς και (δ) τα προαναφερθέντα καθεστώτα της πλήρους σύνδεσης, της μερικής και πλήρους αποσύνδεσης των ενισχύσεων από το επίπεδο του παραγομένου προϊόντος, διευρυμένα με τις ενισχύσεις του δεύτερου πυλώνα για την εισαγωγή περιβαλλοντικά φιλικών δράσεων (extended full coupling, partial and full decoupling regime).

Τόσο υπό την συμβατική υπόθεση της πλήρους ορθολογικής ικανότητας επιλογής, όσο και υπό την υπόθεση της πεπερασμένης ορθολογικής ικανότητας, διαμορφώνεται ο μηχανισμός επιλογής των κοινωνικά βέλτιστων μέτρων πολιτικής. Μέσω αυτού του μηχανισμού καθορίζεται το είδος των παρεμβατικών εργαλείων του πρώτου και δεύτερου πυλώνα της "Ατζέντας 2000" που καθιστά εφικτή την επίτευξη του συλλογικού περιβαλλοντικού στόχου, καθώς και το είδος της συσχέτισης που διακρίνει μεταξύ τους τα εν λόγω παρεμβατικά εργαλεία μέτρα πολιτικής.

Συγκεκριμένα, η αποτελεσματικότητα της "Ατζέντας 2000" να υποκινήσει ολόκληρο τον πληθυσμό των πλήρους ορθολογικών οικονομικών μονάδων να υιοθετήσουν τις κοινωνικά βέλτιστες παραγωγικές επιλογές υπό την συμβατική υπόθεση της ικανότητας επιλογής, διερευνάται τόσο σε στατικό όσο και σε δυναμικό επίπεδο μέσω ενός συστήματος προσδιοριζόμενου από τις συνθήκες βελτιστοποίησης του κοινωνικού σχεδιαστή (social planner) και της αντιπροσωπευτικής οικονομικής μονάδας που υιοθετεί την παραβατική στρατηγική (free-riding strategy). Τα βέλτιστα εργαλεία αγροτικής πολιτικής προσδιορίζονται και υπό την υπόθεση της πεπερασμένης ορθολογικής ικανότητας βάσει του πλαισίου των δυναμικά μιμητικών εξισώσεων. Συγκεκριμένα, στην προκειμένη περίπτωση αποτιμάται η μακροχρόνια βιωσιμότητα της προαναφερθείσας μεταρρύθμισης, καθώς εξετάζεται κατά πόσον η τωρινή δομή της Κοινής Αγροτικής Πολιτικής μπορεί να ωθήσει την πλειοψηφία είτε και την ολότητα του υπό-ρύθμιση πληθυσμού των ομοιογενών οικονομικών μονάδων να υιοθετήσει την στρατηγική που συνεπάγεται συμμόρφωση με τις προβλεπόμενες περιβαλλοντικές ρήτρες.

Η ανάλυση ανέδειξε ότι τόσο το εργαλείο των άμεσων ενισχύσεων όσο και ο μηχανισμός διεξαγωγή ελέγχων και επιβολής κυρώσεων για την παρακίνηση της συμμόρφωσης (compliance enforcement mechanism), μπορεί να κριθούν ανεπαρκή ως μέτρα πολιτικής παρέμβασης καθώς μπορεί να αδυνατούν να ωθήσουν τις αποκλίνουσες οικονομικές μονάδες (deviating agents) να μεταβάλλουν τις παραγωγικές αποφάσεις τους και να υιοθετήσουν μια στρατηγική που προσεγγίζει (είτε και ταυτίζεται με) την στρατηγική συμμόρφωσης. Παρά ταύτα ανεξαρτήτως από το θεωρούμενο επίπεδο ορθολογικής ικανότητας επιλογής, η ενσωμάτωση στο σχεδιασμό της Κοινής Αγροτικής Πολιτικής του ρυθμιστικού μέτρου των περιβαλλοντικών ρητρών καθώς και των ενισχύσεων για την ανάπτυξη της υπαίθρου, έχει συνδράμει στην βελτίωση της περιβαλλοντικής συμπεριφοράς των μεμονωμένων οικονομικών μονάδων και συνεπώς του πληθυσμού αυτών.

Αναφορικά με την σχετική περιβαλλοντική επίδοση των διαφόρων υποκαθεστώτων ενισχύσεων της μεταρρύθμισης "Ατζέντας 2000", το καθεστώς που διακρίνεται από την απουσία πολιτικών παρεμβάσεων (non-intervention regime) είναι προτιμότερο σε περιβαλλοντικούς όρους από το καθεστώς που χαρακτηρίζεται την παροχή επιδοτήσεων συνδεδεμένων με το επίπεδο του παραγόμενου προϊόντος. Ωστόσο η περιβαλλοντική απόδοση του καθεστώτος τόσο της μερικής όσο και της ολικής αποσύνδεσης των ενισχύσεων από το παραγόμενο προϊόν δεν μπορεί να θεωρηθεί ξεκάθαρα ως ανώτερη (superior) εκείνης που προκύπτει υπό τα καθεστώτα της μη-παρέμβασης και της παροχής πλήρως συνδεδεμένων με το επίπεδο παραγωγής ενισχύσεων (fully coupled payments).

Αν και σε όρους πρωτογενών παραγωγικών επιλογών, η πολιτική παρέμβαση μέσω πλήρως αποσυνδεμένων ενισχύσεων (fully decoupled payments) κρίνεται προτιμότερη της παρέμβασης μέσω μερικώς αποσυνδεμένων ενισχύσεων (partially decoupled payments), τόσο υπό την απουσία όσο και παρουσία περιβαλλοντικών ορίων δράσης, η σχετική περιβαλλοντική επίδοση του υπό-ρύθμιση πληθυσμού είναι ασαφής όταν το σύνολο των παραγωγικών επιλογών διευρύνονται με δευτερογενείς παραγωγικές επιλογές. Συνεπώς, σύμφωνα με την υιοθετούμενη δομή για την περιγραφή της αγροτικής δράσης υπό την παρουσία της Κοινής Αγροτικής Πολιτικής, δεν υπάρχουν ξεκάθαρες ενδείξεις ότι η μετάβαση αρχικά (α) αρχικά από το καθεστώς πλήρους σύνδεσης των ενισχύσεων με το επίπεδο του παραγομένου προϊόντος του πρώτου πυλώνα, στο καθεστώς της μερικής και πλήρους αποσύνδεσης των ενισχύσεων αυτών, τόσο υπό την χορήγηση όσο και την μη-παροχή ενισχύσεων του δεύτερου πυλώνα, και η μετάβαση τελικά (β) στο καθεστώς που συνεπάγεται μονάχα την χορήγηση ενισχύσεων του δεύτερου πυλώνα για την ανάπτυξη της υπαίθρου, έχει παρακινήσει τον υπό-ρύθμιση πληθυσμό των ομοειδών οικονομικών μονάδων να περιορίσει τις πρωτεύουσες ενώ ταυτόχρονα να επεκτείνει τις δευτερεύουσες παραγωγικές επιλογές του, συμβάλλοντας στην βελτίωση της περιβαλλοντικής συμπεριφοράς αυτού.

Τέλος, υπό την παρουσία τόσο της πλήρους όσο και πεπερασμένης ορθολογικής ικανότητας επιλογής, η αποτίμηση των κοινωνικά βέλτιστων ρυθμιστικών μέτρων, τόσο του πρώτου όσο και του δεύτερου πυλώνα της κοινοτικής αγροτικής πολιτικής, οδήγησε στο συμπέρασμα ότι η διατήρηση των συνδεδεμένων με το επίπεδο παραγωγής ενισχύσεων μπορεί να είναι κοινωνικά επιθυμητή σε περιβαλλοντικούς όρους. Συνάμα, μπορεί να κρίνεται κοινωνικά ωφέλιμος ο εμπλουτισμός του μηχανισμού διεξαγωγής ελέγχων και επιβολής κυρώσεων για την παρακίνηση της συμμόρφωσης, με ένα ευρύτερο σύνολο κυρώσεων επεκτεινόμενο σε πτυχές της αγροτικής δραστηριότητας όπως είναι οι αποδόσεις των καλλιεργειών, η καλλιεργήσιμη έκταση, η έκταση που τίθεται σε αγρανάπαυση καθώς και οι δευτερογενείς παραγωγικές επιλογές.

Εκ των ανωτέρω συμπεραίνεται ότι η επίτευξη του κοινωνικά βέλτιστου επιπέδου αναφορικά με την ποιότητα της συλλογικά καλλιεργήσιμης αγροτικής γης (aggregate land quality), μπορεί να απαιτεί μέτρα παρεμβατικής πολιτικής τα οποία ωστόσο δεν προβλέπονται από την τρέχουσα δομή της Κοινής Αγροτικής Πολιτικής, καθώς και με ευέλικτα στο χρόνο μέτρα πολιτικής (time-flexible instruments) που είναι πρακτικά ανέφικτα. Συνεπώς, υπό την τρέχουσα δομή της κοινοτικής πολιτικής, όπως αυτή εκφράζεται μέσω των "Ατζέντας 2000" και της Ενδιάμεσης Μεταρρύθμισης (Mid term Review), ο ρυθμιζόμενος πληθυσμός οδηγείται σε καταστάσεις που δύναται να χαρακτηρισθούν ως "περιβαλλοντικά υποβέλτιστες" (suboptimal), όπου τόσο η αποτελεσματικότητα όσο και η μακροχρόνια βιωσιμότητα της Κοινής Αγροτικής Πολιτικής κρίνεται αμφίβολη και εξαρτώμενη από τις υπάρχουσες συνθήκες.

Η συνεισφορά της εν λόγω ερευνητικής εργασίας έγκειται στην:

- ✔ Ανάπτυξη ενός θεωρητικού μοντέλου όπου περιγράφεται η αγροτική συμπεριφορά υπό το γενικευμένο καθεστώς ενισχύσεων της Κοινής Αγροτικής Πολιτικής, όπως αυτές περιγράφονται από το πρώτο και δεύτερο πυλώνα της μεταρρύθμισης "Ατζέντας 2000", παρέχοντας την δυνατότητα για τον προσδιορισμό των διαφόρων υποκαθεστώτων της εν λόγω μεταρρύθμισης μέσω των καταλλήλων απλουστευτικών υποθέσεων.
- ✔ Θεωρητική αποτίμηση και σύγκριση των επιπτώσεων των διαφόρων υποκαθεστώτων της εν λόγω μεταρρύθμισης στις παραγωγικές αποφάσεις και συνεπώς στην περιβαλλοντική συμπεριφορά ενός πληθυσμού ομοιογενών οικονομικών μονάδων.
- ✔ Προσδιορισμός του μηχανισμού επιλογής των κοινωνικά βέλτιστων ρυθμιστικών μέτρων της κοινοτικής αγροτικής πολιτικής, μέσω του οποίου καθορίζεται το είδος των κοινωνικά βέλτιστων παρεμβατικών εργαλείων του πρώτου και δεύτερου πυλώνα, υπό την υπόθεση τόσο της πλήρους όσο

και της πεπερασμένης ορθολογικής ικανότητας επιλογής των υπό-εξέταση οικονομικών μονάδων.

- ✔ Θεωρητική αποτίμηση της στατικής και δυναμικής βιωσιμότητας της μεταρρύθμισης "Ατζέντας 2000" υπό την συμβατική υπόθεση της πλήρους – απεριόριστης ορθολογικής ικανότητας επιλογής, καθώς και της μακροχρόνιας, εξελικτικής βιωσιμότητας αυτής υπό την υπόθεση της πεπερασμένης ορθολογικής ικανότητας επιλογής.

Στην παρούσα ερευνητική εργασία περιγράφεται μια μεθοδολογία, η οποία μπορεί να γενικευθεί περαιτέρω και να εφαρμοστεί για την εξαγωγή ασφαλών συμπερασμάτων αναφορικά με την σχετική επίδραση ρυθμιστικών πολιτικών με πανομοιότυπα αλλά και αντικρουόμενα χαρακτηριστικά γνωρίσματα, στην περιβαλλοντική ή και μη-περιβαλλοντικού συμπεριφορά ενός πληθυσμού οικονομικών μονάδων. Παράλληλα, η εν λόγω μεθοδολογία μπορεί να χρησιμοποιηθεί και για τον προσδιορισμό του τύπου των παρεμβατικών πολιτικών που καθιστούν εφικτή την επίτευξη ενός συλλογικού στόχου στο διηνεκές, υπό εναλλακτικές και αντικρουόμενες υποθέσεις αναφορικά με το επίπεδο ορθολογικής ικανότητας επιλογής των υπό ρύθμιση οικονομικών μονάδων.

Το αναπτυχθέν θεωρητικό μοντέλο περιγραφής της αγροτικής συμπεριφοράς υπό την παροχή ενισχύσεων της κοινοτικής αγροτικής πολιτικής, δύναται να διευρυνθεί περαιτέρω προκειμένου να ενσωματωθούν σε αυτό πιο εξειδικευμένα χαρακτηριστικά γνωρίσματα τόσο της μεταρρύθμισης "Ατζέντας 2000" όσο και της Ενδιάμεσης Μεταρρύθμισης. Συγκεκριμένα, το θεωρούμενο ρυθμιστικό πλαίσιο μπορεί να ενισχυθεί με: (α) τις πιστώσεις (carbon credits) που παρέχονται για την παραγωγή, σε εδάφη που έχουν τεθεί σε αγρανάπαυση, καλλιεργειών που χαρακτηρίζονται ως ενεργειακές και έχουν μηδενική διατροφική αξία (non-food), καθώς και με (β) την αναθεωρημένη αρχή της διασταυρωμένης συμμόρφωσης όπου λαμβάνεται υπόψη η περίπτωση μη-συμμόρφωσης τόσο από αμέλεια (negligence) όσο και από σκοπιμότητα (deliberateness), και κατά συνέπεια διαφοροποιείται το μέγεθος των επιβαλλόμενων ποινών σε έκαστη περίσταση. Τέλος, η περιβαλλοντική συμπεριφορά του εξεταζόμενου πληθυσμού των ομοιογενών οικονομικών μονάδων μπορεί να αποτιμηθεί και υπό (α) την παρουσία αβέβαιων διαταραχών (uncertainty shocks -

όπως είναι οι πλημμύρες) και (β) την άσκηση πιέσεων προς τις ρυθμιστικές ή και ελεγκτικές αρχές από ομάδες συμφερόντων (lobbying groups - όπως οι μη-κυβερνητικές περιβαλλοντικές οργανώσεις).

Κεφάλαιο ΙΙΙ:
"Σχεδιασμός ενός Εθελοντικού Δημόσιου Περιβαλλοντικού Προγράμματος για την Αντιμετώπιση της Αγροτικής Νιτρορύπανσης: Μια Εξελικτική Προσέγγιση"

Το **Κεφάλαιο ΙΙΙ** εξετάζει την ταυτόχρονη εξέλιξη των κινήτρων για συμμετοχή και συμμόρφωση ενός υπό-ρύθμιση πληθυσμού με τις περιβαλλοντικές αξιώσεις ενός δημόσιου εθελοντικού προγράμματος, υπό την παρουσία γρήγορων – αργών δυναμικών επιλογής όσον αφορά την χρονική λήψη της απόφασης για συμμετοχή και συμμόρφωση. Εστιάζει στην διαμόρφωση των χαρακτηριστικών ενός δημόσιου εθελοντικού περιβαλλοντικού προγράμματος, το οποίο στηρίζεται στην βάση των κοινοτικών αναπτυξιακών προγραμμάτων του δεύτερου πυλώνα για την ανάπτυξη της υπαίθρου της Κοινής Αγροτικής Πολιτικής. Προβαίνει στην επισήμανση των παραγόντων που συμβάλλουν στη εξελικτική βιωσιμότητα αυτού, καθώς και στην διατύπωση γενικών κανόνων που καθιστούν εφικτή την επίτευξη ενός επιθυμητού περιβαλλοντικού στόχου τόσο υπό την παρουσία όσο και την απουσία ενός χρηματοδοτικού περιορισμού.

Υπό το προτεινόμενο δημόσιο εθελοντικό πρόγραμμα δίδεται η δυνατότητα στο εξεταζόμενο πληθυσμό των ομοειδών οικονομικών μονάδων να προβεί στην εθελοντική περικοπή των ατομικών εκπομπών ρύπων μέσω της υιοθέτησης μιας ευέλικτης μεθόδου περικοπής δαπανών (flexible cost saving method), ούτως ώστε να επιτευχθεί ένα προκαθορισμένο συλλογικό επίπεδο ρύπανσης. Αν διασφαλισθεί η πλήρης συμμετοχή του πληθυσμού στο εν λόγω αναπτυξιακό πρόγραμμα τότε καθίσταται εφικτή η επίτευξη του συλλογικού στόχου. Ωστόσο στην περίπτωση που επιτυγχάνεται μονάχα η μερική συμμετοχή του πληθυσμού (partial participation), παρατηρείται απόκλιση από τον επιθυμητό περιβαλλοντικό στόχο και υπάρχει η πιθανότητα να επιβληθεί μια συμβατική ευθύς νομοθετική ρύθμιση (direct regulation), η οποία είναι πιο επιβλαβής σε όρους κόστους συγκριτικά με το θεωρούμενο δημόσιο πρόγραμμα.

Η απόφαση για συμμετοχή, ωστόσο, δεν συνεπάγεται κατ' ανάγκη και συμμόρφωση με τις περιβαλλοντικές απαιτήσεις του προγράμματος. Δεδομένου όμως των μη-σημειακών χαρακτηριστικών της αγροτικής δραστηριότητας, δεν είναι πρακτικά επιτεύξιμη η ταυτόχρονη εξακρίβωση της συμμόρφωση ή μη ολόκληρου του πληθυσμού των εμπλεκομένων οικονομικών μονάδων. Στην προκειμένη περίπτωση η ρυθμιστική αρχή διεξάγει τυχαίους ελέγχους για τον εντοπισμό των αποκλινουσών οικονομικών μονάδων, στις οποίες και προβλέπεται η επιβολή κυρώσεων προκειμένου να αποτραπεί η διαιώνιση μια τέτοιας φύσεως παραβατικής συμπεριφοράς. Συνεπώς οι συμμετέχουσες στο πρόγραμμα οικονομικές μονάδες έχουν την επίγνωση ότι υπάρχει η πιθανότητα να επιθεωρηθούν και να επιβληθούν σε αυτές κυρώσεις στην περίπτωση του εντοπισμού μη-συμμόρφωσης με τις περιβαλλοντικές αξιώσεις του προαναφερθέντος προγράμματος.

Υπό την υπόθεση της πεπερασμένης ορθολογικής ικανότητας επιλογής, στην απόφαση τους κατά πόσον είναι επωφελές πρωτίστως να (α) συμμετάσχουν στο αναπτυξιακό πρόγραμμα και μετέπειτα να (β) συμμορφωθούν με τις περιβαλλοντικές υποδείξεις αυτού, οι υπό-ρύθμιση οικονομικές μονάδες στηρίζονται στο εδραιωμένο μιμητικό δυναμικό πλαίσιο που συνεπάγεται υιοθέτηση της στρατηγικής με την καλύτερη απόδοση. Μέσω της συγκεκριμένης εξελικτικής παθητικής διαδικασίας λήψης αποφάσεων, παρέχεται η δυνατότητα αποτίμησης των μεταβολών στην σύσταση του εξεταζόμενου πληθυσμού αναφορικά με τα κίνητρα των οικονομικών μονάδων τόσο για συμμετοχή όσο και για συμμόρφωση με προτεινόμενο δημόσιο εθελοντικό πρόγραμμα.

Οι αποφάσεις αρχικά για συμμετοχή και εν τέλει για συμμόρφωση θεωρείται ότι λαμβάνουν χώρα σε διαφορετικές χρονικές κλίμακες, καθώς νομικές ρήτρες επιβάλουν η μεν απόφαση για συμμετοχή να λαμβάνει χώρα γρήγορα (fast) ενώ η δε απόφαση για συμμόρφωση λαμβάνει χώρα σχετικά πιο αργά (slow) καθώς δεν υπόκειται σε κάποιο νομικό περιορισμό. Η θεώρηση των εν λόγω γρήγορων – αργών δυναμικών επιλογής έχει ως συνέπεια το μερίδιο ισορροπίας (equilibrium share) των οικονομικών μονάδων του πληθυσμού που συμμετάσχει στο πρόγραμμα να επιτυγχάνεται πιο γρήγορα εν συγκρίσει με το αντίστοιχο ποσοστό ισορροπίας των συμμορφωθέντων οικονομικών μονάδων.

Μέσω του ανωτέρω αναπτυχθέντος αναλυτικού πλαισίου καθίσταται εφικτός ο ταυτόχρονος προσδιορισμός του (α) μεριδίου του πληθυσμού των ομοειδών οικονομικών μονάδων που συμμετέχει και συνάμα του (β) μεριδίου του πληθυσμού που συμμορφώνεται με τις υποδείξεις του εθελοντικού προγράμματος, καθώς και του (γ) αποθέματος (stock) της συνολικής ρύπανσης που αντιστοιχεί στην εξελικτικά ευσταθή ισορροπία (evolutionary stable equilibrium). Είναι εμφανές από την ανάλυση ότι τα χαρακτηριστικά των εξελικτικά ευσταθών σημείων ισορροπίας καθώς και του τρόπου σύγκλισης (approach dynamics) του συστήματος προς αυτά εξαρτώνται ταυτοχρόνως από (α) το μέγεθος και τα χαρακτηριστικά τόσο της πιθανότητας επιβολής νομοθετικών ρυθμίσεων (legislation probability) στην περίπτωση της μερικής συμμετοχής, όσο και της πιθανότητας ελέγχου (inspection probability) στην περίπτωση της μερικής συμμόρφωσης (partial compliance), καθώς και από (β) την ύπαρξη ή μη χρηματοδοτικού περιορισμού.

Υπό εναλλακτικές υποθέσεις αναφορικά με την δομή της πιθανότητας επιβολής νομοθετικών ρυθμίσεων, το χρονικά γρήγορο δυναμικό σύστημα (fast time dynamic system) συγκλίνει είτε σε ένα πολυμορφικό ή μονομορφικό σημείο ευσταθούς κατάστασης (steady state), το οποίο συνεπάγεται μερική, πλήρης ή και μηδενική συμμετοχή του υπό-ρύθμιση πληθυσμού στο εξεταζόμενο περιβαλλοντικό πρόγραμμα. Παρομοίως, ανάλογα με την δομή της πιθανότητας ελέγχου το χρονικά αργό δυναμικό σύστημα (slow time dynamic system) συγκλίνει σε ένα σημείο ισορροπίας που μπορεί να διακρίνεται είτε από μερική, πλήρης ή μηδενική συμμόρφωση του πληθυσμού με τις εδραιωμένες περιβαλλοντικές ρήτρες. Ωστόσο όσο πιο πολύπλοκη είναι η δομή των εν λόγω πιθανοτήτων, τόσο πιο πιθανό είναι το εξελικτικό σημείο ισορροπίας να συνεπάγεται μερική συμμετοχή και μερική συμμόρφωση του υπό ρύθμιση πληθυσμού των ομοειδών οικονομικών μονάδων.

Υπάρχει η περίπτωση το δυναμικό σύστημα να διακρίνεται από ένα μοναδικό σημείο εξελικτικής ισορροπίας ή και πολλαπλά σημεία χαρακτηριζόμενα από πιθανές μη αναστρέψιμότητες (irreversibilities). Επίσης η σύγκλιση του συστήματος στα εν λόγω σημεία ευστάθειας μπορεί να είναι μονοτονική ή και σπειροειδής (monotonic or oscillating). Εάν ο απώτερος στόχος της ρυθμιστικής αρχής αποτελεί η πλήρης συμμετοχή και πλήρης συμμόρφωση του υπό ρύθμιση πληθυσμού με το συγκεκριμένο δημόσιο περιβαλλοντικό πρόγραμμα, τότε αυτός καθίσταται επιτεύξιμος (α) είτε μέσω της δέσμευσης της ρυθμιστικής αρχής σε αμετάβλητες στο χρόνο πιθανότητες επιβολής νομοθεσίας και ελέγχου, (β) είτε μέσω της κατάλληλης επιλογής της υποχρεωτικής νομοθετικής ρύθμισης (legislation mandate) καθώς και των κυρώσεων που επιβάλλονται στις εντοπιζόμενες αποκλίνουσες οικονομικές μονάδες. Το ίδιο αποτέλεσμα επιτυγχάνεται υπό συγκεκριμένες αρχικές συνθήκες (initial conditions) και κατάλληλα επιλεγμένες κυρώσεις, όταν οι προαναφερθείσες πιθανότητες ρύθμισης και ελέγχου είναι ενδογενείς στις μεταβλητές κατάστασης του προβλήματος (state variables). Ωστόσο, στην περίπτωση που (α) οι προϋποθέσεις αυτές δεν πληρούνται είτε (β) υπάρχει περιορισμός στο προϋπολογισμό που δύναται να διαθέσει η ρυθμιστική αρχή για την διεξαγωγή ελέγχων, τότε είναι ιδιαίτερα πιθανόν το γρήγορο – αργό σύστημα να συγκλίνει σε ένα εξελικτικό σημείο ισορροπίας το οποίο διακρίνεται από μερική συμμετοχή και μερική συμμόρφωση του υπό-ρύθμιση πληθυσμού.

Η συνεισφορά της εν λόγω εργασίας έγκειται στο γεγονός ότι:

- ✔ Συνδυάζει σε ένα ενοποιημένο αναλυτικό πλαίσιο την έννοια της πεπερασμένης ορθολογικής ικανότητας επιλογής, όπως αυτή περιγράφεται μέσω των δυναμικά μιμητικών μοντέλων, με την έννοια της χρονολογικής διάκρισης στην λήψη αποφάσεων όπως αυτή περιγράφεται μέσω γρήγορων – αργών δυναμικών επιλογής.

Η παρούσα εργασία διαμορφώνει ένα γενικευμένο πλαίσιο που επιτρέπει την ανάλυση της συμπεριφοράς ενός υπό-ρύθμιση πληθυσμού από ομοιογενείς οικονομικές μονάδες, οι οποίες δραστηριοποιούνται σε ένα τυπικό μη-σημειακό πρόβλημα ρύπανσης και διακρίνονται από πεπερασμένη ορθολογική ικανότητα επιλογής. Καθίσταται εφικτή η ταυτόχρονη μελέτη την διαμόρφωση των διαφόρων περιβαλλοντικών και μη κινήτρων (όπως είναι η εισαγωγή καινοτομιών, η απόφαση για έξοδο από την αγορά) ενός ευρέως πληθυσμού αναφορικά με την υιοθέτηση ή μη υποδεικνυόμενων και νομικά θεσμοθετημένων συμπεριφορών. Μέσω του αναπτυχθέν πλαισίου επιτρέπεται η εξαγωγή ασφαλών συμπερασμάτων αναφορικά με τη επίδραση των επιμέρους συστατικών του έκαστου εργαλείου ρυθμιστικής πολιτικής καθώς και της δομής του συναφούς ελεγκτικού μηχανισμού, στην σύσταση του πληθυσμού στο σημείο της μακροχρόνιας εξελικτικής ισορροπίας αναφορικά με την υιοθέτηση ή μη μιας επιθυμητής συμπεριφοράς, επιτρέποντας στην διατύπωση προτάσεων για τον ενδεικνυόμενο και ορθό σχεδιασμό αυτών. Συνεπώς, δεδομένου ότι υπάρχουν αρκετές και διαφαινόμενες ομοιότητες ανάμεσα στο προτεινόμενο δημόσιο εθελοντικό περιβαλλοντικό πρόγραμμα και τα κοινοτικά αναπτυξιακά προγράμματα του δεύτερου πυλώνα για την ανάπτυξη της υπαίθρου, προσφέρεται μια τεκμηριωμένη φόρμα για τον ορθό σχεδιασμό τέτοιας φύσεως εθελοντικών προγραμμάτων, τα οποία θα διασφαλίζουν τουλάχιστον την μερική συμμετοχή και μερική συμμόρφωση του υπό-ρύθμιση πληθυσμού των δραστηριοποιούμενων στο κοινοτικό αγροτικό χώρο οικονομικών μονάδων - αγροτών, σύμφωνα πάντα με τους χρηματοδοτικούς περιορισμούς της κοινοτικής ρυθμιστικής αρχής.

Το ανωτέρω γενικευμένο πλαίσιο δύναται να χρησιμοποιηθεί περαιτέρω για την διεξαγωγή συμπερασμάτων αναφορικά με την αναμενόμενη αποτελεσματικότητα της Κοινοτικής Οδηγίας για την αντιμετώπιση της νιτρορύπανσης (91/676/EEC), καθώς και για την μακροχρόνια σύσταση του υπό ρύθμιση πληθυσμού αναφορικά με τα κίνητρα για συμμετοχή και συμμόρφωση με τις περιβαλλοντικές υποδείξεις αυτής. Όπως διαφαίνεται από την ανωτέρω ανάλυση η εθελοντική επίτευξη των στόχων της Οδηγίας εξαρτάται από την παρουσία μιας αξιόπιστης απειλής για την επιβολή νομικά υποχρεωτικών ρυθμίσεων, οι οποίες συνεπάγονται την υλοποίηση προγραμμάτων δράσεων (action programmes) καθώς και την διεύρυνση των ζωνών αγροτικής δραστηριότητας που κρίνονται επιρρεπείς στην νιτρορύπανση (nitrates vulnerable zones). Για την επίτευξη της συμμόρφωσης με την εν λόγω Οδηγία κρίσιμη επίσης κρίνεται η ύπαρξη κάποιας κύρωσης ή γενικότερα ενός μηχανισμού που θα μειώνει αποτελεσματικά τις απολαβές των οικονομικών μονάδων που υιοθετούν την στρατηγική μη-συμμόρφωσης στην περίπτωση που μια τέτοια φύσεως παραβατική συμπεριφορά εντοπίζεται. Παρόλα αυτά, η διεξαγωγή μιας πιο εξειδικευμένης ανάλυσης και η διατύπωση προβλέψεων αναφορικά με τις μακροχρόνιες επιπτώσεις της εν λόγω κοινοτικής Οδηγίας, απαιτεί ένα λιγότερο γενικευμένο μοντέλο το οποίο θα είναι εξειδικευμένο στην δομή της Οδηγίας και θα λαμβάνει υπόψη την αρχή της διασταυρωμένης-συμμόρφωσης των παρεχόμενων ενισχύσεων.

Πιθανές Προεκτάσεις

Η παρούσα Διδακτορική Διατριβή εστίασε σκοπίμως σε συγκεκριμένες πτυχές των προβλημάτων αγροτικής μη-σημειακής ρύπανσης και πολιτικής παρέμβασης προκειμένου να εξαχθούν κάποια ασφαλή συμπεράσματα αναφορικά με τρία σημαντικά ζητήματα. Συγκεκριμένα, τα ζητήματα που διερευνήθηκαν αφορούν: (α) την πιθανή διαφοροποίηση στην μακροχρόνια συμπεριφορά ενός πληθυσμού ρυθμιζόμενων οικονομικών μονάδων υπό τις εναλλακτικές υποθέσεις της πλήρους και πεπερασμένης ορθολογικής ικανότητας επιλογής (Κεφάλαιο I), (β) την περιβαλλοντική αποτελεσματικότητα υπαρκτών ρυθμιστικών πολιτικών και την σύσταση του κοινωνικά βέλτιστου παρεμβατικού καθεστώτος (Κεφάλαιο II), καθώς και (γ) την ενδεικνυόμενη δομή τόσο ενός αποτελεσματικού δημοσίου περιβαλλοντικού προγράμματος όσο και του αποτελεσματικού μηχανισμού διεξαγωγής ελέγχων (Κεφάλαιο III).

Υπάρχει, ωστόσο, μια πλειάδα από αξιοσημείωτα χαρακτηριστικά γνωρίσματα των προβλημάτων αγροτικής μη-σημειακής ρύπανσης καθώς και των αγρό-περιβαλλοντικών ρυθμιστικών πολιτικών, τα οποία και τα διαφοροποιούν από τα συμβατικού τύπου προβλήματα ρύπανσης και πολιτικής παρέμβασης. Τα εν λόγω χαρακτηριστικά γνωρίσματα θα μπορούσαν να ενσωματωθούν, ως μια επιπλέον προέκταση, στο αναλυτικό πλαίσιο που αναπτυχθηκε στην παρούσα Διατριβή. Συνεπώς, θα ήταν ενδιαφέρον να ληφθούν ερευνητικές περιοχές, οι οποίες συνεπάγονται:

- ✓ Ένα πλαίσιο αβεβαιότητας, δεδομένου ότι η συνάρτηση τόσο της εκπομπής ρύπων όσο και του παραγόμενου προϊόντος επηρεάζεται από στοχαστικούς παράγοντες (όπως είναι ο καιρός, οι βλάβες στον εξοπλισμό).
- ✓ Την περίπτωση ενός ανακριβούς ελεγκτικού μηχανισμού και ισχυρών χρηματοδοτικών περιορισμών.
- ✓ Ένα πλαίσιο διακρινόμενο από ατελή πληροφόρηση, δυική ασυμμετρία στην πληροφόρηση (dual asymmetries) και ετερογένεια αναφορικά με τον

τύπο ή τα διακριτικά χαρακτηριστικά (distinctive characteristics) των υπόρύθμιση οικονομικών μονάδων.

- ✓ Ένα διαφοροποιημένο εξελικτικό πλαίσιο ανάλυσης όπου σε κάθε χρονική περίοδο η έκαστη οικονομική μονάδα αλληλεπιδρά με δύο ή περισσότερες οικονομικές μονάδες, όπως συνεπάγεται ο κανόνας των μέσων απολαβών και ο κανόνας της αποτελεσματικής ποινής.
- ✓ Ένα ρυθμιστικό πλαίσιο που να συνεπάγεται διαπραγματεύσιμες ή μονομερείς εθελοντικές μεθόδους.
- ✓ Την κατάσταση όπου η ύπαρξη πιέσεων από ομάδες συμφερόντων μπορεί να επηρεάσει τις παραμέτρους της παρεμβατικής πολιτικής (όπως είναι οι υλοποιούμενοι έλεγχοι και οι επιβαλλόμενες κυρώσεις).

Τα ανωτέρω μπορούν να θεωρηθούν ως τα επακόλουθα βήματα της εν εξελίξει έρευνας, όπου οι γενικευμένες έννοιες και μηχανισμοί που αναπτύχθηκαν στην εν λόγω Διδακτορική Διατριβή μπορούν να εξειδικευτούν στην δομή συγκεκριμένων δημοσίων εθελοντικών προγραμμάτων ειδικά σχεδιασμένων για τον αγροτικό τομέα της Ευρωπαϊκής Ένωσης.

UNIVERSITY OF CRETE

FACULTY OF SOCIAL SCIENCES

DEPARTMENT OF ECONOMICS

Doctoral Degree Programme in Economics

“Regulation of Environmental Externalities in the Agricultural Sector: An Evolutionary Approach”

PhD Canditate: Passa P. Constadina

Supervisor: Prof. Xepapadeas P. Anastasios

Rethymnon

10 November 2007

A dissertation submitted in fulfilment of the requirements for the degree of Doctor of Economics.

Aknowledgement

Financial support by European Commission, under the activity "Scientific Support to Policies" of the 6th Research Framework Programme, for the project GENEDEC: "A quantitative and qualitative assessment of the socio-economic and environmental impacts of decoupling of direct payments on agricultural production, markets and land use in the EU", No. 502184, is acknowledged.

It is stressed that opinions expressed in this Thesis do not necessarily reflect the views of the European Commission.

Special thanks to my parents, Panayiotis and Panayiota Passa, for the financial and psychological support. I also thank all my colleagues in the Doctoral Program, and in particular: Vaso Mpozani, Nikos Drydakis and Vangelis Mitrokostas, the secretaries of the Department: Eleni Kalogeraki, Maria Mouzouraki and Ioanna Yiotopoulou, as well as the technical staff: Periklis Drakos and Kostis Pigounakis, for being helpful and supporting during these years of work. Furthermore, I thank Mrs Joan Stefan for her useful comments in the final synthesis of the Thesis, as well as Professor Emmanuel Petrakis for his continuous encouragement and constructive criticism.

Finally, I would like to thank especially my supervisor, Professor Anastasios Xepapadeas, for his assistance and patience. Working with him was a great experience that helped me a lot not only to “evolve” as an economist but mostly as a personality.

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PART I:
"Environmental Pressures and Regulation in European Agriculture: A Survey of Current Issues and Policies"

As it is well known agriculture is closely associated with the environment mainly via the production of food and fibre and the habitation of the countryside. Furthermore, agriculture is a decisive factor for maintaining the viability and diversity of rural communities, landscape and habits, for facilitating the provision of tourism, recreational facilities and environmental protection (OECD, 1993). However, despite the potential beneficial environmental services European agriculture has been regarded as contributing to a number of environmental problems.

Economic theory teaches us that, due to well known externalities, in the absence of policy interventions unregulated markets fail to induce farmers to operate in the socially optimal way, and regulatory interventions are required for the achievement of Pareto optimality. Given the non-point-source (NPS) character of agricultural pollution, originating from the associated uncertainty or incomplete information about the location of polluting sources, their contribution in the aggregate pollutant concentration and their distinctive characteristics, standard instruments of environmental policy such as Pigouvian taxes and tradeable permits can not be easily employed. In this context NPS pollution control has focused on other elements that may be observable such as polluter's choices (input-based schemes) and the consequences of polluters' actions (ambient-based schemes), as well as, policy schemes based on a new type of interaction between the regulator and polluters, the so-called Voluntary Approaches.

In **Part I** of this thesis the major pollution problems associated with the EU agriculture, the distinctive characteristics of agricultural pollution as a non-point-source pollution problem, as well as the policy instruments developed in the Environmental Economics literature for dealing with these problems are briefly presented. Emphasis is given on the characteristics of Voluntary Approaches, which is a new and promising policy instrument for agricultural pollution control.

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CHAPTER I:
European Agriculture and Environment

Even though European agriculture is not a major economic sector,[3] it is highly important from an environmental aspect (Baldock et al., 2002). Covering on the average 51% of European Union (EU) territory, farming activities are a decisive factor for maintaining the viability and diversity of rural communities, landscape and habits, for facilitating the provision of tourism, recreational facilities and environmental protection (OECD, 1993). Among the environmental services of European agriculture are:

- The maintenance of many cultural pastoral and arable landscapes, as well as semi-natural habitants.
- The decline of greenhouse emissions through soil carbon storage and biomass energy crops.
- The conservation of valued cultural landscapes and farmlands with high natural value in mountainous regions, though low-intensity farming systems.
- The promotion of soil conservation through farming practices such as drip or moderate irrigation.
- The conservation and enhancement of biodiversity and landscape diversity through certain traditional or "leaky" irrigation systems.

However, despite the potential beneficial environmental services farming activities have been responsible for a series of environmental pressures, such as:

- *Loss of biodiversity* due to abandonment of farming activities, drainage of wetlands, irrigation of arid lands and ploughing up of unproved grasslands.[4]

[3]Agriculture contributes about 1.8% of EU GDP.

[4] There is evidence that the 1950s in a UK RAMSAR site an average of 35 species was recorded in spring-fed areas but by 1992 only 5 species were found.

- *Threats to high natural value farming systems and traditional forms of agriculture in marginal areas* due to economic trends, enlargement and intensification.
- *Loss of landscape diversity and quality as well as decline in important habitants and species* due to increasing production scale, homogenization of landscapes; intensively managed and irrigated farmlands; lowland dairying, along with large-scale and long-distance water transfers.
- *Degradation of soil quality* in the form of reduced organic content, acidification, salinity and soil erosion due to heavy machinery use, excessively large field sizes and abandonment of hand-irrigated traditional terrace agriculture.[5]
- *Degradation of* air *quality* through the production of ammonia, methane, greenhouse gas emissions and toxic substances.[6]
- *Degradation of water quality* in the form of eutrophication, salinization of groundwater, pesticide and fertilizer contamination,[7] as well as soil sediment.

In the presence of such externalities regulatory intervention is required to induce farmers internalize the externalities to operate in the socially optimal way. However, agricultural pollution problems fall into the category of non-point-source (NPS) pollution problems a fact that sets restrictions in the design of agri-environmental policy.

1. Agricultural Pollution: A Non-Point-Source Pollution Problem

In the environmental economics literature pollution problems are classified as point-source (PS) or non-point-source (NPS) problems. This categorization is based on the available information and particularly on the degree of uncertainty or incomplete

[5] Water erosion in Portugal and Spain is recorded to 22 tons/hectare per annum.

[6] In several EU countries agriculture accounts for 95% of ammonia emissions, where 80% arises from livestock wastes and most of the reminder from nitrogen fertilizers. In 1990-1997 agriculture contributed about 11% of total EU greenhouse gas emissions.

[7] Residual nitrogen, or else know as nitrates leaching, is potentially one of the most notable and widely discussed, in economic literature, agricultural pollution problems.

information about the location of polluting sources, the magnitude of their contribution in the aggregate pollutant concentration and their distinctive characteristics (Kaplan et al., 2003). In a PS problem there is perfect information regarding individual emissions, while the opposite occurs in a typical NPS problem. Agricultural pollution is a typical NPS problem and probably the most important. There is evidence that agricultural non-point sources represent over 90% of the nitrogen load flowing into the Gulf of Mexico (Cason et al, 2003).

Hence, given that the most important problems associated with EU agriculture are predominantly NPS pollution problems, emphasis is given on the non-point-source features of agricultural pollution and the many aspects of the problem that should be considered into the design of an effective EU agri-environmental policy.

1.1 Point-Source Pollution Problems

The pollution problem is a "pure" point source problem if there is perfect information and complete certainty of the location of polluting sources and the individual contribution to aggregate pollution (Kaplan et al., 2003). This is a full information framework that marks the one end of the spectrum of pollution problems (Kaplan et al., 2003), since a pollution problem is also defined as point-source under an incomplete information framework if the regulatory body can eventually identify the origin and the amount of agricultural pollutants with sufficient accuracy and at a low cost.

Point-source pollution is associated with fixed sources usually emitting high levels of pollutants in a well-defined location (Owen et al., 1998). For instance discharges of waste water from the pipes of industrial plants into a stream are point sources of nitrogen emissions (EC, 2004).[8] To internalize the external cost of pollution and thus induce individual agents to manage the emissions of pollutants at the socially desirable levels, emission-based instruments can be applied (Xepapadeas, 1995). Such regulatory policy instruments are distinguished in:

[8]Even though industrial emissions measured at the factory's pipes are considered as PS pollution their further consequences on soil or water are classified as NPS pollution. Therefore the distinction between PS and NPS pollution is not always clear-cut (Cochard, 2003).

- Charges per unit of emissions, known as Pigouvian taxes.
- Systems of marketable emission permits.
- Direct controls on emission levels.
- Subsidies as rewards for emission reduction.
- Deposit or refund systems according to whether certain prespecified conditions of behaviour are satisfied by a potential polluter.

Under certainty and perfect monitoring emission taxes or permits are preferable since they directly deal with the source of discrepancy between private and social costs (Schmutzler and Goulder, 1997) and the first best solution is straightforward: each polluter should pay the marginal external costs of his emissions according to the well known *polluter pays principle*.

1.2 Non-Point-Source Pollution Problems

The pollution problem is a "pure" NPS problem if the regulatory body has no knowledge of the location of polluting sources or the individual contribution in aggregate pollution (Kaplan et al., 2003).[9] Nevertheless, a pollution problem is called NPS problem - or second generation pollution problem (Xepapadeas, 1995) - mainly because the estimation of individual emissions is a technically very demanding task and potentially prohibitively costly (Cochard, 2003). In general:

> NPS pollution can be characterized as an information or uncertainty problem, where informational issues are the core of NPS externalities analysis and the question "*What information is available at what cost?*" plays crucial role in the determination of the best regulatory mechanism (Cabe and Herriges, 1992; Kaplan et al., 2003; Legras, 2004).

Potentially the most important feature of NPS problems is the associated uncertainty about decision makers (polluters) and the degree of each agent's responsibility. In short the origins of this uncertainty can either be attributed to stochastic influences affecting fate and transport of pollutants, the great number of sources of pollution

[9] This extreme information framework marks the other end of the spectrum of pollution problems (Kaplan et al., 2003).

emissions that can be either static (farms, households) or mobile (vehicles), and /or the regulator's inability to infer individual emissions from ambient pollution levels or inputs used (Xepapadeas, 1995).

Specifically the non-point-source pollution problems are characterized by:

- **"Stochastic pollution processes"**

NPS emissions are typically unobservable, stochastic and site-specific (Classen and Horan, 2001; Horan R.D. et al., 2002). Stochastic pollution processes do not only result from variability in natural processes (i.e. weather, topology) (Kampas and White, 2004) but also by technological uncertainty (Xepapadeas, 1992a) such as equipment malfunctions, variations in input quality and process upsets (Malik, 1993). In a NPS pollution problem only ambient pollution can be observed at prespecified receptor points, but no specified portion of the pollutant concentration can be attributed to a specified discharger (Xepapadeas, 1991) - only quantified approximations can be made (Franckx, 2002; Camacho and Requate, 2004).

- **"Multiple dischargers and diffuse pollution"**

By definition NPS pollution sources are numerous and spatially distributed (Legras, 2004), while NPS pollution is diffuse in origin, originating from a wide range of actions and geographic locations (Herriges et al., 1994). The fundamental relation between polluted area and source is not known with certainty (Kaplan et al., 2003). It is difficult and very costly for the regulator to obtain information that enables him to link the damage to the responsible agent among a large population of potential polluters (Millock and Zilberman, 2004) due to the off-site consequences of individual chemical applications (Cabe and Herriges, 1992) that involve moving and mixing over large areas (Larson et al., 1996). In particular:

> The effects of nitrate leaching can be felt and measured (if at all) after they have entered the ecosystem, but identifying the sources of pollution may be impossible since agricultural pollutants do not enter waterbodies at a defined point, they dissipate quickly and the area vulnerable to pollution is extensive (Chambers and Quiggin, 1996; Johnson et al., 1991; Helfand and House, 1995; Kampas and White, 2004).

The pollutant can cause harm in multiple zones due to biogeophysical processes (Wu and Babcock, 2001) that transform human activity in one place into chemical concentrations in another (Cabe and Herriges, 1992), which are also affected by stochastic environmental variables that influence the transport and the fate of pollutants.[10]

- **"Monitoring and measurement inefficiency"**

By definition individual emissions can not be observed directly or be inferred indirectly by observed inputs or ambient pollution concentration (Xepapadeas, 1997). Even though individual emissions could be approximated through inspection and monitoring (Cremer and Gahvari, 2002), the extent of controls is often limiting (Kaplan et al., 2003). Such an inability to monitor and measure efficiently individual emissions or abatement efforts is associated with budgetary restrictions related to the cost of monitoring technology, personnel limitations or legal restrictions such as the inability to enter polluters' premise (Xepapadeas, 1991). These limitations are more noticeable when continuous monitoring is required (Schmutzler and Goulder, 1997) since it is relatively easy to determine whether adequate abatement equipment has been established but it is difficult to verify that the equipment is operating at the desirable level (Xepapadeas, 1991). It is notable that even though the current monitoring technology renders prohibitive the accurate measurement of emissions at reasonable cost and introduces uncertainty about nonpoint emissions and their fate (Shortle et al., 1998):

> The classification of an individual source of pollution as NP may change over time as monitoring technology advances and the cost of monitoring declines (Millock et al., 2002).

An important difference between the PS and NPS regulatory mechanisms is the cost structure for the acquisition of information regarding important parameters of the problem such as individual emissions (Cabe and Herriges, 1992), often creating an ill-

[10] In the case of waterbodies pollution the number of involved agents can be restricted to those located above the watertable (Legras, 2004).

posed estimation problem (Kaplan et al., 2003).[11] Moreover, limitations on the capability of existing monitoring technology (Millock et al., 2002) impose some imperfections since the regulator may not correctly infer the existing pollution state and erroneously fine a farmer (Malik, 1993). For agriculture it is extremely difficult and expensive to determine how much a certain action pollutes ground or surface water (Underwood and Caputo, 1996), as well as to monitor and determine the groundwater pollution and quality (Cabe and Herriges, 1992).

- **"Informational asymmetries"**

NPS pollution problems operate in a setting of incomplete information and dual information asymmetry (Cason et al., 2003).[12] Neither the regulator nor farmers have full information, instead have access to a subset of the information set (Horan et al., 2002). Imperfect knowledge of relevant physical processes and ambient concentrations, along with uncertainty about the exact specification of emission, the nature of transport mechanism is experienced both by the regulator and the farmers.[13] However, the information often needed for policy design is only known by those who are to be regulated (Wu and Babcock, 2001) and this is one reason why it is particularly impossible to achieve the first-best solution to NPS pollution reduction problems (Šauer et al., 2003). The regulator is usually unfamiliar with the full range of microeconomic parameters of the problem (Šauer et al., 2003) and has limited information about the strategic environment of private polluters, who have better information about aspects of their operation - such as production techniques, abatement or polluting input choices (Cremer and Gahvari, 2002). Moreover, benefits and environmental damage costs are not well known and some times are completely unknown by the regulator due to either imperfect information about the true costs and benefits of pollution abatement or stochastic factors (Wu and Babcock, 2001; Spraggon, 2002). Thus:

Under such informational asymmetries the NPS pollution problems are

[11]This can be avoided if the regulator could wait for a sufficiently long time so that data are collected, to balance, in any given period, the number of observations with the large number of polluting sources. However there is a risk that irreversible damage could occur in the mean time (Kaplan et al., 2003).

[12]They are often casted as non-cooperative, asymmetric games.

[13]They both form different priors on the distribution of the unknown factors (Cabe and Herriges 1992).

subject to moral hazard in teams, characterized by hidden actions, and/ or adverse selection.

Moral hazard is defined as the incentive problem of inducing polluters to provide socially targeted levels of abatement effort given that their actions cannot be effectively monitored (Herriges et al., 1994).[14] In this case polluters choose higher emission levels (lower abatement level) than the socially desired to increase their profits (Xepapadeas, 1992a), since their actions can not be observed and expected costs of shirking are lower under this information barrier. On the other hand, adverse selection is associated with the inability to know the specific characteristics or type of each polluter (Xepapadeas, 1999). Agriculture is a collective enterprise where the outcome of all dischargers' combined effort is observed by the regulator (e.g. in water quality terms), while the exact conditions under which production takes place cannot be observed (nitrogen use) (Chambers and Quiggin, 1996) and thus the individual contribution to the team's output (nitrate leaching) is not distinguishable (McAfee et al., 1991). Therefore in a situation characterized by such informational asymmetries it is impossible to charge agents according to their individual emissions productivity. Difference between socially and individually optimal actions is observed, leading to inefficient equilibria and environmental shirking that involves too little effort and too much pollution (Herriges et al., 1994). Consequently, the relative performance of NP pollution controls depends on their effectiveness to reduce environmental shirking (Shortle et al., 1998).

2. Modelling of Agricultural Pollution as Non-Point-Source Pollution Problems

Since the interdependence between agriculture and environment is becoming more apparent, the formal modelling of agricultural pollution is becoming necessary. In the majority of environmental economic literature this is mostly done in the context of optimization models, which have been regarded as providing and adequate description of the mechanisms underlying the agents actions (farmers, regulators), even if actors

[14] Moral hazard occurs whether the relationship between individual net emissions and ambient concentration levels is deterministic or stochastic (Xepapadeas, 1991).

are not strictly speaking maximizing.[15] These maximization problems faced by farmers and regulators, can be defined under various contexts, given that the generation of pollution is a flow variable but its impact could be related to a flow or a stock variable. Henceforth the NPS pollution model is analyzed under a static and dynamic context, as well as under an asymmetric information framework. Finally, given that pollution in the form of agricultural pollutants is widely recognized to be stochastic (Malik, 1993) the problem is defined in a context of certainty and uncertainty.

- **Under certainty**

In the static context ambient pollution is a deterministic function, strictly increasing in productive inputs and strictly decreasing in abating inputs.[16] Each polluting farmer choose the input vector that provides the maximum private net benefits from production in the absence of any regulatory intervention,[17] while the regulator seeks to achieve an efficient allocation of resources that maximizes social net benefit resulting from agricultural operations. On the other hand, in a dynamic context the deterministic model is described by the evolution of the pollution stock as determined by collective emissions generated in each time period and the amount of pollution removed through natural processes (Xepapadeas, 1997).[18] Individual farmers seek to maximize the present value of their payoff function under different behavioural rules regarding the evolution of pollution stock: myopic, open-loop or feedback,[19] while the regulator seeks to maximize the present value of social welfare by choosing the

[15] This is the well known "as if" argument in economic theory, where agents are regarded as if maximizing some objective function, since the outcome of their observed behaviour can be explained in terms of maximizing behaviour. Thus models based on maximizing behaviour can be used to explain the underlying mechanisms that generate observed data.

[16] For further details see Xepapadeas (1997).

[17] Farmers may also target the maximum utility from profits or the minimum abatement costs.

[18] Pollution accumulation can also be augmented by an additional term representing either an internal positive feedback loading mechanism of the pollutant (Brock and Starrett, forthcoming; Mäler et al., 2003), or the abatement rate undertaken by farmers (Huhtala and Laukkanen, 2004).

[19] In practice the stock of pollutants can negatively affect agricultural production (Xepapadeas, 1997). If farmers systematically ignore the evolution of pollution stock and treat it as fixed (Xepapadeas, 2005b), they adopt the myopic behaviour rule and they actually face a static problem. Under the open-loop (OL) information structure each farmer takes into account only the initial state of the system, while under the feedback (FB) information structure the current state. For further details about the analysis of these information structures see Xepapadeas (1992a), (1997) and (2005b).

optimal path of the input vector for each farmer, subject to transition equations reflecting the dynamic constraints of the problem.[20]

- **Under uncertainty**

The agricultural ambient pollution model is augmented in the static context[21] by stochastic elements that may affect emission generation and abatement, as well as transport and fate of the pollutant.[22] In the dynamic context uncertainty could be modelled by a stochastic term, introduced into the model through a stochastic process, known as Brownian motion or Wiener process. Under such an uncertainty framework both the static and dynamic maximization problem of the individual farmers and the regulator,[23] is expressed in expected value terms.

- **Under asymmetric information**

The ambient pollution is a stochastic function of input choices and a scalar parameter[24] representing the type of the discharger augmented also by a random variable reflecting observation errors of individual emissions (Xepapadeas, 1997). The considered heterogeneity parameter is incorporated in the maximization problem of both the regulator and individual polluting agent.

3. Policy Instruments for Agricultural Non-Point-Source Pollution Control

[20] Environmental damages are now defined as an increasing and convex function of the accumulated stock of nitrate emissions.

[21] For further details about regulation under uncertainty see Horan et al. (1998), (2001) and (2002), as well as Shortle et al. (1998) and Cochard (2003).

[22] For a more specific ambient nitrates pollution model see Fleming and Adams (1997).

[23] Stochastic processes influence the economic consequences of ambient pollution concentration levels (Horan et al., 1998), making difficult to measure the true cost of damages (Fleming and Adams, 1997). Under such a context the regulator can alternatively maximize the objective function under a "generic goal" that can involve a lower bound on expected private net benefits, an upper bound either on private pollution control costs (Horan, 2001) or on expected ambient pollution (Cochard, 2003). Finally, in a risk-averse society the regulator wishes to maximize the expected social welfare from the utility of profits and damages (Horan et al., 2002).

[24] The heterogeneity characteristic can embody the farmer's ability, proximity to a receiving body, soil composition (i.e. higher quality soils utilize chemicals better) (Xepapadeas, 1997), soil retention capacity, costs of abatement (Spulber, 1988), or pollution generation efficiency reflected by an index of efficiency in input use (i.e. the energy efficiency of a car) (Millock et al., 2002).

The theory of environmental economics mainly involves agents (farmers and regulator) who adopt an explicit maximizing behaviour, seeking to achieve the allocation of resources that maximizes their respective payoff functions. After comparing the optimality conditions resulting from the regulator's and farmers' problems in the various contexts, it is evident given the associated environmental externalities that that there is deviation between the social and private optimal choices. In the unregulated competitive market farmers over-pollute, since they do not take into account the external effects of their production choices on ambient environment. The first fundamental welfare theorem, which implies that the market economy leads to a Pareto optimal result, is violated. Hence, in the absence of policy interventions unregulated market fails to induce farmers to operate in a way that would result in the socially optimal environmental pollution, leading to sub-optimal equilibrium and calling for regulatory intervention and the introduction of environmental policies to bring competitive equilibrium closer to the social optimum without impeding agents' maximizing behaviour.

NPS pollution is a major source of environmental quality problems in developed countries which have advanced pollution policies and a growing cause of environmental degradation in developing countries (Shortle et al., 1998; Horan et al., 2002). Public concerns about the adverse impacts of agricultural production practices have drawn attention towards policies for environmental improvements in the area of NPS pollution. Even though there is a substantial agreement that more aggressive NPS control policy is needed, there is less agreement about the kinds of actions that represent good policy (Shortle et al., 1998). The characteristics of NPS agricultural pollution limit the range of potential policy instruments and also the efficiency of many remaining options (Horan et al., 2002; Classen and Horan, 2001).

By definition NPS pollution problems are not susceptible to traditional direct policy controls, since they are based on individual emissions that are unobservable and typically stochastic. Standard instruments, such as Pigouvian taxes, tradeable permits and emission standards, appear to be inadequate to handle efficiently the NPS pollution problem and deliver the Pareto optimum outcomes, in terms of environmental quality (Xepapadeas, 1999). Even though the regulation of NPS pollution problems such as the nitrate pollution of water resources is a major policy challenge (Hansen, 2002; Cochard et al., 2004), it is:

> the combination of inability to employ emission-based policy and agricultural land features that makes NPS pollution unique and more difficult to control than PS pollution (Wu and Babcock, 2001).

Due to the limited relevance of emission-based economic incentives NPS control has focused on other elements of NPS pollution problems that may be observable. Policy schemes based either on output, inputs, emission proxies, ambient pollution or ex post liabilities for real damages are among the options of the regulatory authority. It is evident that the potential NPS measures can either be associated with polluters' decisions (inputs, management practices and technologies) or with the consequences of their actions (output and ambient pollution) (Cochard, 2003). These measures can be further distinguished in fiscal approaches (price-based) consisting of tax or subsidies, and command-and-control approaches consisting of mandated technologies or performance standards (restrictions on inputs or outputs).

In economic literature relative emphasis has been given on fiscal policy schemes that can be classified into two main classes of policy schemes: *input-based schemes* and *ambient-based schemes*. Input-based measures are purely individual schemes that involve the indirect control of ambient concentrations through the control of observable inputs, related to the creation of emissions. Particularly, they include non-uniform or uniform taxes for inputs that increase NPS emissions, as well as subsidies for inputs that reduce NPS emissions such as observed pollution control equipment (Shortle et al., 1998). On the other hand, ambient-based schemes are dependent on observed ambient pollution in a given receptor point. They involve direct control of ambient concentrations either through collective or random penalties, with budget or nonbudget balancing features. This category also includes NPS instruments consisting of collective ambient and individual Pigouvian charges, known as mixed-based schemes, which can be regarded as a separate NPS policy instruments.

In short the existing policy options for NPS pollution problems, under each potentially available information set, are:

	Available information	*Potential regulation*
Input use	may be observable	Input-based schemes
Individual emissions	Unobservable or observable at very high cost	no regulation
Ambient pollution	may be observable	Ambient-based schemes

Source: Cochard F., (2003)

The environmental economics literature has managed to provide a substantial body of environmental policy instruments to deal with agricultural NPS pollution control. Over the last two decades a number of approaches have been developed and implemented in order to deal with agricultural NPS pollution problems. The policy schemes developed in environmental economic literature are discussed briefly below:

3.1 Effluent-based Schemes

Even though measures based on individual emissions are not widespread in practice, they form the theoretical foundation of the most applied measures of environmental policies.[25] For the case of agricultural NPS pollution an emission-based policy scheme is in principle designed on the basis of nitrate leaching generated by farms. Such instruments include charges, known also as Pigouvian taxes, which can either be linear to individual emissions, nonlinear or piecewise linear (Schmutzler and Goulder, 1997) or state-dependent (Cochard, 2003).[26] Uniform or nonuniform emission-reduction subsidies, as well as performance standards can be employed to handle the NPS pollution problem.

Such emission-based policy schemes can be imposed to all farmers in the regulated region or to only a fraction of randomly inspected agents given the monitoring costs

[25] Examples of emission-based tools are the Swedish NO_x charge and the Japanese SO_x charge, based on metered emissions (OECD, 1994).

[26] The linear tax rate induces the socially optimal individual discharge and pollution stock level only if the farmer uses a single input. If more than one input is used then it is overdetermined (Cochard, 2003).

of actual emissions (Cochard, 2003).[27] Nevertheless, under imperfect monitoring Pigouvian measures can be imposed on all farmers based on imprecise estimates of individual emissions (Schmutzler and Goulder, 1997),[28] or on information provided by polluting agents themselves (Schmutzler and Goulder, 1997; Cremer and Gahvari, 2002).[29] Relative to the availability of monitoring technology three different types of emission-based policy schemes can be employed (Millock et al., 2002):[30]

- A lump sum tax applied uniformly to all farmers if no monitoring technology is available.[31]
- Nonuniform Pigouvian taxes imposed on all farmers if monitoring technology is mandatory.
- Differentiated taxation if monitoring technology is voluntary. A nonuniform tax scheme based on individual emissions is imposed on the adopters of monitoring technology, while nonadopters pay a uniform lump sum tax. Particularly, adopters face a linear tax per unit of emissions they generate and are subsidized for any overestimate of pollution, measured before they installed monitoring equipment.

Emission-based instruments are also considered under an asymmetric information and dynamic context. Under the alternative behavioural rules adopted by farmers regarding the evolution of pollution stock (i.e. myopic, open-loop and feedback), time

[27] The smaller the auditing probability is, the higher the tax rate is, threatening the financial hypostasis of operations and increasing the risks of bankruptcy (Cochard, 2003). Even though greater monitoring effort amounts to a greater number of monitored farms (Schmutzler and Goulder, 1997) and decreases bankruptcy risks, it might not be desirable by society to incur additional monitoring costs.

[28] This turns individual tax payments partly random (Schmutzler, 1996) and introduces an undesired unpredictability of emission tax payments.

[29] It could be considered equivalent to self-reporting - that is nearly universally needed for regulation of water pollution and toxic/ hazardous chemical releases (Malik, 1993). Moreover, such policy schemes involve fines for agents submitting dishonest reports.

[30] The policy schemes involving self-reporting and monitoring - Millock et al., (2002), Cremer and Gahvari, (2002), Schmutzler and Goulder (1997) - are based on the assumption of perfect monitoring technology allowing the accurate revelation of discharge levels. Imperfect monitoring implies that the regulator can erroneously fine a farmer even though he has met the standard (Malik, 1993).

[31] For instance, municipal waste charges for households are generally levied at flat rates, with each household paying a fixed sum, unconnected to the quantity of waste actually supplied (OECD, 1994). However, in the case of agriculture such policy schemes decrease ambient pollution only at the extensive margin and threatens the economic viability of the less productive farmers (Millock et al., 2002), given that in the case of agriculture, nitrates entering a river at different places with different assimilative capacities have different impact on ambient pollution (Helfand and House, 1995).

dependent, farm-specific effluent taxes (or subsidies) are imposed (Xepapadeas, 1992a; Mäler et al., 2003). However, such policy instruments require continuous change of tax rates and knowledge of individual emissions, shadow costs, in addition to the behavioural rule followed by agents. The dynamic Pigouvian tax scheme can be modified to a second best scheme that can either be time invariant, considering that the desired emissions are kept constant for the whole time period, or even allow for discrete changes (or shaped-in policies) over time (Xepapadeas, 1997).[32] Time invariant taxes rates can also be determined by the corresponding steady state values under the alternative behavioural rules (Xepapadeas 2005b).

Finally, under asymmetric information the effluent-based policy scheme defines individual effluent levels and individual taxes for each polluter based on messages received by all farmers regarding the heterogeneity parameter (i.e. cost, ability) (Spulber, 1988).[33] It is worth mentioning that full information policies are feasible if policy schemes are supplemented by a costly subsidy for truth-telling. Given, however, the formidable amount of required information, the scheme is modified to the second best that does not require private information or even relays on uniform tax rates (Cochard, 2003).

3.2 Input-based Schemes

In the context of NPS pollution problems, individual discharges are not directly observed and thus emission-based schemes are not in generally feasible. Nevertheless, the inherent informational constraints can be circumvented through input-based schemes that are more feasible for NPS pollution control (Helfand and House, 1995) and have been recognized as substitutes for direct taxes on negative externalities (Shortle et al., 1998). Such policy schemes have been suggested as a means to induce changes in farmers' behaviour and there is economic evidence that they can be effective in bringing changes in resource allocation, depending of course on how they are structured (Johnson et al., 1991; Shortle et al., 1998).

[32] In the latter case the second-best tax rate can be improved over time, however this is strongly dependent on the necessary adjustment cost.

[33] In a reduced-form each farmer’s incentive scheme depends on his responses (Xepapadeas, 1997).

Under the assumption that the agency knows each individual farm's physical attributes the marginal conditions for an efficient solution can be replicated if a set of differential linear taxes rates or performance standards are imposed on each polluting agent for each input choice affecting agricultural pollution (Shortle et al., 1998; Wu and Babcock, 2001).[34] An input tax / subsidy policy scheme can be also used, imposing a vector of input tax rates on inputs that increase a detrimental externality and providing a vector of subsidy rates on inputs that reduce it (Shortle et al., 1998).[35] Moreover, nonuniform design standards can be employed to require the use a specific technology or practices that can either be pollution prevention technologies that reduce the use of polluting inputs per unit of output or pollution-treatment technologies that reduce nitrate pollution (Abler and Shortle, 1995).[36]

Given the often extreme spatial variation of the agricultural resource base, such efficient input-based NPS pollution control may be administratively costly and informationally demanding (Classen and Horan, 2001), or even impossible. Indirect nonuniform measures are modified to the second-best, applied on a single or a subset

[34] Several restrictions on water use have been imposed in US, while in Denmark the Aquatic Environment Action plan of 1987 defines standards for manure storage capacities and manure application on agricultural land (OECD, 1993). Land set-aside is the most notable production input constraint and under Agenda 2000 a long-term set-aside mechanism (ten years) for arable land is proposed in place of the existing rotational set-aside (EC, 2004). Apart of land the EU agricultural input-based policy schemes imply the development of policies on inputs such as fertilizers, pesticides and water.

[35] Input taxes can be imposed on fertilizer use such as nitrogen, potassium and phosphate (Austria, Finland, Norway, Sweden), while subsidies can be provided for less polluting fuels such as natural gas (Canada), as well as for irrigation (Japan) (OECD, 1993). Particularly, in Austria there has been a levy on fertilizer use since 1986, imposed per kg of pure nutrients contained in inorganic fertilizers (i.e. nitrogen, potassium, phosphate). In the same context in Norway a general tax of around 15% on fertilizers is introduced and a list of approved fertilizers for agricultural use is renewed every five years. Finally, in Finland a tax on phosphate fertilizers has been operation since 1990, while in Sweden a tax on both nitrogen and phosphate is implemented. It is notable that in Japan irrigation subsidies are not regarded as environmentally undesirable and no salinity problems have been detected since their introduction. However, the provision of production input-oriented subsidies, such as grants for draining wetlands or cleaning woodlands, may have direct and indirect negative environmental effects (i.e. wildlife habitat destruction) (OECD, 1993).

[36] Such a design standard can imply the use of reduced tillage, establishment of buffer strips, construction of manure storage facilities, land retirement (Segerson and Wu, 2006), heat sensors to determine soil moisture, soil erosion control to minimize surface runoff (Owen et al., 1998), drip irrigation, integrated pest management and site-specific farming (Isik, 2004). A known example of design standards is the Best Management Practices (BMPs) to reduce erosion or runoff, used by US agricultural pollution control programs (Helfand and House, 1995).

of inputs,[37] which are both relatively easy observed and often imperfectly correlated with ambient impacts (Shortle et al., 1998; Schmutzler and Goulder, 1997; Huhtala and Laukkanen, 2004). The fact that nonuniformly regulated inputs can be subject to resale among farmers (Shortle et al., 1998; Helfand and House, 1995), requires that input-based schemes should be applied at uniform rates across producers (Classen and Horan, 2001), involving identical taxes, restrictions or more precisely pre-acre restrictions. Such second-best indirect measures can be imposed broadly on all farmers (Helfand and House, 1995) [38] or target certain categories of polluters operating on certain soil types (i.e. coarser more permeable soils) or employing certain production systems where pollution is most likely to occur (Mapp et al., 1994).

The system of farm-specific, per-unit input tax / subsidy rates under uncertainty can also include a covariance term acting as a risk premium or reward (Shortle et al., 1998) to correct marginal incentives for input use. [39] The substitution effects of restricted[40] and unrestricted inputs on expected damages, as well as the input and output market price effects created by the tax must also be considered in the agricultural NPS regulations.

To deal with agricultural NPS pollution the dynamic input-based schemes can involve a vector of continuously changing, farm-specific input tax and / or subsidy rates, evaluated under the alternative informational structures adopted by farmers regarding the evolution of pollution stock. Given the informational requirements of such policy

[37] Water and nitrogen appear to be the key variables for nitrate production (Helfand and House, 1995) and are highly correlated with water pollution (Abler and Shortle, 1995). Thus the regulation of both nitrogen and water use is effective in reducing nitrogen leaching (Wu and Babcock, 2001). However, often policy-schemes involve the regulation of a single input, since coordination among all the agencies - authorized to monitor or regulate inputs without authority over each other (Helfand and House, 1995) - to get taxes right can be difficult at best (Larson et al, 1996). If only one input is to be taxed or constrained then water appears to be the preferable input to regulate (Helfand and House, 1995; Fleming and Adams, 1997; Larson et al., 1996), especially when it is administered by a water district.

[38] Broad policies are imposed either uniformly on all land types or are set at per-acre level basis (Mapp et al., 1994). Even though they are inefficient in NPS problems (Underwood and Caputo, 1996) since potential gains from differential treatment of polluters are eliminated (Shortle et al., 1998), they may be preferable in the agricultural case because they may be easier to administrate and seemingly more fair to producers and resource owners (Classen and Horan, 2001).

[39] If the number of farmers is not optimal then an additional instrument would be necessary to guarantee that the optimal number of farmers (Shortle et al., 1998).

[40] A restricted input must be verifiable (Nyborg, 2000) in the sense that it is covered by a formal tax base and can be enforced by a third party (i.e. legal court), otherwise farmers can refuse paying the tax.

schemes, the input-based regulation is modified to the second best involving either time invariant instruments determined by the corresponding steady state values or semi-time invariant instruments allowing for discrete changes over time. Under strategic interactions the dynamic input policy scheme can be based on a linear Markov perfect tax rule that is linear in inputs and depends on the current pollution stock level (Legras, 2004). The purpose of such a tax rule is to send the polluters a message that the more inputs they use now, the higher their emissions are and thus the higher the pollution stock and their future tax liability. Dynamic input-based tools can be modified to account of quantity-quality problems (Xepapadeas, 2005b),[41] where the tax scheme imposed on irrigation water has an element accounting for water overextractions and another for excess pollution. Finally, under asymmetric information nonlinear or linear (Xepapadeas, 1997) input-based mechanisms are defined in terms of adverse selection models (Hansen, 2002), where individual tax rate are based on agent's input use and revealed information regarding the type of all farmers, given that truth-telling is pursued.

3.3 Output-based Schemes

Within the price-based approaches the regulator can also impose taxes on outputs that are closely related to emissions but often imperfectly correlated with them (Schmutzler and Goulder, 1997). The idea behind the implementation of such measures is that the regulator can rely on output quantities to receive information about the emission levels and thus impose output taxes to control nitrate emissions (Schmutzler, 1996). Thus output taxes have a Pigouvian role (Cremer and Gahvari, 2002) and can substitute emission taxes, inducing thus first-best outcomes. It is worth mentioning that in the context of the EU policies that land-set-aside is primarily a policy instrument to control output supply which at the same time can be beneficial to the control of agricultural pollutants (Kampas and White, 2004).

Nevertheless, output-based schemes have been shown to be inefficient instruments in the long-run (Kampas and White, 2004). Even though output taxes would be more

[41] Overextractions have resulted in pollution of groundwater resources because of percolation of agricultural pollution (i.e. nitrate pollution) or seawater intrusion in coastal aquifers (i.e. salinity). Moreover, irrigation agriculture puts into danger the sustainability of its use and thus the sustainability of agricultural production.

sensible to be applied in sectors where small owner-managed operations are dominant (i.e. agricultural sector), their undeniable disadvantage is that they can only influence emissions insofar they depend on output level encouraging only a very specific kind of pollution reduction (Schmutzler, 1996). Moreover, if the regulator cannot measure output precisely then the mechanism to nitrate leaching control cannot be based on ex post output, since farmers are the residual claimants and first handlers of the harvest crop and can understate their output either by consuming it directly or by misrepresenting actual output (Chambers and Quiggin, 1996). Finally, input substitution, employing different technologies and abatement imply that a given level of output may result in different levels of emissions and thus the considered equivalence between output and emission taxes breaks down (Cremer and Gahvari, 2002).

Nevertheless, output taxes may be useful tools in cases where input taxes induce substitution from the targeted, less dangerous input to a non-targeted, environmentally dangerous substance, since they can indirect reduce both inputs even though they do not induce necessarily the most desirable adjustment (Schmutzler, 1996).

3.4 Ambient-based Schemes

In reality neither individual discharges nor individual productive choices are directly observed in a NPS pollution problem, rendering thus emission-and input-based schemes inadequate for regulating NPS emissions in an effective way. Nevertheless, NPS pollution problems can be handled through policy schemes based on ambient pollution which is observable or can be measured at a reasonable cost. Such ambient-based measures shift the location of monitoring from the choices of agents suspected of contributing to environmental degradation, to the environmental media (Horan et al., 1998) and have been proposed as a means of reducing administrative information requirements and monitoring costs associated with NPS pollution control, and eliminating polluters' incentives for moral hazard (Horan et al., 2002).

For the agricultural case an ambient policy scheme is in principle imposed on the collective nitrate leaching generated by farms and measured at some spatial locations - in a static setup - or on the nitrate pollution accumulated at a particular receptor point (i.e. lake, groundwater aquifer) - in a dynamic context. Five variants of ambient-based measures are usually met in environmental economic literature, known as the Segerson type ambient-based schemes (Cochard et al., 2004; Spraggon, 2002):

(i) Group incentive instrument, involving either a tax plus a lump-sum fine if the cut-off ambient pollution level is exceeded, or a subsidy and a bonus otherwise.

(ii) Tax / subsidy scheme that combines a tax and a subsidy depending upon whether the total pollution level is above or below the cut-off level.[42]

(iii) Tax scheme involves a Pigouvian tax paid by all polluters on deviations from optimal aggregate pollution. No subsidy is provided when the group total is below the cut-off level.

(iv) Subsidy scheme provides a subsidy and lump-sum bonus if total pollution is equal or below the cut-off level.[43]

(v) Group fine scheme, or else known as collective punishment, imposing a lump-sum fine on all whenever their actions result in an aggregate pollution level above the cut-off level.[44]

Such ambient measures could be applied nonuniformly if the regulator makes public the information he must elicit about farmers' profits and emission functions (Hansen, 1998). However, the dissemination of required information is likely to be costly and it is unlikely that farmers would be able to process easily and accurately (Horan et al., 2002). Hence, given the trade-off between costs and mechanism design (Larson et al.,

[42] The abatement decisions of one polluter reduce the tax payments of other polluters, providing incentives for coalition formation among polluters to increase abatement above its individually optimal level (Hansen, 1998), forcing the regulator to pay a large amount of subsidies (Spraggon, 2002).

[43] This instrument is undesirable due to the inherent collusion incentives.

[44] Real examples of collective punishments are certainly found in military and schools, but environmental ambient taxes are difficult to find since it is seen as a quite drastic form of policy (Millock and Zilberman, 2004). Nevertheless, the California drainage water policy that threatened to stop water supply unless farmers had cleaned up their site and developed alternatives to the drainage canal, as well as the threat to increase the land tax in Florida for all the farmers if the aggregate phosphorus reduction goal is not met can be considered as representative examples (Millock and Zilberman, 2004). Moreover, the Dutch water pollution charge involves a fixed tax payment for households and small firms that is independent of actual emissions (Xepapadeas, 1999). Finally, there is the experience in Germany, Thailand and Japan for specific types of industries or for specific locations which are given a chance to attain a certain ambient level of water or air quality, otherwise charges or even a direct regulation can be imposed by the regulator (Franckx, 2002).

1996),[45] the ambient-based schemes are applied symmetrically across individuals. Such uniform policy schemes can also involve state dependent, nonlinear taxes based on the effects of polluters' (environmental damage),[46] as well as linear state-dependent taxes proportional to aggregate pollution (Horan et al., 1998, 2002; Hansen, 1998, 2002).[47]

Ambient-based schemes can be either imposed collectively to all farmers within a region or randomly on one or more farmers. The fact that collective penalties are triggered even by small deviations from desired ambient levels (Xepapadeas, 1991) and that farmers who undertake costly abatement may face a penalty due to environmental shirking of others, questions the political and ethical acceptability of collective punishments (Shortle et al., 1998). As alternative random fining mechanisms are proposed, where only one agent (or more) is randomly chosen[48] and penalized if the cut-off level is exceeded (Xepapadeas, 1991).[49] Such collective and random punishment mechanisms can be formulated either as non-budget balancing if each farmer is liable for the whole environmental damage, or as budget-balancing[50] if the damage is shared between the group members (Camacho and Requate, 2004).

Under uncertainty both linear and nonlinear state dependent instruments are determined after the realization of all random variables and are applied uniformly across all polluters (Shortle et al., 1998). Given farmers' risk-aversion additional instruments (i.e. reward) associated with the use of each polluting input need to be included to account for the risk associated with stochastic ambient tax (Horan et al.

[45] Ambient schemes could also be spatially applied in the sense that each production (soil) zone faces its own unique tax scheme (Fleming and Adams, 1997). However, the fact that some local nitrate is generated by a source upstream should be taken into account.

[46]Farmers perceive that an increase in tax payment corresponds to the increase in damage and they are automatically penalized for the damage caused by increased emissions (Hansen, 1998). However, the efficiency of the mechanism is questionable since polluters' emissions are interdependent and polluters have limited information about their strategic environment (Cochard et al., 2004; Hansen, 2002).

[47]They are considered to be the modified Segerson's linear scheme (Shortle et al., 1998).

[48]Even if he does not constitute the source of the excess pollution, implying that its abatement effort has not been monitored (Herriges et al., 1994).

[49] Successful application of the instrument requires participation of all dischargers in the region and there might be some legal problems in enforcing such a random punishment (Xepapadeas, 1997).

[50]According to Spulber (1988) the budget-balancing feature implies that the sum of transfers across agents sums to zero. Under budget balancing random schemes net collected penalties are redistributed to the remaining firms.

2002). Moreover, when abatement has two effects on ambient concentration[51] a variance-based tax scheme utilizing a separate linear tax rate for each effect is foreseen (Hansen 2002). Finally, if expectations regarding the distribution of stochastic events influencing ambient pollution are different between farmers and regulator (Cabe and Herriges, 1992), then incentives must be augmented by an additional term to correct for differences in expectations.[52]

Dynamic ambient incentive schemes are analogue to Segerson's static Pigouvian tax, accounting of the endogenous nature of the externality (Xepapadeas, 1992a). The OL and FB time flexible tax rates are applied uniformly across farmers and depend on pollutant's shadow cost, discount rate, natural pollution decay rate, and information structure (Xepapadeas, 1992a). Under uncertainty the given policy schemes are augmented by an additional element that acts as a stabilizing factor and reflects the effect of environmental uncertainty (Xepapadeas, 1992a). Given that deviations from the optimal path can be attributed to stochastic variations in natural pollution contributions or weather a confidence belt is introduced and charges are imposed if deviations outside the belt are observed (Xepapadeas, 1992a).[53]

However, in a dynamic setup agricultural nitrate ambient pollution can be attributed to polluting activities that go back many years, implying that in each period active polluters are not fully or at all responsible for the current pollution level and that responsible agents may have disappeared (Cochard, 2003).[54] Therefore, even if current input choices and emissions are optimal, farmers may be asked to pay an ambient tax due to a deviation from the optimal pollution stock path observed in the present but originating in past overdischarges (Legras, 2004).

[51] Abatement affects the mean ambient concentration but also its variance. The variance-based measure is considered to be superior compared to the Segerson's tax scheme and the damage-based tax.

[52] It transforms agents' expectations so that, ex-ante, they evaluate uncertainty in the same way as the regulator, according to the regulator's density function. To mitigate problems arising from expectations' discrepancy the regulator either educates farmers about his conditional probability function for uncertain environmental relations, or proceeds in monitoring to acquire information on the physical processes influencing fate and transport of pollutants to update prior beliefs and thus increase the policy flexibility (Cabe and Herriges 1992). It is worth mentioning that such problems are not met under input-based schemes since farmers do not need information about fate and transport (Cochard, 2003).

[53] If monitoring shows cheating and the ambient standard is not exceeded then it is considered that there is monitoring error and no fine is imposed (Xepapadeas, 1991).

[54] Nitrates and pesticides may take years to move from fields to wells (Shortle et al., 1998).

Finally, under asymmetric information an ambient tax on the deviations between the optimal and observed ambient concentration of the pollutant is foreseen, which can lead to under-implementation of inputs and thus under-emissions.

3.5 Mixed-based Schemes

Ambient-based schemes have substantial theoretical appeal compared to input tax schemes[55] because there is no need to devise farm-specific policies, and through these schemes the regulator could optimally coordinate point and NP control without the need to develop and implement separate point and nonpoint instruments (Shortle et al., 1998). However, even under complete information they appear to have many and notable drawbacks that render their final implementation difficult or even impossible.[56] Given the difficulties associated with pure ambient-based instruments, a combination of policies could be considered an attractive regulatory alternative for NPS pollution problems regulation. Such policies are known as mixed incentive schemes, based on individual and collective efforts (Cochard, 2003).

Mixed instruments are drawn on at least two basic instruments and are often superior to pure tax policies (Schmutzler and Goulder, 1997) since the regulator can gather the advantages of the several basic instruments (Cochard, 2003) to secure the socially optimal emission level. They may involve either a combination of ambient and Pigouvian taxes the relative size of which depends heavily on revealed individual emissions (Xepapadeas 1995),[57] or a system of ambient level inspections if ambient pollution exceeds the social optimum involving the imposition of fines and enforcement of statutory regulation at inspected noncompliant farmer (Franckx,

[55] They seem to reduce the complexity of policy design relative to input-based incentives.

[56] These disadvantages deal with (i) the collective nature of ambient taxes that weakens of Nash equilibrium concept and introduces collusion incentives among farmers, (ii) the non-budget balancing feature, (iii) the time lags in pollution transport, (iv) entry / exit incentives, (v) polluters' risk-aversion and their need to know their environmental types, (vi) the difficulty in metering ambient pollution, (vii) the coordination on a Nash equilibrium and (ix) divergences between regulator's and farmers' beliefs about the pollution process (Cochard, 2003).

[57] In particular, farmers that do not reveal individual emissions pay an ambient tax per unit of deviation from the cut-off level, while in the intermediate situation between full and no observability farmers revealing individual decisions pay a Pigouvian tax on individual emissions and a reduced or even zero ambient tax rate.

2002).[58] Moreover, when a public random monitoring system is ineffective[59] the policy scheme employs the background threat of a probabilistic collective penalty to induce self-reporting of accidents in the absence of public monitoring (Millock and Zilberman, 2004).[60] Finally, a two-part penalty system of individual and collective fines is proposed (Kritikos 2004), targeting a reduction of individual and total emissions.[61]

3.6 Concluding Remarks

Apart of these regulatory measures agricultural NPS pollution can be also handled through liability for damages, land-set aside programs promoted by the EU in the context of voluntary approach type regulation, markets and moral suasion. Markets involve trades between PS and NPS emissions permits, even though there is still question about the appropriate basis for measuring NPS performance (Cochard, 2003). Moreover, moral suasion involves educational programs supplemented by technical and financial assistance for the reduction of chemical inputs by farmers (Abler and Shortle, 1995).

Finally, agricultural NPS problems such as nitrate pollution can be handled via Voluntary Approaches (VAs). This particular new instrument is actually a complement to a conventional regulatory system since it combines both voluntary and mandatory tools (i.e. input-related performance standards, ambient taxes), and can be regarded as a very important instrument of EU's current agricultural policies. VAs are based on a new type of interactions between regulators and economic actors, and are

[58] If an inspected farmer is found in noncompliance with the optimum then a fine is imposed and he can be obliged to incur the cost of compliant technology. On the other hand, non-inspected farmers are not liable for any tax no matter their compliance status (Cochard, 2003).

[59] In the case of water contamination the pollutant dissipates quickly and it may be very costly to trace the pollution back to its source.

[60] The excess use of agricultural inputs and thus excessive emissions flow could be perceived as an accident. If the regulator detects the damage from an accident that has not been reported then there is a positive probability of a tax imposed on all farmers. Hence, farmers are offered the chance to self-report the accident and undertake abatement in exchange of a reduced individual fine compared to the probabilistic collective penalty.

[61] If ambient pollution exceeds the target then a collective penalty is imposed on every farmer. At the same time the regulator can spot-check compliance with individual limits via unannounced monitoring of arbitrarily chosen farmers and individual linear penalties imposed only on monitored noncompliant farmers. If found in compliance then the collective penalty is not imposed. Not-inspected producers are liable for the collective penalty.

usually classified as unilateral commitments, public voluntary schemes and negotiated agreements. Apart from this first classification there is large list of criteria to further differentiate voluntary approaches such as: initiator, degree of detail, legal obligation, sanction types.

Due to the increasing importance of Voluntary Approaches as an environmental policy instrument and the particular importance they acquire in the context of the EU policies, the latest available developments in the area are presented in some detail for the better understanding of the properties and the various aspects of the instrument.

CHAPTER II:
Voluntary Approaches in Environmental Policy

Since the early 1970s environmental policies have focused heavily on command-and-control regulation to ensure adequate protection of environmental quality. However, from nearly the beginning these instruments have been widely criticized for being costly and inflexible (Lyon and Maxwell, 2002), as well as complex and characterized by interdependencies (Pesaro, 2001). Due to their substantial inability to reverse the environmental degradation process (Pesaro, 2001), the search has turned towards less costly and more efficient means of achieving environmental protection goals (Dawson and Segerson, 2002). Thus regulators turned to market-based incentives such as emission taxes or tradable permit systems that became increasingly common by the late 1980s. Nevertheless, a new instrument, namely voluntary environmental approaches, has recently been added to the regulator's tool box (Lyon and Maxwell, 2003), which goes beyond even market-based environmental regulation.

The expression Voluntary Approaches (VAs) usually means a series of "*commitments from polluting agents or industrial sectors to improve their environmental performance*" (Brau et al., 2001). They are complements to the current regulatory system and not a substitute, primarily used to alleviate the economic impact of new environmental laws on heavily affected sectors, as well as to extend the scope and efficacy of individual air, water, waste and toxic laws (Šaeur et al., 2001; Mazurek, 1998). VAs are based on a new style of interaction between public and economic actors, where all social forces and activity fields participate in the prevention and maximum possible reduction of environmental impacts, leading from polluter pays principle to a precautionary and shared responsibility principle (Pesaro, 2001). Such activities appear to be a *softer* form of regulation and, in effect, can be broader and more encompassing than mandatory requirements and regulations (IEA, 1997).

Such instruments are expected to lead to socially less expensive solutions to given environmental problems, since they have the potential to reduce both environmental compliance costs and the associated administrative and transaction costs (Segerson and Miceli, 1998). They can further increase environmental effectiveness and social welfare, as well as contribute to innovation processes and information dissemination (Šaeur et al., 2001). However, despite their growing popularity[62] since the beginning of 1990s, the novelty of voluntary programs, the lack of data, along with the weak metering and evaluation methods make it difficult to determine the extent to which voluntary programs have actually reduced pollution, or reduced abatement and administrative costs (Mazurek, 1998).

1. Voluntary Approaches: some Introductory Issues

The major features of voluntary approaches as presented in the recent environmental economics literature are discussed, with the purpose of enhancing our understanding regarding this environmental policy instrument. In particular, a description of the various differentiation criteria of VAs, the factors that motivate their establishment, as well as the economic agents who appear most likely to initiate or participate in VAs are provided. Moreover, the benefits and drawbacks, as well as the existing implementation difficulties, are described. Finally, the effectiveness of VAs is assessed and some rules about their effective use are presented.[63]

1.1 Typology of Voluntary Approaches

Voluntary approaches can be classified according to various perspectives, but the prevailing taxonomy is based mainly on the degree of public intervention, meaning the degree of public authority's impact on a certain hierarchical level of public administration (Šauer et al., 2001). Based on this criterion VAs typically fall into one of Lévêque's three basic categories: *unilateral commitments*, *public voluntary schemes* and *negotiated agreements* - the distinctive characteristics of which are given below:[64]

[62]Even though the use of VAs has become more common since the beginning of the 1990s, there are some precedents of voluntary approaches in the OECD member countries as far back as the 1960s and early 1970s. For instance, the first environmental agreements between industries and authorities in Japan and France were reported in 1964 and 1971 respectively (Šaeur et al., 2001).

[63]The review of voluntary approaches is not restricted to environmental contracts designed for the agricultural sector. Therefore the term "farmers" is often replaced by the term "agents", "polluters" or "producers".

[64]These categories of VAs are referred by Mazurek (1998) as “Lévêque’s basic categories” since this taxonomy was offered by Lévêque (1997).

1. *Unilateral commitments.*

Unilateral commitments or agreements are environmental improvement programs undertaken by a single producer or a group of producers and further communicated to their stakeholders (Brau et al., 2001). Such actions are often encountered in economic literature as: business-led corporate environmental programs, self-regulation and corporate environmentalism (Alberini and Segerson, 2002). Their main characteristic is that the initiative rests solely with the polluters themselves. Even though unilateral programs may be developed after consultation with governmental bodies (Lyon and Maxwell, 2002), the regulator does not play any active role in their design (Alberini and Segerson, 2002). Industries, producers and trade associations prepare their complete environmental improvement programs, define the environmental goals and state measures leading to their achievement (Šaeur et al., 2001). Moreover, they may authorize another third party to monitor and resolve conflicts, in order to increase credibility and the environmental effectiveness of their commitment. The ultimate aim of such agreements is not only to encourage polluters to voluntarily adopt better environmental management codes, but also to improve public perception and / or regulatory goodwill in order to reduce costs associated with permitting and reporting indirectly, as well as minimize the threat of more stringent regulation (Mazurek, 1998).

It is noteworthy that unilateral agreements usually belong to an industry trade association (Lyon and Maxwell, 2003), where participation is a condition of trade association membership and the ultimate sanction for a participant that fails to implement the established voluntary practice codes or make adequate progress towards program goals is the threat of dismissal from the trade organization (Mazurek, 1998).[65]

Notable examples of unilateral agreements are Arco's voluntary introduction of reformulated gasoline, the German Industry and Trade Association's plan to reduce carbon dioxide emissions (Lyon and Maxwell, 2002) and the Czech Association of the Petrol Industry and Commerce’s initiative concerning fuel quality characteristics

[65]In practice noncompliant participants are mostly provided information and technical assistance, and in some case sanctions means letters of inquiry at a first stage and terminate with dismissal.

(Šaeur et al., 2001). Similar commitments are the 3M's 3P programme, Dow Corporation's WRAP and CMA's Responsible Care programme (Dawson and Segerson, 2002). Responsible Care (1988) is the most prominent unilateral program in the US to date (Mazurek, 1998). The scheme was prepared in response to the decreasing level of public trust in the chemical industry and to the looming danger of stricter regulation (Šauer et al., 2001). It aims at regaining society's trust and limiting regulatory intervention to a level that is acceptable to the industry (Lyon and Maxwell, 2002). Accordingly, the initiator Chemical Manufacturers Association (CMA) provided its members with general guidance documents that explain how to adopt six management practice codes that range from pollution prevention to product stewardship and allowed participants to use a registered Responsible Care trademark in order to obtain public recognition (Mazurek, 1998).

2. *Public voluntary schemes.*

Public voluntary schemes or agreements are environmental programs explicitly developed by some public body (i.e. US EPA) or a quasi-public but non-governmental body (i.e. International Organization for Standardization / ISO) and to which polluting agents and sector associations can only agree with (Brau et al., 2001). The initiator of such schemes is the regulator who unilaterally determines the rewards and obligations from participation, as well as the eligibility criteria (Alberini and Segerson, 2002). Participating agents just agree to certain non-mandatory rules that affect their activities, technology or management. These rules include the characteristics of the given program such as the requirements for individual participation, measures to be undertaken, ways of monitoring commitment[66] and means of evaluating the results (Šaeur et al., 2001). Supplementary funds for science and research, technical aid, as well as rights to use an ecological logo or certification symbol are also provided to secure a broader and more efficient implementation of voluntary environmental actions.

[66] Progress is monitored primarily via annual self-reports that in some cases are verified by a third, independent party. However, reporting requirements vary from facility to facility and may be annual, biannual or quarterly (Mazurek, 1998).

Examples of public voluntary programs are the environmental management systems certification standards, EMAS and ISO 14000 respectively (Šaeur et al., 2001). In this category fall the Conservation Reserve Program and its successor, the Environmental Quality Incentives Program (Dawson and Segerson, 2002), as well as the US Green Lights and Energy Star programs aiming to reduce energy-related CO_2 emissions or minimize specific process emissions (IEA, 1997). It is noteworthy that of the 42 US national voluntary initiatives, 31 are purely public voluntary programs (Mazurek, 1998). The 33 / 50 Program (1991) is the major US public voluntary program, designed to induce manufacturers to progressively cut the emissions of 17 key toxic chemicals by providing some favourable publicity and some limited technical assistance, as well as by signalling the increased threat of federal regulation (Lyon and Maxwell, 2002). Finally, among the US public voluntary schemes the "AgStar" and "Ruminant Livestock Efficiency" programs are designed exclusively for the agricultural sector, aiming to encourage farmers to adopt best management practices to reduce agricultural methane emissions (Mazurek, 1998).

The EU rural development programs developed under the second pillar of Common Agricultural Policy (CAP) fall into the category of public voluntary schemes. In order to promote the competitiveness and viability of the multifunctional farming activity in a sustainable way, the communal rural development policy promotes a coherent series of measures that complement the market policy reforms (Pillar I). Such measures are related to the (i) modernisation of farms,[67] (ii) processing and marketing of quality agricultural products,[68] (iii) setting-up of young farmers,[69] (iv) improved conditions for early retirement,[70] (v) conservation and improvement of ecological stability of the

[67] Aid is provided for investments in agricultural holdings that pursue certain objectives such as reducing production costs, promoting best possible product quality, improving or diversifying productive activities, conservation and improvement of natural environment, health and hygiene conditions or animal welfare standards (EC, 2004b).

[68] The measure aims to increase the competitiveness and added value of agricultural products by improving their presentation, processing procedures and marketing channels, reorienting production to new outlets, applying new technologies, monitoring quality and health conditions, encouraging innovation and protecting the environment.

[69] Farmers who are under the age of 40 years and set up in farming for the first time are provided with aid in the form either of a single premium or an interest subsidy on loans taken to cover establishment costs.

[70] Early retirement schemes aim to renew labour force by providing annual support to farmers and farm workers over the age of 55 years but not yet of retirement age that stop all commercial farming activity

forestry sector,[71] (vi) vocational training,[72] (vii) exhortation of farming in less-favoured areas,[73] as well as the (viii) protection and maintenance of the European countryside (agri-environment)[74] (Garaulet and Lawyer, 1999; EC, 2004a, 2004b). Actions that promote the environment are the only compulsory element of the rural development programmes and like the market policy measures (i.e. land usage direct payments), the provided payments are conditional on compliance with a common set of environmental provisions (i.e. horizontal regulation) and the principle of cross-compliance, involving partial or full removal of aid in the event of detected non-compliance (EC, 1999).

Within the EU territory there is a large number of rural development programs, where emphasis is given to agri-environmental schemes, indicating the political priority attached by the Commission to agri-environmental issues. Notable examples of such a type of public voluntary programs are the UK Environmental Stewardship Scheme (ESS) and English Woodland Grand Scheme (EWGS), supporting the sustainable management of landscape, forests and woodlands (DEFRA, 2007a),[75] the Finnish Agri-Environmental Programme (FAEP) pursuing reduced fertilizer and pesticide use,

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and reassign their land to other farmers or to non-agricultural uses (i.e. forestry, ecological reserves). Eligible farmers must have practised farming for at least 10 years before stopping, while farm workers must have devoted at least half of their working time to farm work during the 5 years before stopping.

[71] Such schemes offer aid to private forest owners or municipalities to preserve woodlands (i.e. maintain fire breaks), afforest farm land, proceed in investments on non-farm land to upgrade harvesting, processing and marketing of forestry products, as well as open up new outlets for forestry products.

[72] Training intends to improve the occupational skill and competence of persons involved in agricultural and forestry activities, facilitate their adaptability to changing market conditions and opportunities, as well as to raise awareness of environmental impacts and management techniques compatible with environmental protection and maintain landscape, hygiene and animal welfare (Baldock et al., 2002).

[73] Per hectare compensatory payments are provided to farmers operating in less-favoured areas (LFA) in order to apply for at least 5 years usual good farming practices compatible with the requirements of environmental protection, maintenance of countryside and sustainable farming. LFA are areas with environmental disadvantages (i.e. mountainous areas), with agricultural disadvantages (i.e. number of agricultural holdings), as well as small areas, hilly regions, wetlands and flood plains, border regions.

[74] For a minimum 5 year period, per hectare supports are provided to farmers that use agricultural production methods designed to protect and maintain the agri-environment and aim to promote environmental planning, extensification, conservation of farmed environments of high natural value and the upkeep of landscape. A longer period may be set for certain types of undertaking (Garaulet and Lawyer, 1999).

[75] The Environmental Stewardship Scheme is built on the success of the Environmental Sensitive Areas Scheme and the Countryside Stewardship Scheme, while the English Woodland Grand Scheme has replaced Woodland Grand Scheme and the Farm Woodland Premium Scheme (DEFRA, 2007a).

along with pollution reductions (UN, 2007),[76] as well as the Austrian Programme for Environmentally-Oriented Agriculture (ÖPUL) addressing environmental problems arising both from the abandonment of marginal land and the intensification of productive land (DEFRA, 2007b).

The present Doctoral Thesis focuses on the category of public voluntary programs.

3. *Negotiated agreements.*

Negotiated agreements refer to contractual arrangements between a regulatory authority and an individual polluter, a sector or association. Even though the prime initiator behind a new program, falling into the previous categories of VAs, was either the polluter or the regulator, under such formal approaches these two actors are both active participants (Lyon and Maxwell, 2002). Negotiation is not a bargaining form to solve conflicts but a peculiar interaction model of a new way of policy-making, where economic actors are no longer only part of the problem but also part of the solution (Pesaro, 2001).[77]

Involved parties negotiate for the terms of the agreement that include a specific goal, clearly defined tasks, a time schedule and other conditions necessary for the fulfilment of expected results (Šaeur et al., 2001), as well as reciprocal commitments and shared responsibility on the part of all participating parties (IEA, 1997). Polluters are obliged to improve their environmental performance in the time and ways outlined by a number of constraints and clear rules, while the regulator is committed either not to enforce a particular action against the polluter or to exempt him from certain regulations (Alberini and Segerson, 2002). The regulator's commitment could also involve considerable up-front specific financing and technical assistance, a law for using ecological logos, or granting of a particular permit or approval for other activities (Alberini and Segerson, 2002) in order to ease some of the additional

[76] The Finnish Agri-Environmental Programme consists of the General Agricultural Environment Protection Scheme, the Supplementary Protection Scheme, the Scheme for Advisory Services and training, along with the Scheme for Demonstration Projects (UN, 2007).

[77] Negotiated agreements are also termed as environmental covenants, voluntary environmental agreements, voluntary partnership, bilateral or cooperative agreements and formal voluntary approaches.

administrative and organizational burden and thus encourage participation (IEA, 1997).

The primal goal of negotiated strategies is to improve the effectiveness and efficiency of laws by reducing the regulatory burden and providing relief to regulated industry (Mazurek, 1998). Their use can be mainly justified in cases where environmental goals can be achieved through technology innovation, especially when market imperfections exist or when environmental innovation has positive spillovers (Xepapadeas, 1997). Such bilateral agreements tend to be heterogeneous in nature (Lyon and Maxwell, 2003) and may also take on the status of legal binding contracts if either legislation gives the authority to executive branches governmental to sign them (Lyon and Maxwell, 2002) or the existing law allows the regulator to sign such agreements (Šaeur et al., 2001). However, legal obligations may also be included and operate only if the agreed goal is not fulfilled or the bargaining process does not always end up with the signing of an agreement.

Such voluntary approaches are also called *private environmental agreements* if concluded between polluters and those harmed or their representatives (Šaeur et al., 2001). One theoretical justification is Coase's idea of direct negotiation between polluters and victims, which however requires favourable conditions such as clearly defined ownership rights toward environmental goals, access to information, zero transaction costs etc.

Characteristic examples of negotiated agreements are the French agreement on the treatment of End-of-Life Vehicles to reduce car waste destined for a land fill site, the New Zealand agreement of the cement industry with government to reduce carbon dioxide emissions, as well as the German agreement of the energy sector with government to reduce CO_2 emission through a 20% reduction in energy consumption in order to deter the passage of a waste heat ordinance and the implementation of a carbon/energy tax (Dawson and Segerson, 2002). In the same context are the Swedish agreement of producer responsibility for packaging and the Dutch policy on implementing target emissions levels in the chemical industry (Lyon and Maxwell, 2002). Finally, even though both Project XL and the Common Sense Initiative involve negotiation aiming to reduce administrative costs associated with reporting, monitoring and permitting, they also resemble public voluntary programs (Mazurek, 1998).[78]

[78] These projects were designed in response to complaints from the regulated community regarding the growing details and complexity of federal pollution control laws, to reform environmental regulation.

1.2 Criteria for Differentiating Voluntary Approaches

The discussion above suggests that Voluntary Approaches can be identified as the "*commitments undertaken by producers and sector associations, which are the result of negotiations with public authorities or are explicitly recognized by the authorities or producers themselves*" (Mazurek, 1998). Based on Šauer et al. (2001) further criteria can be identified to differentiate voluntary approaches within the scope of the three basic categories described previously. These differentiation criteria are:

a) *The degree of detail of the agreement.*[79]

VAs can be rather generic or very detailed in their definition of the actions, objectives and content, the number of sectors involved etc. (IEA, 1997).[80] The regulator can distinguish between *target-based agreements* that are based on exactly specified and quantified goals (i.e. German energy sector's negotiated agreement) and *implementation agreements* that determine the means that develop a consensus with previously established environmental policy goals.

b) *Level of legal obligation toward fulfilling the agreement.*

Depending on existing laws the established VAs may or may not comprise any legal obligation of the involved agents to fulfil the agreement's targets. If taxes or direct regulations can not be enforced by a third party (i.e. legal court), then agreements can be sustained only by the mutual compliance of involved parties (Nyborg, 2000).[81]

c) *Sanction types in case of failure to fulfil the agreement.* [82]

[79]This criterion can also be referred to as "degree of structure" (IEA, 1997).

[80] Project XL and CSI have established less precise environmental targets (Šaeur et al., 2001).

[81] In Netherlands the majority of negotiated contracts have civil-law features, implying that if a participating agent fails to fulfil the agreement's goals then he is responsible before a civil court (Šaeur et al., 2001). In US only the Project XL contains legally binding features, providing relief from existing laws and regulations in exchange for environmental performance superior to status quo standards (Mazurek, 1998). In Norway negotiated agreements employed to deal with non verifiable packaging emissions, wastes not covered by a formal tax base, cannot be sustained by legal enforcement (Nyborg, 2000).

[82] Most EPA voluntary initiatives are non-binding and impose no sanctions - compliance actions and fines - for program withdrawal (Mazurek, 1998).

The sanction types that operate if signatory agents fail to fulfil the agreement's provisions can be financial, moral, different means of regulation or even cost associated with the resignation from bilateral agreements (Šaeur et al., 2001).

d) *Agreement initiator.*

Accordingly to the nature of the environmental problem and the degree to which legislative laws and regulatory policies address the problem (Mazurek, 1998), the initiator of the agreement can either be a public body, an individual polluter or a group of polluters, a sector representative, a non-governmental organization (Šaeur et al., 2001), or it can even be the result of their coordination.[83]

e) *Characteristics of the subjects damaging the environment and participating in the agreement.*

"Liable" to voluntary approaches can be individual activities, industries or sectors, as well as a "group of subjects", whose economic activity pollutes the ambient environment, starting from extraction activities (i.e. mining, forestry) up to manufacturing (i.e. chemicals, electronics and computers), or agriculture.[84]

f) *The level of openness toward third parties.*

Negotiated agreements involve the widest array of participants up front to minimize potential legal challenge later on,[85] while unilateral agreements may exclude organizations from their development to preserve project's autonomy (i.e. Responsible Care).

g) *The level at which the agreement is concluded.*

[83]The most common case of VAs in Europe are negotiated agreements (Šauer et al, 2001).

[84] The US Energy Star programs include agreements with construction, electronics, office equipment and energy firms (Mazurek, 1998).

[85] Project XL requires industry participants to recruit residents living near participating facilities or have a direct interest in the outcome, to participate in a 6-month negotiation process (Mazurek, 1998).

Relative to the application level voluntary approaches can be separated into agent-specific, industry-wide, national, federal or regional approaches.[86] Nevertheless, all these features can be comprised by a single VA.[87]

h) *The no-surprise feature of the agreement.*

"Non-surprise" VAs offer assurances to participants that the terms of the agreement will not change in response to changing environmental protection needs (Langpap and Wu, 2004).[88]

i) *The nature of enforcement instruments.*

"Carrot" and / or "stick" instruments can be employed to induce participation and achievement of established environmental goals (Segerson and Miceli, 1998). *Carrot-based approaches* involve the provision of total-cost or sharing subsidies, information subsidies, technical assistance and / or public recognition through awards, press announcements or a law for the use of product logos that bears the program's name (Mazurek, 1998).[89] *Stick-based approaches* entail the implementation of existing mandatory restrictions (Segerson and Miceli, 1998) or the establishment of a new regulation.[90] Finally, a *mixed-based approach* that uses in combination the carrot and stick approach can also be implemented (Segerson and Miceli, 1998).

[86] Japan has 30.000 negotiated agreements regulating industrial activities on local level (Šaeur et al., 2001). In US, 42 national voluntary initiatives have been developed since 1988 (Mazurek, 1998).

[87] The Italian Part for Energy and Environment agreement, developed under the Kyoto Protocol commitments, was signed in national, regional and local level, as well as by individual economic actors (Pesaro, 2001).

[88] Examples of such non-surprise policies are the Habitat Conservation Plans, the Safe Harbor Agreements and Candidate Conservation Agreements with Assurances (Langpap and Wu, 2004). The US Department of Interior has developed a "No Surprise" policy under which it signs agreements with companies or individual landowners committing not to change the rules applying to a particular piece of property for a fixed period of time (Lyon and Maxwell, 2002).

[89] Into this category fall the US Conservation Reserve Program, Green Lights and Energy Star (Mazurek, 1998). The US agricultural water quality policy has mostly relied on carrot-based approaches (Segerson and Wu, 2006).

[90] Even though the difference between an agreement and a direct regulation lies in the fact that regulation is enforced without agents' consent, while the agreement requires mutual acceptance of the terms (Nyborg, 2000), under stick-based approaches this difference can be fairly trivial and the use of the term "voluntary" is not successful. Examples of such VAs are the Superfund Act and Clean Air Act Amendments (Khanna and Damon, 2002).

1.3 Motivation behind Voluntary Approaches

Voluntary initiatives have been attributed to a variety of motives. Lyon and Maxwell (2002), as well as Alberini and Segerson (2002) provide some insights regarding the great appeal of VAs and identify the basic motives behind voluntary actions.

In detail the basic motivations entail the following:

1. *Personal stewardship.*

Voluntary actions are stimulated by personal satisfaction or utility gained from voluntary environmentally friendly activities and such a personal stewardship is important for the effective "massive" reduction of pollution activities.

2. *Response to government-created incentives.*

Under a carrot-based VA the level of agents' profit or net benefit must be at least as high as under the pre-policy level, while under a stick-based VA the default / non participation policy must be made the more costly policy.

3. *Response to market-based incentives.*

Voluntary actions to improve the public image of producers with respect to environmental issues increase the goodwill of "green" consumers to pay a premium for environmentally friendly products (i.e. organic products, reformulated gasoline, and biodegradable plastic bags), leaving potential room for an increase in sales and profits (Khanna and Damon, 1999). Moreover, they can improve access or terms received in input markets, given the existence of *"green" investors* that avoid investing in producers deemed environmentally irresponsible (i.e. tobacco, nuclear power).[91]

4. *Improving productivity.*

[91]Notable example is the 33/50 program where the publication of TRI figures damaged the stock values of the heaviest polluters, forcing them to substantially reduce their releases (Khanna and Damon, 1999).

Even in the absence of regulatory, output and / or input market incentives, producers proceed with voluntary pollution reduction if such an action improves the efficiency of manufacturing processes, a fact that reduces costs and increases profitability.[92]

5. *Optimizing corporate regulatory strategy.*

Producers may take strategic actions trying to influence and hence shape regulatory decisions in order to preempt or mitigate the effects of future regulation, reduce the monitoring extent or alternatively raise rivals' costs. In particular:

a. *Preempting tougher regulation.* Through self-regulation producers attempt to conciliate society (i.e. environmentalists) and thus deter the demand for regulation and remove the background threat of legislation.[93]

b. *Weakening Forthcoming Regulations.* High quality producers can influence the subsequent regulations and potentially gain a comparative advantage over market competitors if they choose their environmental friendliness level before the regulator sets standards.

c. *Reducing regulatory monitoring.* Producers can use VAs to gain public recognition for responsible environmental management so as to reduce monitoring rate or lessen the scrutiny from the regulator, as well as to turn monitoring and enforcement efforts to other producers.

d. *Encouraging Anticompetitive Regulation.* In an uncertainty context large producers can voluntarily abate pollution to stifle competition and raise industry-wide rents. As the regulator cannot know whether the costs of the new regulation are too high to lead small producers off the market, large firms can try to convince the regulator via their voluntary actions that the industry-wide compliance costs are low so that a strong regulation is imposed.

1.4 Characteristics of Agents Undertaking Voluntary Initiatives

[92] Notable example is the 3M Corporation's "Pollution Prevention Pays" Program where line workers identified opportunities for waste reduction leading to cost savings.

[93] Voluntary environmental improvements, such as "Responsible Care" program and "Big Three" automakers' Vehicle Recycling Partnership, can be perceived as an attempt to avoid the transaction and / or compliance costs associated with the traditional mandatory legislative / regulatory process.

The economic agents' willingness and ability to initiate or participate in a voluntary program is affected by various factors, the basic ones of which are listed below: [94]

1. *Producer-specific characteristics: size,*[95] *R&D expenditures, financial and environmental performance, customer interfacing.*

Voluntary initiatives appear to be skewed towards large producers due to the higher public profiles and thus the higher exposure to liability, the presence of economies of scale making compliance with regulations relatively cheaper, the better access to capital markets and / or the higher ability to influence the regulator through overcompliance. [96] Poor environmental performance is positively related to the willingness to participate. The revealing of such information attracts the attention of media and pressure groups, as well as affects negatively the market value of the producer since it is viewed as a negative economic signal by investors (i.e. inefficient production or intensive regulatory monitoring).

Producers with higher advertising to sales ratios and producers of final-good products are more likely to voluntarily cut emissions, since the product characteristics or production practices are more visible or recognizable to consumers. Even though participation is expected to be higher in R&D intensive industries there is no strong evidence to support this thesis, while the same holds for the impact of profitability and recent growth of the company on the initiation and participation incentive.

2. *External Pressures: community, environmental and industry group, regulator.*

The perceived level of future regulatory incentives, the allocation of bargaining power and the nature of bargaining process affect the likelihood and extent of corporate voluntary actions. Green consumers can raise the benefits from friendly corporate environmental actions through increased sales, while environmental organizations can raise costs through the pressure on the regulator for future regulations. Finally,

[94]For further details see Lyon and Maxwell (2002), as well as Alberini and Segerson (2002).

[95]As a proxy of the agent size variables such as sales' figures; the number of employees; the value of assets can be used (Lyon and Maxwell, 2002).

[96]Producers with a good environmental record may not be willing to incorporate voluntary actions due to the fear of bad publicity if they fail to maintain their outstanding performance.

industry groups may be another source of motivation, since association members may pressure each other to coordinate actions needed to forestall threat of regulation.

3. *Industry characteristics: degree of competition.*

Arguments have been put forward suggesting that the adoption of voluntary approaches is affected by the competition extend. However there is no evidence to support the perception that corporate environmentalism is more likely under less concentrated industries.

1.5 Assessment of Voluntary Approaches: Benefits and Drawbacks

The remarkable turn towards voluntary approaches has been strongly connected with the associated advantages over mandatory tools.

The benefits of voluntary actions include:[97]

1. *Adaptability, flexibility and cost effectiveness.*

Under VAs the polluting agents are left free to find the cost effective solutions by which the target is to be fulfilled. This "solution variability" may involve greater flexibility and administration / transaction cost savings compared to traditional tools. Agents can correspond rapidly and adjust their strategies to the timely changes of technical and economic parameters (Šauer et al., 2001), providing great stability in long-term requirements (IEA, 1997).[98]

2. *Promoting understanding and trust in the sector*, as well as *continuous dialogue with the regulator.*

VAs require positive actions and not passive reactions to policy instruments, leading to a collective understanding of environmental problems (Šauer et al., 2001). Increased cooperation and functional representativeness among industry, non-government organizations and the public is promoted, which can shift from a centralized and authoritative environmental policy into a participatory and decentralized policy (Pesaro, 2001). The trustworthiness towards polluting parties can be improved by including a third, independent party in the goal establishment step (i.e. monitoring).

3. *Encouraging innovation, information exchange on best practices and potentially more efficient and quicker implementation.*

[97] An extensive list of benefits and drawbacks is provided by IEA (1997), Table 2.

[98] The perception that negotiated agreements are more cost effective than administrative approaches (Šauer et al., 2001) is strongly dependent on the assumption that mandatory approaches are inflexible, which in practice may not always hold (Alberini and Segerson, 2002).

A forum for information sharing among agents is provided, leading to information dissemination regarding the alternative abatement techniques (Lyon and Maxwell, 2002). The flexibility of VAs may encourage creativity, leading to technical and organizational innovations that reduce compliance, administrative and transactions costs associated with the preparation, conclusion and inspection of concluded agreements (Šauer et al., 2001). VAs may imply the faster achievement of established goals in a way that other approaches cannot (Pesaro, 2001).

4. *Delegating responsibility to local level, and integration of environmental improvements into business planning cycle*.

Producers and sectors are encouraged to proceed in proactive approaches, as well as to alter the input usage that may increase productivity and savings on materials, energy, wages (Khanna and Damon, 2002).

5. *Providing "green image" to participating agents* and *creating soft effects.*

VAs are a way to promote favourable public opinion and influence consumers' choice, leading to the substitution of less environmentally friendly products with products that process desirable characteristics in environmental terms.

Despite the advantages there are some drawbacks that reduce the effectiveness of VAs and justify observed implementation difficulties. These drawbacks are:

1. *Disturb competition and restrain trade.*

VAs can disturb the conditions of economic competition and thus restrain trade,[99] offering private benefits to participants but not to society (Mazurek, 1998), by blocking some producers from entering the market, prohibiting a third party from entering the system or even gradually driving a product out of the sector (Šauer et al., 2001).[100]

2. *Room for the activities of the free riders*.

[99] In 1977 the European Committee evaluated 20 instances of such disturbances (Šauer et al., 2001).

[100] Unilateral agreements are considered to have the greatest potential to restrain trade (Mazurek, 1998).

If the VA is signed by an industry representative or a group of firms in the industry (i.e. industry-wideVAs), the benefits deriving from the fulfilment of the established goal are often collective and characterized by no rivalry and no excludability (Brau et al., 2001).[101] Free riding is likely to emerge through non-compliance and short-term thinking to take advantage of non participation (IEA, 1997), a fact that may lead to the failure of an agreement before the potential benefits are realized.[102]

3. *Uncertainty about legality and anti-trust legislation.*

The legislative framework and uncertainties about the instrument's legality restrict the use of VAs given the attention and resources required for meeting legal requirements and judicially imposed deadlines (Mazurek, 1998).[103] Anti-trust law may constrain the type of decision-making tools or enforcement mechanisms if the instrument is perceived as an attempt to restrain trade. Agents' incapability and unwillingness to understand the conditions and constraints of VAs, as well as create new policy networks and ways of interaction, restrains their applicability and effectiveness (Pesaro, 2001).

4. *Insufficiencies in monitoring, inadequate clarity and accountability.*

The transparency of VAs is questioned due to the lack of clearly defined decision making, participatory, monitoring and reporting procedures (Mazurek, 1998), a fact that damages their public trustworthiness, making difficult their fulfilment and the ex post evaluation of their effectiveness (Lyon and Maxwell, 2002).[104]

5. *No guarantee of parties obeying agreement, VAs could be open to abuse.*

[101] For example, if a group of firms, by signing a VA, can deter the implementation of a cost-ineffective regulation, the benefit goes to all firms in the industry (Brau et al., 2001).

[102] Free-riding agents either decide not to fulfil the goal from the beginning (ex-ante) or at the very end (ex-post) if they do not anticipate a long-term cooperation with the VA partners (Šauer et al., 2001). Even if all polluters are identical, it is possible to have an equilibrium in which a subset of polluters in the industry participates and the remaining free-ride (Dawson and Segerson, 2002).

[103]Concerns about the legality of Project XL led to lower participation rates than expected, leading to lower environmental benefits.

[104]The Project XL and Responsible Care have failed to develop independent, third party verification methods to monitor companies.

6. *No incentive to go further than the agreed objectives, VAs may appear not demanding enough.*

7. *Technological innovation may not be encouraged unless stated or included in the agreement.*

8. *Number of participants could be restricted due to transaction costs.*

When polluting agents are very heterogeneous, fragmented and loosely organized then VAs may not be well-targeted, limiting their ability to deal effectively with environmental and adverse selection problems (Alberini and Segerson, 2002).[105]

9. *Negotiations can be quite time-consuming, costly and bureaucratic.*

A lengthy preparation and negotiation process may delay the solution of urgent ecological problems and may even produce serious, irreversible environmental changes (Šauer et al., 2001). VAs relaying on carrot approaches hinge on the ability to generate necessary funds and can be socially costly given their impact on industry size and the excess burden of taxes necessary to raise funds (Alberini and Segerson, 2002).

1.5.1 How to Enhance Effectiveness?

Despite the increasing trend towards the instrument of voluntary approaches, there is evidence that in certain cases implementation problems have led to lower than expected environmental results (Mazurek, 1998). Nevertheless, the effectiveness of voluntary approaches - mostly negotiated VAs - can be improved if the instrument embodies certain features.

In particular, VAs must be written contracts enforceable either by private or public law to bind involved parties to their doable commitments. The wording of references, premises, implementation deadlines, starting conditions, objectives and proposed means of achieving them must be clear and plausible (Pesaro, 2001), involving a minimum participation and abatement level so that VAs are operational and cosmetic

[105] In the design of VAs both the terms of participation and abatement obligations must be clearly set, since high participation rates do not guarantee that the environmental target is achieved due to the fact that agents may proceed in cosmetic abatement.

emission abatement is avoided (Brau et al., 2001). Open access and transparency during both the negotiation and implementation process must be ensured to exclude any anticompetitive, discriminatory use of the instrument (Brau et al., 2001) and to establish a climate of trust and understanding (Pesaro, 2001). Finally, to facilitate the evaluation of measurable and observable goals, information concerning all the activity phases (i.e. competitive conditions, environmental performance) must be accessible by a trustworthy and independent party, while a credible mechanism of sanctions is also required to motivate the willingness of participating parties to attain defined goals.

2. Voluntary Approaches in Agriculture

Public concerns about the adverse impacts of agricultural activities on environmental quality (i.e. water, soil, biodiversity) have led to the design of various Voluntary Approaches focusing exclusively on environmental improvements in agricultural activities. The US federal farm Environmental Quality Incentives and Conservation Security programs are notable examples of such agricultural VAs, aiming to encourage the adoption of improved nutrient management practices, such as drip irrigation, integrated pest management and site-specific farming, by offering farmers green payments (Isik, 2004). In the same context the Groundwater Management Area approach, developed in Oregon, aims to reduce nitrogen applications through Best Management Practices (BMPs) relying on the background threat of mandatory actions if the nitrate contamination at all monitoring wells are not reduced to the established standard by a defined time period (Fleming and Adams, 1997).[106]

Furthermore, the US Conservation Reverse Program involves a contract between the USDA and individual farmers in order to withdraw erodible farming from crop production for 10 years and the further establishment of a long-term vegetation cover (i.e. grass, trees) to stabilize the soil, through the provision of rental payments per acre per year (Owen et al., 1998). Finally, the US Natural Resource Conservation Service (NRCS) is a voluntary program that provides technical assistance to farmers by a

[106]In some US states farmers are offered reduced property taxes in order to adopt soil-conserving BMPs (Helfand and House, 1995).

professional conservationist so that they can better set up and maintain a sound conservation program, consistent with the soil needs (Owen et al., 1998).

In the EU context there is a series of voluntary approaches, the so-called rural development schemes that fall into the category of public voluntary programs. They are formal contracts between the individual farmers and the Commission, providing annual aid in order to assist the modernization of farms, processing and marketing of quality agricultural products, setting-up of young farmers, early retirement, the conservation and improvement of ecological stability of the forestry sector and the wider agri-environment (Garaulet and Lawyer, 1999; EC, 2004). To safeguard the integration of environmental considerations in farmers' decision making the provided payments are both conditional to a series of environmental rules involved by horizontal regulation and the principle of cross-compliance of aid imposed in the event of detected noncompliance.

The most widespread voluntary contracts within the EU are the agri-environmental programs, requiring signatory farmers to use agricultural production methods designed to protect and maintain the agri-environment for a minimum 5 year period. Voluntary programs like the Danish MVJ-Scheme, the German HEKUL and MEKA Programme, the Irish Rural Environment Protection Scheme (REPS) [107] and the Belgian Walloon Whole Farm Plan horizontal and vertical programs [108] provide support in order to promote environmental planning, extensification, conservation of farmed environments of high natural value and the upkeep of landscape. In particular, the MVJ-Scheme is a subsidy-scheme providing various types of supports to farmers applying particular environmentally friendly approaches (i.e. afforestation, winter catch crops, reduction in nitrogen fertiliser) to land based activities in environmentally sensitive areas such as the Mariager Fiord (DAAS, 2007). In the same context the MEKA Program, one of the biggest German environmental programs, is based on a

[107] The given agri-environmental program rewards farmers for a five year period for carrying out their farming activities in an environmentally friendly manner in accordance with an agri-environmental plan approved by the Department of Agriculture and Food (DAF, 2007).

[108] There are six horizontal agri-environmental programs accessible to all farmers in the Walloon region, while there are five vertical programs accessible to farmers only in the environmentally sensitive areas. Under these programs farmers are recompensed for their environmentally friendly activities and to improve the environment of existing farms, protect wildlife habitants and endangered species, as well as to reduce livestock densities (Roosen and Ordóñez, 2007).

point system related to land area with rewards for environmentally compatible land management in order to reduce agricultural overproduction and protect cultivated landscape, while the HEKUL Programme supports the extensive land-use management, the conversion and maintenance of organic farming methods and intensification measures (INFRC, 2007).[109]

To obtain better insight into the structure and the mechanisms of the VAs, the latest developments in environmental economic literature regarding the modelling of voluntary agreements are presented, both in static and dynamic context.

2.1 Static Context: Individual and Multiperson Voluntary Approaches

Consider an economy consisting of $i = 1, 2, \ldots n$ farmers, which operate under competitive conditions and employ a vector of $\mathbf{x}_{ij} = \left(x_{i1}, x_{i2}, \ldots x_{im}\right)$ inputs, selected among a set of $j = 1, \ldots, m$ production choices. Agricultural production is, however, associated with the unintended generation of emissions that cause external damages, exceeding the socially-desirable levels a fact that stimulates intervention through voluntary actions initiated either by the regulatory authority or farmers themselves.

Both the regulator and the individual farmer decide to initiate or participate in a voluntary action if and only if their respective payoff function under the VA is greater or at least equal to the payoff under the unregulated or mandatory state. From the regulator's perspective, a VA can increase the social net benefits $NSB\left(\mathbf{x}_{ij}\right)$ since it may solve environmental problems effectively rather than ineffectively (Šauer et al., 2001). On the other hand, a VA can increase the net benefits $\pi_i\left(\mathbf{x}_{ij}\right)$ of the individual farmer i since it may alternatively stimulate an increase of sales due to either the improved market image with regard to environmental issues, a reduction of expenses

[109] In the same context are the Bavaria Cultural Scene Programme (KULAP) promoting agricultural production methods compatible with environmental protection, maintenance of the cultivated landscape and the conservation of nature and landscape management, as well as the Bavaria Nature Protection Contract Programme (NPCP) providing financial assistance to farmers in order to introduce or to maintain extensive production methods of valuable biotopes (INFRC, 2007).

via savings on materials, energy, lower risks etc. (Šauer et al., 2001), or the preemption of mandatory approaches that impose unwanted net costs (Alberini and Segerson, 2002).

Henceforth, the necessary conditions in order for the involved agents to proceed to the initiation of an environmental voluntary approach, are respectively:

$$Regulator: \quad NSB_v\left(\mathbf{x}_{ij}\right) \leq NSB_s\left(\mathbf{x}_{ij}\right) \quad (1)$$

$$Farmer: \quad \pi_i^v\left(\mathbf{x}_{ij}\right) \geq \pi_i^s\left(\mathbf{x}_{ij}\right) \quad (2)$$

where s represents either the unregulated or mandatory state, while v the state under the VA.

A voluntary initiative could emerge under the background threat of regulation that can either involve: (i) a pure ambient tax on deviations from the desired cut-off level or a reduction in governmental subsidies imposed with certainty if the aggregate environmental target is not met (Segerson and Wu, 2006), or (ii) a prespecified mandatory abatement vector imposed legislatively under an exogenous probability (Segerson and Miceli, 1998). A notable example of the initial type of background threat is the principle of cross-compliance[110] involving partial or full removal of aid provided to EU farmers through the CAP regime, in the event of detected deviation from statutory farming standards (EC, 1999). This type of background threat has many similarities with the codes of good farming of the Nitrate Directive (91/676/EEC) that are mandatory for all the farmers located in areas characterized as vulnerable to nitrate pollution (EC, 1991) and may cover issues such as construction of manure storage facilities, reduced tillage, establishment of buffer strips near water resources etc. (Segerson and Wu, 2006).

2.1.1 Negotiated Agreements

The necessary condition (2) of the farmer i can be alternatively defined in terms of cost $C_i\left(\mathbf{x}_{ij}\right)$, given that a VA may involve no direct benefits but only reduced costs (Segerson and Miceli, 1998). In such a case the farmer proceeds to the initiation of a

[110]Cross-compliance: observance of environmental criteria (pg 35) (Garaulet and Lawyer, 1999).

voluntary action if and only if his cost is lower or at least no higher under the VA than under the unregulated or mandatory state s:

$$Farmer: \quad C_i^v\left(\mathbf{x}_{ij}\right) \leq C_i^s\left(\mathbf{x}_{ij}\right) \qquad (3)$$

Conditions (1) and (3) provide the upper and lower bound of the abatement vector that could emerge under the bargaining of a bilateral VA (Alberini and Segerson, 2002). The range of these bounds depends on the magnitude of the background threat, the social costs of financial incentives, as well as the allocation of bargaining power between involved agents. These factors determine whether the negotiated VA induces the first best abatement vector leading to efficient environmental protection.

According to the *bilateral VA model* proposed by Segerson and Miceli (1998), the regulator and farmer (or a sector representative) negotiate to define the voluntarily implemented pollution abatement vector under the background threat of a probabilistic legislatively imposed mandatory abatement vector if the agreement is not reached. [111] Under such a "stick-based approach", condition (1) determines the minimum $\left(\mathbf{x}_{iv}^{\alpha}\right)^{\min}$ and maximum acceptable abatement levels that the regulator can accept under a VA, while condition (3) defines the maximum abatement value $\left(\mathbf{x}_{iv}^{\alpha}\right)^{\max}$ that is acceptable by the farmer.

In particular, the abatement values $\left(\mathbf{x}_{iv}^{\alpha}\right)^{\min}$ and $\left(\mathbf{x}_{iv}^{\alpha}\right)^{\max}$ are defined by:

$$\left(\mathbf{x}_{iv}^{\alpha}\right)^{\min}: \quad NSB_v\left(\mathbf{x}_{ij}\right) = NSB_s\left(\mathbf{x}_{ij}\right)$$

$$\left(\mathbf{x}_{iv}^{\alpha}\right)^{\max}: \quad C_i^v\left(\mathbf{x}_{ij}\right) \leq C_i^s\left(\mathbf{x}_{ij}\right)$$

denoting the abatement values that set both the regulator and the farmer i indifferent between the voluntary action and the state s.

Hence, a bilateral voluntary agreement is expected to be the equilibrium outcome of a bargaining process if and only if the minimum abatement vector the regulator is

[111] The legislation is more costly both in terms of total and marginal compliance and transaction costs compared to the VA. The farmer derives no direct benefit from the VA, he just incurs reduced costs as compared to the regulatory alternative.

willing to accept is less than or equal to the maximum abatement vector the farmer is willing to accept. Consequently, a necessary and sufficient condition for the attainment of a negotiated environmental agreement is:

$$\left(\mathbf{x}_{iv}^{\alpha}\right)^{\min} \leq \left(\mathbf{x}_{iv}^{\alpha}\right)^{\max} \qquad (4)$$

indicating the existence of an abatement vector that is mutually beneficial and thus acceptable to both parties. However, condition (4) does not guarantee that the first best abatement vector is mutually acceptable, since the actual bargaining outcome depends on the allocation of bargaining power or the nature of the bargaining process (Alberini and Segerson, 2002).[112] In the case of the agricultural sector, the magnitude of background threat is considered to be low, since there is limited political will regarding the imposition of mandatory controls in agriculture (Segerson and Miceli, 1998). In such a case, the voluntarily implemented abatement vector and thus the environmental effectiveness of the agreement can be enhanced through a cost-sharing subsidy used in combination with the stick-approach. Hence, under the mixed-based approach the bargaining outcome defines the equilibrium combination of the mutually beneficial abatement vector and cost-sharing subsidy, which depend on the allocation of bargaining power, the magnitude of legislative probability and the social cost of the subsidy since the necessary funds are raised via distortionary taxes.

2.1.1 Sector Representative

The farmer involved in negotiations with the regulator can also be the representative of a sector or a group of farmers. In such a case the abatement level proposed to the regulator must be collectively acceptable or rejected by the negotiating group of farmers. This means that farmers must reach a prior agreement regarding the abatement vector they are willing to accept under the VA, before communicating their final proposal to the regulator (Manzini and Mariotti, 2003). Although farmers are all on the one side of the bargaining process, they do not always share the same preferences and the regulation may have a different impact on each of them. Thus the regulator must ensure the proposed abatement vector is acceptable to all the farmers.

[112] The abatement vector that is mutually beneficial to involved parties can be even less than the legislatively imposed abatement vector.

Under heterogeneity there is a farmer that entirely drives negotiations and the resulting equilibrium abatement vector to some extent depends on his characteristics. Particularly, the farmer with the most aggressive attitude towards environmental control (i.e. the lowest admissible abatement level) induces the lowest abatement vector. It is possible that the "toughest" farmer is a low profit farmer that exploits his weakness to achieve a better deal in negotiations and all other farmers effectively free-ride on him to avoid at a minimum cost the probabilistic legislative intervention.

2.1.3 Public Voluntary Programs

Most agricultural VAs do not involve a negotiation process. They are voluntary actions designed exclusively by the regulator and to which individual farmers or their representative can only agree. A public voluntary scheme has been designed by Segerson and Wu, 2006), where the regulator uses the background threat of an ambient tax to induce the individual farmer to abate pollution so that the pre-specified environmental goal is met. Contrary to the previous model no specified pollution abatement vector is dictated, and if reliance on the VA appears insufficient to control NPS pollution the mandatory treat is imposed with certainty. It is the farmer's choices that determine whether or not the ambient tax is imposed. Therefore, under a stick-based public VA the magnitude of the ambient tax is chosen in such a way as to induce the implementation of the abatement vector that guarantees the achievement of the target, requiring however that the regulator knows the physical characteristics of the farmer.

Most US agricultural policies use carrot instruments to induce the voluntary use of environmentally friendly practices. In such a case the public VA pays the individual farmer a pre-specified subsidy if the target is met voluntarily, while in the opposite case the background threat involves a reduction of the subsidy. Therefore, under a mixed-based public VA the subsidy reduction rate is set in such a way as to induce the abatement vector that guarantees the achievement of the quality target. This kind of background threat has many similarities with the principle of cross-compliance, a sanctioning mechanism introduced by the European Commission to stimulate compliance of European farmers with a set of statutory farming standards such as the codes of good farming involved by the Nitrates Directive (EC, 1999).

It is worth mentioning that green payments may be required to encourage the voluntary adoption of improved nutrient management practices, since uncertainty about the impact of adopted farming systems (and technologies) and the irreversibility of investment impose important barriers to adoption, even when the investment appears to be profitable.[113] However, the increasing reliance on subsidy programs may create expectations for future such programs, and the uncertainty about their final implementation may delay the voluntary adoption of site-specific technologies. Hence, the effectiveness of cost-share subsidy policies is enhanced if the regulator enacts such a program immediately, threatens to remove it soon and promises never to restore it again (Isik, 2004).

2.1.4 Multiperson Voluntary Approaches

Free-riding is likely to emerge if a voluntary program is signed by a sector representative or a group of farmers. Even though such non-compliant behaviour can discourage participation and lead to a failure of an agreement before the potential benefits are realised, it does not always deter a subgroup of farmers from signing the voluntary agreement and forming *a coalition VA*. There is an equilibrium number of farmers $\left(K^*\right)$ that signs the VA if and only if the payoff for signatories $\left(\pi_v(K^*)\right)$ is higher or at least equal to the payoff when no VA is signed $\left(\pi_{NV}\left(0\right)\right)$.[114] Thus, based on Brau et al. (2001) the necessary condition for the existence of such an equilibrium coalition K^* is given by:[115]

$$\Pi^v(K^*) \equiv \pi_{iv}(K^*) - \pi_{NV}(0) \geq 0 \qquad (5)$$

followed by the stability conditions:

$$\begin{aligned} \pi_{iv}(K^*) \ &\geq \ \pi_{iNV}(K^* - 1) \\ \pi_{iv}(K^* + 1) \ &\leq \ \pi_{iNV}(K^*) \end{aligned}$$

[113] Agricultural abatement also involves reversible small scale measures such as change in fertilizer use and other farming practices (i.e. changes in tillage, buffer strips) (Huhtala and Laukkanen, 2004).

[114] According to Brau et al. (2001) $\pi_{NV}(0)$ is the "business-as-usual" payoff, reflecting profits in the unregulated case. Finally, symmetry is considered among farmers.

[115] The number of signatory farmers *K* belong to the interval [1,*n*].

involving that no individual farmer that has an incentive either to leave (not sign) or join (sign) the coalition VA. This is a standard internal –external stability condition. Depending on the profit-maximizing number of signatory farmers and the value for which the condition (5) is satisfied, the equilibrium coalition is the grand coalition in the sense that all the farmers that belong in the specific agricultural industry sign the VA. To assure the establishment of the grand coalition the regulator must introduce a minimum participation constraint that requires at least a number of farmers to sign the VA. Nevertheless, farmers may also have an incentive to form a VA club (or profit maximizing coalition) that excludes some farmers from the possibility of signing the VA, eroding the environmental effectiveness of the agreement. In such a case the regulator can prevent farmers from adopting exclusive membership rules by establishing an open membership rule.

The fact that the benefits of an industry-wide VA can be reaped by non-signatory farmers affects farmers' decision to sign the VA. If the signatory and non-signatory farmers are benefited by the same amount, then no farmer agrees to sign the VA. To minimize spillovers to non-signatories and safeguard that the most benefits are reaped by signatory farmers, a policy mix which penalizes only farmers that do not sign the VA is suggested. Finally, a minimum binding abatement constraint is imposed to guarantee the environmental effectiveness of VAs,[116] since if farmers are left free they may proceed with cosmetic abatement to maximize their profits (Brau et al., 2001).[117]

2.2 Dynamic Context: Individual and Multiperson Voluntary Approaches

Even though the dynamic analysis of voluntary approaches takes place in infinite time, in practice their time horizon involves a limited number of years (Cavaliere, 2000). For instance, the EU agri-environmental measures last for a minimum five year

[116] The Danish CO_2 Agreement Scheme has introduced a minimum environmental tax (Brau et al, 2001).

[117] Under heterogeneous farmers, requiring all agents to participate is infeasible since high-cost agents are unwilling to participate and the regulator needs to balance carefully the VA terms to induce at least most firms to participate (Lyon and Maxwell, 1999).

period (EC, 2004). Nevertheless, if it is assumed that such voluntary actions can be renovated, the use of an infinite time horizon is justifiable.

2.2.1 Individual Voluntary Approaches

The methodology of negotiating a voluntary approach provided by Segerson and Miceli (1998) is extended with a second period representing the entire future time horizon in order to incorporate surprise and non-surprise features. According to the modified negotiated VA model developed by Langpap and Wu (2004), the regulator and individual farmer negotiate in period 1 about the voluntary combination of abatement vectors $\left(\mathbf{x}_{1v}^{\alpha}, \mathbf{x}_{2v}^{\alpha}\right)$ to be implemented in period 1 and 2 respectively. During the negotiation in period 1 the current status of pollution S_1 is taken into account, while involved agents form expectations about the status of pollution S_2 in period 2. Involved agents are aware that if the agreement is not reached then a mandatory combination of abatement vectors $\left(\mathbf{x}_{1L}^{\alpha*}, \mathbf{x}_{2L}^{\alpha*}\right)$ is to be legislatively imposed in period 1 and 2 respectively under an exogenous probability p. Under regulation the expected payoff of the individual farmer i is defined as $\left(C_L^1(\mathbf{x}_{1L}^{\alpha*}) + EC_L^2(\mathbf{x}_{2L}^{\alpha*})\right)$, while the expected net social benefit of the regulator by $\left(NSB_L^1(\mathbf{x}_{1L}^{\alpha*}) + ENSB_L^2(\mathbf{x}_{2L}^{\alpha*})\right)$.

If during period 2 the nitrate pollution in a nearby water body increases more than expected due to unpredictable environmental factors, then the regulator should require the farmer i to increase the land set-aside or the size of the buffer strip. This is feasible only when the concluded VA does not contain a "no-surprise" provision that binds the regulator to the agreed abatement vector $\mathbf{x}_{2v}^{\alpha}$ regardless of the new available information. Under a "surprise VA" there is a probability q that the regulator revises the agreed upon vector and imposes the welfare maximizing mandatory vector $\mathbf{x}_{2L}^{\alpha*}$. In such a case the expected payoff of the farmer and regulator are given as $EC_L^2(\mathbf{x}_{2L}^{\alpha*})$ and $ENSB_L^2(\mathbf{x}_{2L}^{\alpha*})$ respectively, while under a “non-surprise” VA their associated expected payoffs are $EC_v^2(\mathbf{x}_{2v}^{\alpha})$ and $ENSB_v^2(\mathbf{x}_{2v}^{\alpha})$.

Hence, under uncertainty about the future state of the world a surprise VA is mutually accepted if and only if the following inequalities hold simultaneously:

$$\text{Farmer:} \quad C_v^1(\mathbf{x}_{1v}^{\alpha}) + qEC_L^2(\mathbf{x}_{2L}^{\alpha*}) + (1-q)EC_v^2(\mathbf{x}_{2v}^{\alpha}) \leq p\left[C_L^1(\mathbf{x}_{1L}^{\alpha*}) + EC_L^2(\mathbf{x}_{2L}^{\alpha*})\right] \tag{6}$$

$$\text{Regulator:} \quad NSB_v^1(\mathbf{x}_{1v}^{\alpha}) + qENSB_L^2(\mathbf{x}_{2L}^{\alpha*}) + (1-q)ENSB_v^2(\mathbf{x}_{2v}^{\alpha}) \geq p\left[NSB_L^1(\mathbf{x}_{1L}^{\alpha*}) + ENSB_L^2(\mathbf{x}_{2L}^{\alpha*})\right] \tag{7}$$

By condition (6) it is involved that the farmer i enters into the agreement if his cost under the VA, defined as $\left(C_v^1(\mathbf{x}_{1v}^{\alpha}) + qEC_L^2(\mathbf{x}_{2L}^{\alpha*}) + (1-q)EC_v^2(\mathbf{x}_{2v}^{\alpha})\right)$, is no larger than his expected costs under the mandatory regulation $\left(i.e.\ p\left[C_L^1(\mathbf{x}_{1L}^{\alpha*}) + EC_L^2(\mathbf{x}_{2L}^{\alpha*})\right]\right)$. Similarly, condition (7) implies that the regulator enters the agreement if the expected net social benefit under the VA is higher than the expected net social benefit under the regulation.

Although the provision of assurances encourages participation in the VA, it does not however allow using the new available information, a fact that might undermine the efficiency of the agreement. Therefore, the regulator faces the dilemma of whether to provide assurances or not when negotiating a voluntary action with an individual farmer.

2.2.2 Individual Public VA

In an infinite time horizon the regulator can use a trigger strategy to induce voluntary abatement of nitrate pollution in each time period (Segerson and Wu, 2006). In particular, during the first period no tax is imposed and the individual farmer is left free to decide whether or not to voluntarily meet the standard e_s. If the farmer i selects the announced or intended by the VA abatement vector $\mathbf{x}_{iv}^{\alpha}$, then the target is met and no further policy is imposed. In such a case the associated costs are given as $C_i\,(\mathbf{x}_{iv}^{\alpha}, \Theta_i)$, where Θ_i are the physical characteristics of the farmer i. However, if at the end of the first period the ambient target e_s is not met, then an ambient tax $\left(i.e.\ t\left(e - e_s\right)\right)$ is imposed for all the remaining periods, implying that the regulator gives no second chance to the farmer to meet the target at no additional cost. The magnitude of the tax is set to induce the farmer to choose the abatement vector $\mathbf{x}_{it}^{\alpha*}$ that ensures that the standard is ultimately met. Under the ambient tax the incurred costs are $C_L(\mathbf{x}_{it}^{\alpha*},\Theta_i)$.

Hence the farmer decides to meet the ambient target voluntarily if and only if the following inequality holds:

$$C_i\,(\mathbf{x}_{iv}^{\alpha},\Theta_i)\left[\delta+\delta^2+\delta^3...\right]<\left[C_L(\mathbf{x}_{it}^{\alpha*},\Theta_i)+t\left(e-e_s\right)\right]\left[1+\delta+\delta^2...\right] \tag{8}$$

$$C_i\,(\mathbf{x}_{iv}^{\alpha},\Theta_i)\frac{1}{1-\delta}<\left[C_L(\mathbf{x}_{it}^{\alpha*},\Theta_i)+t\left(e-e_s\right)\right]\frac{\delta}{1-\delta}$$

where $\delta=1/(1+r)$ is the discount factor and r the discount rate. By condition (8) it is indicated that the farmer decides to abate voluntarily pollution in the first period if the present value of the infinite stream of total costs under the VA $\left(i.e.\ (1/1-\delta)C_i\,(\mathbf{x}_{iv}^{\alpha},\Theta_i)\right)$, are lower than the present value of the infinite stream of total costs under the ambient tax $\left(i.e.\ (\delta/1-\delta)\left[C_L(\mathbf{x}_{it}^{\alpha*},\Theta_i)+t\left(e-e_s\right)\right]\right)$. It is stressed that meeting the target voluntarily is optimal for the farmer if and only if the discount rate r is sufficiently low (Segerson and Wu, 2006).

2.2.3 Multiperson / Industry wide VAs

Under the proper design of the industry-wide VA the majority or even the entire agricultural sector can be induced to comply with the agreement.

High compliance rates can be feasible under low inspection probabilities and small fines, if imposed at all. According to Friesen (2003) noncompliance can be deterred through targeting schemes that divide regulated farmers into two groups: *target group* (G2) and *non-target group* (G1). Such schemes can be either based on farmers' past compliance record or on random targeting. Under the past compliance targeting scheme, the individual farmer is moved into the target group if noncompliance is revealed during an inspection, otherwise he is moved into the non-target group as a reward for compliance. Inspections in the G2 group are more frequent than in group

G1 and the regulator can increase the compliance incentive in G2 by affecting the fines and transition probabilities between the groups.

Under the optimal targeting scheme the farmer is randomly moved into the target group. In such a case the farmer can escape from G2 and move back to G1 on the basis of observed compliance behaviour during an inspection. By randomly selecting farmers for the G2 group, more frequent inspections in the target group are needed while inspections in the non-target group have no additional deterrent effect in the target group. It is likely that even though the optimal targeting scheme involves lower enforcement costs, the past compliance targeting scheme has a wider range of applicability, since it can be used for "large" partial compliance rate goals (Friesen, 2003).

PART II:
"Non-Point-Source Pollution Problems: Another Perspective on Analysis and Regulation"

Review of the environmental economics literature indicated that the analytical framework for regulating environmental problems associated with agriculture and in particular with non-point-source pollution problems is based on the standard theory of optimizing behaviour and thus the assumption of unboundedly rationality. Little work has been done however in the area of voluntary approaches to environmental regulation based on an alternative and plausible approach which is associated with bounded rationality and evolutionary frameworks described by imitation dynamics modelled by replicator dynamics.

Henceforth, the present Doctoral Thesis focuses on:

- ⇨ Voluntary Approaches as an alternative regulatory measure of agricultural non-point-source pollution problems, in combination with replicator dynamics as an alternative analytical method for approaching agricultural non-point-source pollution problems.

The intention of the Thesis is to address the following issues:

- ⇨ Assessment of the effectiveness of existing public voluntary environmental programs dedicated fully to the agricultural sector, as described by the Nitrates Directive and / or the CAP reforms of the European Commission.
- ⇨ Assessment of the dynamic behavior of a population of regulated farmers when the regulator selects monitoring effort and capital with the analysis based on the alternative assumptions of unboundedly and boundedly rational economic agents.
- ⇨ Description of the selection mechanism of optimal regulatory policy instruments under the optimizing and imitation behavioral contexts.
- ⇨ Analysis and policy implications, for the proper design of a public voluntary program and an inspection mechanism.

To facilitate the exposition a brief introduction to the concept of bounded rationality is initially provided, where the model of replicator dynamics that constitutes the basic core of analysis of the three Chapters of Part II is presented.

The remainder of Part II of the Doctoral Thesis is structured as follows. Chapter I examines the potential impact on the compliance incentives of a population of regulated farmers from the introduction of restrictions on their rationality. The implication of the optimizing behavioural rule, based on the traditional assumption of unboundedly rationality, and the evolutionary behavioural rule, based on the assumption of bounded rationality, are contrasted through a problem of monitoring effort selection, which is further extended with investment decisions for selecting monitoring capital under a regulatory framework combining features of Council Nitrates Directive (91/676/EEC) and the second pillar of the Common Agricultural Policy. Chapter II examines the impact on the environmental performance of a representative farmer of the different type of CAP measures, as prescribed by the first and second pillar of Agenda 2000. It also describes the set of CAP instruments, along with type of interdependence characterizing them, which fulfill the attainment of a social target within the analytical framework of unbounded and bounded rational agents. Chapter III examines the joint evolution of the participation and compliance incentives of the regulated population under a public voluntary program of the form of a rural development program of CAP, in the presence of fast-slow selection dynamics in the time scall of the participating and complying decision. The analysis is further extended to include a budget constraint in order to provide policy implications for the proper design of the rural development program, as well as the inspection mechanism.

Economic Structure: The Behavioral Rules of Individuals

Standard economic theories traditionally assume that agents are "infinite in faculties" (Conlisk, 1996), that they act "*as if*" unboundedly rational, "*as though*" they were consciously gathering all the necessary data to consider all possible alternatives and thus solve a complicated problem of differential equations to calculate the optimum response that maximizes their payoff (Binmore, 1992; Noailly et al., 2003). Such a fully rational economic choice strongly implies that individuals perform exhaustive searches, have perfect information over all possible decisions, possess the compulative abilities to solve the optimization problem (Noailly et al., 2003) and thus do not need to interact with each other (Lipatov, 2005).

Even though the assumption of unbounded rationality has dominated economics for several decades, there are arguments suggesting that there is a finite limit to the amount of information the human brain can hold and the amount of calculations it can understand (Conlisk, 1996). The statement cited below is typical of this debate:

> "*Yes, but you don't understand; no one assumes that people are unboundedly rational, only that they act as if unboundedly rational. Agents are bounded rational, they learn optima through practice and in the end act as if unboundedly rational. Economists just take a shortcut and assume unbounded rationality from the start.*" Conlisk, (1996)

Hence, in practice agents exhibit a certain degree of rationality, although limited. They are bounded rational in the sense that they perform limited searches, have imperfect information about the strategies and payoffs of other agents, they are unable to compute the optimal strategy that maximizes their own payoff and choose between predetermined strategies (Noailly et al., 2003). Under such a context agents accept the first satisfactory decision and suboptimization occurs.

According to Conlisk (1996) there are four reasons why the economic models should incorporate bounded rationality in their design:[118]

- Strong empirical evidence,
- Models of bounded rationality work well,
- Unconvincing justifications for assuming unbounded rationality, and
- Deliberation costs should be included in models.

In recent years bounded rationality has been blended within an evolutionary dynamic mechanism (Noailly et al., 2003),[119] which contrary to the standard theory of optimizing behaviour, deals with entire populations of agents all programmed to use some strategy (or type of behaviour) and not with an individual agent (Hofbauer and Sigmund, 2003). Dynamic evolutionary theory supposes that large populations of boundendly rational players learn, imitate and adapt to the strategies of others in light of payoff experience and the economic environment over time (Cressman, 1998).[120] When new strategies are introduced agents tend to imitate the most successful one or the one that yields a "satisfactory" level of profits. Strategies with higher payoff will spread within the population at the expense of less successful agents and activities, involving a change in the probability distribution of possible actions (Nelson, 1995).[121] However, changes in the population combination are a gradual process due to the imperfect diffusion of information, introducing some inertia in agents' response to superior payoffs (Sethi and Somanathan, 1996) that provides continuity of what survives the winnowing (Nelson, 1995).[122]

Nevertheless, it is worth mentioning that bounded rational agents - or else known as myopic or short-sighted - sometimes find their way to optimal solutions by trial-and-

[118] It is worth mentioning that there are many contexts in which the hypothesis of unbounded rationality surely works well (Conlisk, 1996).

[119] Evolutionary dynamics is the application of population dynamical methods introduced by evolutionary biologists to game theory (Hofbauer and Sigmund, 2003).

[120] Such behavioural patterns can also be viewed as the outcome of a process of adaptation, imitation and learning, copying or inheriting strategies, word-of-mouth communication, fads and fashion, bandwagons, threshold effects, herding, increasing returns, lock-ins and information cascades (Conlisk, 1996).

[121] This principle is called compatibility and implies some relationship between the payoff and the corresponding dynamics (Friedman, 1998).

[122] A further difference between the evolutionary theory and the traditional theories, since the later imply assume that rational agents will immediately adopt equilibrium strategies (Kolstad, 2007).

error adaptation if the situation is encountered sufficiently frequently (Binmore, 1992). Adaptation, adjustment, tậtonnement, learning-by doing, evolution - are some of the terms that describe the process that may lead agents who have no clear idea about what is going on to behaviour that may look very rational indeed to a kibitzer.

Evolutionary game theory has employed a large and quite varied set of dynamic models to describe how the frequencies of strategies within a population change in time according to the strategies' success.[123] These game dynamics can be discrete or continuous, stochastic or deterministic (Hofbauer and Sigmund, 2003; Friedman, 1998). The deterministic dynamic systems include:

- Differential inclusions - the best response dynamics,
- Reaction-diffusion systems,
- Imitation dynamics,
- Smoothed best reply,
- Brown-von Neumann-Nash dynamics,
- Difference equations such as fictitious play, and
- Ordinary differential equations and particularly the replicator dynamics.

Common features of these evolutionary models is that (i) involved agents are repeatedly and randomly matched to play a game, (ii) a dynamic process describes how players adapt their behaviour over time (Kolstad, 2007) and (iii) agents do not systematically attempt to influence other agents' future actions (Friedman, 1998).[124]

The most commonly employed dynamic systems to describe such mass action approaches are the replicator dynamics models. It is worth mentioning, however, that the emphasis given on replicator dynamics (or occasionally known as Malthusian dynamics (Friedman, 1998)) is not meant to suggest that it is as important as all other dynamics together, but it serves conveniently for expository purposes and reflects some of the history of the subject (Hofbauer and Sigmund, 2003).

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[123] The evolutionary approach can also be described as a "mass action approach" (Hofbauer and Sigmund, 2003).

[124] Condition (i) is a version of the basic "survival of the fittest" maximum, condition (ii) underlines that aggregate behaviour does not change too abruptly, while (iii) is the game against nature condition (Friedman, 1998).

Finally, even though evolutionary game theory has many applications in non-biological fields (Hofbauer and Sigmund, 2003), economic applications remain few and isolated (Friedman, 1998).[125] Among the noticeable economic applications of the replicator dynamics framework are classified the works of Noailly et al. (2003) and Xepapadeas (2005) examining the evolution of common pool resources (i.e. fisheries), of Sethi and Somanathan (1996) and Kolstad (2007) in the area of social norms, as well as of Cressman et al. (1998) modelling behaviour of agents in shadow sectors such as crime deterrence.[126]

I. Replicator Dynamics: An Introduction

In general a replicator system is a process of change over time in the frequency distribution of the replicators in which strategies with higher payoffs reproduce faster in some appropriate sense (Gintis, 2000).

In the modelling[127] process of replicator dynamics it is assumed that at a given time t the population of the industrial sector considered (manufacturing, agricultural etc) consists of m groups of agents, where each group follows different strategy and x_j is the frequency of type j for $j = 1,...,m$. To simplify the exposition it is assumed that the population consists only of two groups of agents.[128] Let $x_g(t)$ denote the proportion of the $i = 1,...,n$ agents adopting the strategy g, while $x_h(t)$ the remaining proportion of agents at time t adopting strategy $h,$ with $x_g(t) + x_h(t) = 1$.[129]

In every time period dt there is a positive probability kdt that an agent i, following a certain strategy $(i.e.\, g)$, will compare his payoff and consequently his strategy, with

[125] Even though evolutionary game theory and environmental economics have a potentially close relationship, these to fields have been developed independently (van de Bergh, 2007).

[126] For further economic applications of the replicator dynamics framework see the works of Dawid et al. (2005), Cheung and Friedman (1998), Antoci et al. (2007), Heller (2004), Oechssler and Riedel (2001), Taylor et al. (2004), as well as Hofbauer and Schlag (2000).

[127]In motivating the replicator dynamics we follow Gintis (2000). For further details see Schlag (1998) and Binmore (1992).

[128]This is a reduced form of the replicator dynamics model. For further details about the generalized form of the replicator dynamics under the assumption that $m > 2$ see Hofbauer and Sigmund (2003).

[129]The initial distribution of agents is characterized by $0 < x(0) < 1$ to indicate the heterogeneous information agents possess (Vilen, 2005).

the corresponding payoff and strategy of another randomly chosen agent j. If i perceives that j's payoff are sufficiently higher, then he switches his strategy. Under imperfect information concerning the difference in the expected payoffs of the two strategies, due to uncertainty about the law determining the auditing probability and possible uncertainty regarding the true payoff functions, the probability that agent i will change strategy increases the higher the profits difference is. Particularly, agent i following strategy g at time t, might decide to switch strategy and adopt strategy h, by imitating agent j if the profits Π_i, are sufficiently smaller than the profits Π_j of agent j. Hence, the probability that agent i will change his strategy and adopt strategy h, after comparing profits, is given by:

$$P_{gh}^t = \begin{cases} \beta\left[\Pi_h^t - \Pi_g^t\right] \text{for } \Pi_h^t > \Pi_g^t \\ 0 \qquad \text{for } \Pi_h^t \le \Pi_g^t \end{cases}$$

where β is sufficiently small that $P_{gh} \le 1$ for all g,h.

The expected proportion of agents that employ strategy h at time $t+dt$ is:

$$\begin{aligned} Ex_h^{t+dt} &= x_h^t + \alpha dt x_h^t \sum_{j=i+1}^{n} x_g^t \beta(\Pi_g^t - \Pi_h^t) + \sum_{j=1}^{n} \alpha dt x_h^t x_g^t \beta(\Pi_h^t - \Pi_g^t) \\ &= x_h^t + \alpha dt x_h^t \sum_{j=1}^{n} x_g^t \beta(\Pi_h^t - \Pi_g^t) \\ &= x_h^t + \alpha dt x_h^t \beta(\Pi_h^t - \overline{\Pi}^t) \end{aligned}$$

where $\overline{\Pi}$ denotes the average payoff for the whole population, defined as:

$$\overline{\Pi} = x_g \Pi_g^t + x_h \Pi_h^t = (1 - x_h)\Pi_g^t + x_h \Pi_h^t \qquad \text{(I)}$$

By assuming that the considered population is infinitely large or that it is the expected value of an ansemble of populations, the x_h is a differential function of time t and postulates a low of motion (Hofbauer and Sigmund, 2003). Therefore, Ex_h^{t+dt} is replaced by x_h^{t+dt} and if we subtract from both sides the term x_h^t, divide by dt and finally take the limit as $dt \to 0$, the equation describing the motion of the group of agents adopting the strategy h over time is derived as:

$$\dot{x}_h = \alpha\beta x_h^t \left[\Pi_h^t - \overline{\Pi}\right] \qquad \text{(II)}$$

This is the replicator dynamics equation, indicating that strategies yielding above (below) average profits $\overline{\Pi}$ of all strategies in the population are more (less) demanded so that they end up accounting for a larger (lower) part in the population (Noailly et al., 2003). The greatest the deviation in profits from the average is, the faster does the population share increase or decrease, indicating that the rate of growth or reduction of the population using a strategy is proportional to the amount by which that strategy's payoff exceeds or falls short of the average payoff of the strategies in the population (Sethi and Somanathan, 1996).[130]

The frequency of strategy h increases when its profits Π_h are above the average profits and proportional imitation rules can be modelled by replicator dynamics. After substituting (I) into (II) the general form of the replicator dynamics equation for two strategies, g and h, is:[131]

$$\dot{x}_h = \alpha\beta x_h^t (1 - x_h^t)\left[\Pi_h^t - \Pi_g^t\right]$$

indicating that if the payoff of strategy h exceeds (falls short) the payoff of strategy g then the change in the proportion of individuals using strategy h is positive (negative) (Noailly et al., 2003). Payoff differentials exert evolutionary pressures on the population composition (Sethi and Somanathan, 1996) and in these models two types of rest points can emerge: (i) the non-interior equilibrium where the population adopts a pure strategy and the strategy h converges either to zero tending to extinction or to unit becoming ubiquitous (Kolstad, 2007) and (ii) the interior rest point implying coexistence of both types (Hofbauer and Sigmund, 2003). Based on the principle of evolutionary stability the stable equilibrium outcomes of the evolutionary game are defined (Kolstad, 2007).

[130] In the case that either $\Pi_h^t = \overline{\Pi}$ or $\Pi_g^t = \overline{\Pi}$ then the share x remains constant over time, in the sense that either $x_h = 1$ or $x_h = 0$ (Noailly et al., 2003).

[131] The constant factors $\alpha\beta$ affect the rate of adjustment and are often set equal to unit without affecting analysis.

Therefore, as a conclusion one can think of an evolutionary model of this kind:

> As a contest between strategies, strategies that do well multiply, strategies that do poorly dwindle (Kolstad, 2007).

This analytical context is to be employed in the following Chapters of Part II.

CHAPTER I: Regulation of Farming Activities: An Evolutionary Approach

Farming activity is modelled under an intervention policy regime, combining the environmental requirements of the Council Nitrates Directive (91/676/EEC) and the compensatory provisions of the second pillar of the Common Agricultural Policy. The optimizing behavioural rule along with the evolutionary rule is employed in order to model the individual farmer's decision making, regarding compliance or not with regulatory provisions. The impact of these different behavioural rules on the selection of monitoring effort and thus on the compliance incentives of a population of farmers is examined. Furthermore, the dynamics of the population of compliant farmers is also assessed under accumulation of monitoring capital.

1. Introduction

Nitrogen (N) from mineral fertilizers and animal manure is the major source of N input in European agriculture essential for crop growth and the achievement of desirable crop yields. Excessive nitrogen surpluses,[132] however, pose a threat to the environment leading to air and soil pollution,[133] and appear to be a major pollutant[134] in many European underground and surface watersheds,[135] associated with health risks.[136] To provide a general level of protection for all waters against nitrate

[132]There is evidence that the amount of N fertilizers taken by crops is typically closer to 50% and rarely greater than 70%, while when crop yields are near optimum, 90% of applied N is lost (Classen and Horan, 2001).

[133] Excessive nutrients are lost to air through volatilization of ammonia or as N_2O (a powerful greenhouse gas), while cause eutrophication in soil, degrading soil fertility and producing N_2O (Pau Vall and Vidal, 2006).

[134]At least 30-40% of rivers and lakes show eutrophication symptoms or bring high N fluxes to coastal waters and seas. The agricultural origin of such fluxes accounts for 50 to 80% of total N inputs to EU waters (EC, 2002).

[135]Nitrates leaching (NO_3) is N removed from soil by the action of water (Owen et al, 1998), which can result in eutrophication of slow flowing rivers, lakes, reservoirs and coastal areas, appearing through the proliferation of algal bloom which degrades bottom fauna, fish stock and wetlands (Huhtala and Laukkanen, 2004; Isik, 2004), reducing water value to humans and nature (Owen et al., 1998).

[136]N exposure is responsible for the blue-baby syndrome (methemoglobinemia) in infants, gastric cancer in adults and other human risks (Fleming and Adams, 1997; Abler and Shortle, 1995), while few cases of death or severe illness are directly linked to agricultural contamination (Johnson et al., 1991).

pollution, the European Council established in 1991 the Nitrates Directive (91/676/EEC), defining a series of codes of good agricultural practice[137] that concern mostly issues of land application, plans and records on fertilizer N inputs usage (EC, 1991).[138] The accomplishment of the Directive's objectives is facilitated by the rural development (pillar II) regime of the CAP, through the aid provided via the agri-environmental programs to European farmers that commit themselves to go beyond usual good agricultural practices, and thus reduce substantially the fertilizer use for a five-year minimum period (EU, 1998).[139]

However, the non-point-source characteristics[140] of agricultural pollution pose a substantial problem in the effective regulation of water pollution problems. The inability of regulatory authorities to directly observe individual decisions (i.e. nitrogen usage) provides the farmers incentives to deviate from statutory requirements and retain nitrogen usage at the unregulated profit maximizing levels, with the associated adverse environmental and human health consequences. To ensure that regulated farmers comply with statutory nitrogen performance standards and that foreseen noncompliance sanctions are imposed on those deviating so that compliance is further enforced, both the environmental and agricultural policy require Member States to incorporate a substantial monitoring mechanism in their policy design. An environment agency has the task of undertaking occasional random spot-checks, visiting farms and inspecting the operation field as well as the field records (DEFRA,

[137]For further details see Axis II (EC, 1991).

[138]Codes are mandatorily implemented either through out the territory of Member States or at specific zones vulnerable to nitrates pollution (i.e. NVZs). Farming activities within NVZs are subject to action programs, promoting actions that are mandatory by law and are built on the guidelines set out in the codes and impose additional restrictions. Farmers failing to comply with such statutory requirements can be prosecuted and if found guilty by the Court they may face a fine or imprisonment in the worst scenario (DEFRA, 2004).

[139]Payments aim at compensating farmers for additional costs and loss of income (EC, 2003) and are subject to both a set of basic farming requirements (i.e. horizontal regulation) and the cross-compliance principle involving partial or full removal of aid in the event of deviation from defined standards (EC, 1999), including compliance with the provisions of ND as foreseen by the 2003 CAP reform (EU, 2003; Aquamedia, 2006).

[140]A pollution problem is called an NPS problem if there is uncertainty on the regulator's behalf about the location of the decision makers (polluters) and the degree of each agent's responsibility in the aggregate pollution. In short the origins of this uncertainty can either be attributed to stochastic influences affecting fate and transport of pollutants, the great number of sources of pollution emissions that can be either static (farms, households) or mobile (vehicles), and/or the regulator's inability to infer individual emissions from ambient pollution levels or inputs used (Xepapadeas, 1995).

2004).[141] Given the technological and/or budgetary restrictions, only a fraction of farmers is monitored and thus only their emission flows can be regarded as observable. It is evident thus, that the effectiveness of the existing regulatory policies to induce restricted usage of nitrogen input is heavily dependent on the ability of the monitoring and enforcement mechanism to provide adequate compliance incentives, and thus implement the Nitrates Directive.

The purpose of the present paper is to examine the effectiveness of a monitoring and enforcement mechanism to induce in the long-run a large population of homogeneous farmers to comply with the statutory requirements of a regulatory regime under different assumption regarding the way that farmers choose to comply or not with regulation. The examined regulatory regime falls into the category of public voluntary environmental programs given that no bargaining is involved between farmers and the Commission in the definition of environmental goals and means of achieving them.[142] Regulated polluting agents (i.e. farmers) can only agree with the terms of regulation affecting their activities, and a combination of "carrot" financial inducements provided through the agri-environmental programs of the second pillar of CAP and "stick" legal binding features of the action programs[143] of the European Council Nitrates Directive (91/676/EEC) is employed to induce compliance with the given regulation.[144]

In our approach, and in contrast to the majority of the enforcement literature, farmers do not necessarily adopt an optimizing behavioural rule in their decision to comply or not with the suggested nitrogen usage constraint, but may follow evolutionary rules modelled by imitation dynamics.[145] Most economic models assume that agents are "infinite in faculties", they act "as if" unboundedly rational (Conlisk, 1996). If farmers

[141]Guidelines for the monitoring referred to in Articles 5 and 6 may be drawn up in accordance with the procedure laid out in Article 9 of the Nitrates Directive (EC, 1991).

[142]Public voluntary agreements are environmental programs entirely developed by a regulatory body and farmers can only agree to adopt them or not. For further details see Mazurek (1998), Lyon and Maxwell (2002) and Šaeur et al. (2001).

[143]Examples of such action programs are the Nitrogen Management Program (Denmark), Ferti-Mieux Initiative (France) and Prop'eau - Sable pilot project (Belgium) (EC, 2002).

[144] "Carrot" incentives involve total-cost or sharing subsidies, information subsidies, technical assistance and /or public recognition (Mazurek, 1998), while "stick" measures involve the implementation of existing mandatory restriction or the establishment of a new regulation.

[145]For such an exception to the traditional enforcement literature see Xepapadeas (2005).

are characterized by full rationality then they adopt optimizing behavioural rules and they behave as though they had all the necessary information when they decide about complying or not.[146] In such a case farmers have full knowledge of the structure of payoffs and after comparing the payoff that each strategy entails they define their optimal response to the regulation. This response is maintained across time and space if there is no modification of the policy parameters by the regulator. On the other hand, under bounded rationality agents "*are no longer assumed to be mathematical prodigies with access to encyclopaedic manuals written by omniscient game theorists*" (Binmore, 1992).[147] Farmers cannot choose their individual strategy in an optimal manner and their decision about whether to comply or not is adapted to the information revealed via their interaction over time. We assume that such passive decision making is based on the imitation of the better-off performing strategy and is modelled by the replicator dynamics, imitation rule. Under such an evolutionary process more successful agents and activities gradually increase their share in the population at the expense of less successful agents and activities (Conlisk, 1996), leading potential agents who have no clear idea what is going on to behaviour that may look very rational indeed to a Kibitzer (Binmore, 1992).

Individual compliance incentives, along with the aggregate environmental performance of a given population, are affected by the monitoring undertaken given the homogeneity assumption. An environmental agency that engages into costly and accurate monitoring is considered, where the number of random spot-checks is defined either in an arbitrary way, based on the alternative behavioural compliance rules assumed to be adopted by farmers, or selected optimally by minimizing a social welfare criterion, defined as the sum of monitoring costs and social environmental damages, constrained by the farmers' full or bounded rationality behavioural rules. Under each approach the selection criteria for monitoring effort stimulating long-term compliance of farmers are discussed, allowing comparisons of equilibrium outcomes under different rationality assumptions.

[146] Rational economic choice involves optimization in the sense that agents consider all possible alternatives and choose the best (Conlisk, 1996).

[147] According to Conlisk (1996), though people are bounded rational, they learn optima through practice and in the end act as if unboundedly rational. Economists just take a shortcut and assume unbounded rationality from the start.

The contribution of this paper consists of the development of a dynamic model of optimal monitoring constrained by an evolutionary imitation behavioural rule. The steady-state equilibrium proportion of complying farmers of this model, as well as the corresponding monitoring effort level is contrasted with the equilibrium proportion resulting from a conventional optimal monitoring model which considers that agents are fully rational. Indeed the main distinction between the two behavioural rules and the main finding of this paper is that under full rationality monomorphic outcomes[148] are the equilibrium outcomes, while under bounded rationality and imitation rules polymorphic outcomes [149] are very likely as evolutionary stable equilibria. In particular, our analysis indicates that if the monitoring effort level is chosen arbitrarily, that is not through an optimal monitoring model, then the characteristics of the equilibrium outcome are unaffected by the assumed behavioural rule regarding farmers' decision about choosing compliance decisions. In such a case the equilibrium outcome is monomorphic, implying either full compliance, or noncompliance with the Directive's provisions. To guarantee full compliance the environmental agency should precommit to a monitoring effort value that is higher than the critical value for which farmers are indifferent between compliance and deviation. The number and the type of equilibrium steady-states determining farmers' compliance are affected if monitoring is chosen optimally. A monomorphic behaviour is the steady state outcome if the social welfare criterion is minimized conditional to an optimizing behavioural rule by the farmers, while if the problem is constrained by replicator dynamics representing the passive imitation rule, then the population may adopt either a monomorphic or polymorphic behaviour. In the latter case whether the population converges in the long-run to the socially-desired outcome of full compliance, or to an intermediate status characterized by partial compliance, depends on the initial conditions of the problem given the fact that both the monomorphic and polymorphic steady-states satisfy a saddle point property. It is evident that the assumption regarding the farmers' adopted behavioural rule and the way that the environmental

[148] The long-term equilibrium is monomorphic if the entire population of farmers follows the same strategy and adopts a homogenous behaviour. This implies that either all the farmers comply with the provisions of the Directive or that they all deviate from the action program rules.

[149] A steady state is so-called polymorphic if a heterogeneous strategic behaviour is evolutionary stable in the long-run. This implies that only a proportion of farmers comply with the Directive, while the remaining proportion deviates.

agent selects monitoring effort level, affects the long-term behaviour of the population of farmers. Finally, population dynamics with regard to compliance with the given regulation are reassessed under the presence of investment in monitoring capital.

2. Modelling Farm Activity under the Nitrates Directive

Consider an agricultural area characterised as a nitrates vulnerable zone (NVZ)[150] consisting of $i = 1,2,...v$ small and identical farmers operating under competitive conditions. Individual production choices $\{\mathbf{x}_{ij}, n_i\}$ positively affect crop yields:[151]

$$y_i = f(\mathbf{x}_{ij}, n_i)$$

where $\mathbf{x}_{ij} = (x_{i1}, x_{i2}, ...x_{im})$ is the vector of agent i's choices among a set of $j = 1,...,m$ inputs and n_i the employed nitrogen input, either organic or manufactured.

Production is associated with unintended generation of nitrates leaching (N_i) that contaminates underground and surface water resources.[152] At time t aggregate emissions flows $N(t)$ are:

$$N(t) = \sum_{i=1}^{v} N_i(t) = \sum_{i=1}^{v} n_i(t) \quad (1)$$

indicating by an appropriate choice of units a positive, one-to-one relation between individual nitrate leaching $N_i(t)$ and employed nitrogen input $n_i(t)$.

In the absence of any regulatory intervention, farmer i employs the profit maximizing amount of nitrogen (n_o) and obtains the maximum payoff defined as.[153]

$$\Pi^o(n_o) : n_o = \arg\max_n \Pi^o(n) \qquad (2)$$

[150]Nitrate vulnerable zones cover about 37% of EU-15 total area (EU, 2003) and are identified as land areas which drain into waters contributing to nitrates pollution and are defined by paragraph 1 of Article 3 (EC, 1991).

[151]It holds $f_x, f_n > 0$ and $f_{xx}, f_{nn} > 0$

[152]The term nitrates leaching (NO_3) refers to the nitrate removal from the soil by the action of water (Owen et al, 1998). This phenomenon includes both leaching below the crop's roots due to the downward movement of water (percolation) and leaching due to the flow of water over the surface of the land (runoff).

[153]Assuming identical farmers we drop subscript i to simplify notation.

$$\Pi^{o}(n) = \max_{\mathbf{x}}\left[pf(\mathbf{x}, n) - \mathbf{wx} - w^{n} n\right] \quad (3)$$

where $\mathbf{w} = (w_1,...,w_m)$ is the vector of input prices, w^n the nitrogen price and p the output price in the competitive market.

In the unregulated case the generated nitrate emissions N^o exceed the socially-desired levels, since the externality is not internalized, a fact that stimulates intervention. Each farmer i is required by the action program of the Nitrates Directive to meet an annual per hectare aggregate nitrogen usage standard $(\overline{n})$:[154]

$$n \leq \overline{n} \qquad (4)$$

When the Directive is combined with an agri-environmental program of the second pillar of CAP, the given performance standard becomes stricter and farmers are provided with a subsidy s^n per unit of nitrogen fertilizer used beneath the benchmark n_D^* that goes beyond basic standard $\overline{n}$, in the sense that $\overline{n} > n_D^*$. The compensation payment is:

$$s^n (n_D^* - n)$$

Under such a "*mixed*" policy regime combining the environmental requirements of the Directive and the financial provisions of the rural development regime of CAP, the payoff structure of farmers complying with n_D^* is:

$$\Pi^{D}(n, n_D^*) = \max_{\mathbf{x}}\left[pf(\mathbf{x}, n) - \mathbf{wx} - w^{n} n + s^{n}(n_D^* - n)\right]$$

where the nitrogen application is chosen such that $\Pi^D(n, n_D^*)$ is maximized, or:

$$\Pi^{D}(n_D):\ n_D = \arg\max_{n} \Pi^{D}(n, n_D^*)\ s.t.\, n \leq n_D^* \qquad (5)$$

We assume that after the subsidy is paid profits are lower, relative to the unregulated case, thus making the compliant farmer worse off than the unregulated farmer $\left(i.e. \Pi^{D}(n_D) < \Pi^{o}(n_o)\right)$.

[154]The standard is specified into 250 kg N/ha for livestock manure the first four years of the action program and 170 kg N/ha per year after the first four years, while the limit for manufactured nitrogen fertilizers is dependent on the crop requirements (EC, 1991).

Such a profit loss might be averted given the non-point-source characteristics of agricultural pollution. The fact that individual actions (i.e. nitrogen usage) can not be directly observed by a third party provides farmers incentives to keep both the nitrogen application at the profit maximizing level n_o, and the full amount of the subsidy $s^n(n_D^* - n_D)$, by falsely reporting compliance with regulation and nitrate use at the level n_D, without incurring the costs that compliance with the Directive entails. The payoff of such noncompliant behaviour, if it remains undetected, is:

$$\Pi_1^{nc}(n_o) = \Pi^o(n_o) + s^n(n_D^* - n_D) \quad (6)$$

However, farmers are aware that if detected in deviation from the action program rules then there is an exogenous probability q to be prosecuted and pay a fine $F \in (0, F_{\max}]$ if found guilty of causing nitrate leaching pollution by the Court.[155] Moreover, given that CAP payments are subject to the cross-compliance principle, the detected noncompliant farmer faces a reduction or even cancellation of provided payments by the amount:

$$\gamma s^n(n_D^* - n_D)$$

where $\gamma \in (0,1]$ is the cross-compliance reduction rate.

Let p the auditing probability, to be specified more precisely later. If the deviating farmer i is caught, his expected payoff is given by the profit maximizing profits plus the amount of the agri-environmental payment left after the imposition of the cross-compliance penalty, minus the legislatively imposed fine:

$$\Pi_2^{nc}(n_o) = \Pi^o(n_o) + s^n(n_D^* - n_D)(1 - \gamma p) - qpF$$

$$= \Pi^o(n_o) + s^n(n_D^* - n_D) - p\Upsilon$$

where $p\Upsilon = \left[s^n \gamma p(n_D^* - n_D) + qpF\right]$ represents the total expected penalty for noncompliance with the environmental requirements.

[155]The fine is considered to be a fixed amount. Nevertheless, it may be set to cover the damage caused and the regulator's cost (DEFRA, 2004).

To ensure that the deviating farmer incurs a positive cost, if inspected, and that his payoff is lower than the payoff in both the compliant and unregulated case, the structure of penalties should be such that:

$$\Pi_1^{nc}(n_o) > \Pi^o(n_o) > \Pi^D(n_D) > \Pi_2^{nc}(n_o)$$

Despite the adequate compliance incentives, the final decision to comply or not depends mostly on the inspection probability given the fact that individual nitrogen usage can not be directly observed and thus compliant behaviour is not directly verifiable. Let p be the probability that deviating activity is detected by an environmental agency undertaking a number of random inspections:

$$p = p(\beta, \omega_v) \;\; with \;\; \frac{\partial p(\beta)}{\partial \beta} > 0 \text{ and } \frac{\partial^2 p(\beta)}{\partial \beta^2} < 0 \qquad (7)$$

where ω_v is a vector of parameters affecting the probability of regulation (i.e. legislative procedures, transaction costs) and β is the monitoring effort (i.e. on the spot visits) required for the implementation of an auditing scheme. By (7) the detection probability is increasing in undertaken monitoring effort and displays diminishing returns in β.

Hence, the expected profits of deviating farmers are:

$$E\Pi^{nc}(n_o) = \Pi^o(n_o) + s^n(n_D^* - n_D)(1 - p(\beta)\gamma) - p(\beta)qF \qquad (8)$$

$$= \Pi^o(n_o) - z(s^n, n_D^*, \gamma, q, F, \beta)$$

where $z(s^n, n_D^*, \gamma, q, F, \beta) = [p(\beta)qF - s^n(n_D^* - n_D)(1 - p(\beta)\gamma)]$ involves the expected penalty imposed on the detected, noncompliant farmer. The total derivative of the expected penalty z with respect to policy parameters and monitoring effort indicates that the imposed noncompliance penalty increases as the performance standard (n_D^*), the undertaken monitoring effort (β) and the enforcement mechanism (q, F, γ) become stricter, while it decreases as the nitrogen usage subsidy (s^n) increases.[156]

Therefore, the sufficient condition for compliance is:

[156]It holds $dz/ds^n, dz/dn_D^* < 0$ and $dz/dq, dz/dF, dz/d\gamma, dz/d\beta > 0$.

$$\Pi^{D}(n_{D}) > \Pi^{o}(n_{o}) - z(\mathbf{g}, \beta)$$

depending on the magnitude of the undertaken monitoring effort β and thus the inspection probability $p(\beta)$ as well as the rest of the policy parameters summarized by the vector $\mathbf{g} = (\gamma, s^{n}, F, n_{D}^{*}, q)$.

3. Implementation of the Directive

Monitoring effort is of crucial importance both for the detection of potential violators and the stimulation of compliance through the enforcement of foreseen sanctions. Consider an environment agency (EA) engaging into costly and perfectly accurate monitoring in order to induce the majority or even the entire population of farmers to comply with the aims of the Directive.[157] The selection of the monitoring effort level β that accomplishes this goal can either be arbitrary, based on the alternative behavioural rules adopted by farmers, or it can be optimal in the sense that it is obtained by minimizing a social welfare criterion conditional to the assumed behavioural rules which involve either full or bounded rationality.

Depending on their rationality type, farmers use either the optimal decision rule or the replicator dynamics imitation rule in order to decide whether or not to comply with the statutory environmental requirements. If farmers are fully rational then they adopt the optimal behavioural rule, while if there is bounded rationality then the passive, imitating behavioural rule is adopted. Under the optimal behavioural rule farmers have all the necessary data, have knowledge of the structure of payoffs, compare the profits that each strategy entails and decide their optimum response to the given policy. On the other hand, if economic agents are characterized by bounded rationality then a passive decision making is adopted based on imitation of the better-off performing strategy, and the decision whether to comply or not depends on the information revealed by the interaction of farmers over time.

[157]The EA can not influence the range of the policy parameters $\mathbf{g} = (\gamma, s^{n}, F, n_{D}^{*}, q)$ but only the level of undertaken monitoring effort (β).

Henceforth, according to the adopted behavioural rule the environmental agent can choose the monitoring effort level that stimulates compliance and eventually leads to the socially-desired outcome of full compliance or an intermediate status characterized by partial compliance.

3.1 Arbitrary Regulation Design

Assume that the level of monitoring is chosen arbitrarily based on a behavioural context involving initially full and then bounded rationality.

3.1.1 Fully Rational Compliance Decisions

Given the policy $\{s^n, n_D^*, \gamma, q, F, \beta\}$ the choice between the *optimal compliance decision* (n_D) and the *optimal noncompliance decision* (n_o) depends on the structure of payoffs under each strategy. Fully rational farmers will decide about complying or not by maximizing expected profits. Thus, farmers' optimal response implies:

$$n^* = \begin{cases} n_D & \text{if} \;\; \Pi^D(n_D) > E\Pi^{nc}(n_o) \\ n_o & \text{if} \;\; \Pi^D(n_D) < E\Pi^{nc}(n_o) \end{cases}$$

Assume that a minimum monitoring effort value $\beta^{\min}$ and thus a minimum inspection probability $p(\beta^{\min})$ exists for given values of the rest of the parameters, making farmers indifferent between the complying and deviating strategy, in the sense that:

$$p\left(\beta^{\min}\right) : \Pi^D(n_D) = E\Pi^{nc}(n_o) \qquad (9)$$

Henceforth, if the undertaken monitoring effort exceeds the minimum value required to induce compliance, then the noncompliance decision is not profit maximizing and farmers' optimum response is $n^* = n_D$. Individual farmers perceive that the imposition of the noncompliance sanctions is more probable and thus prefer the profit losses that compliance entails rather than the losses involved by detected noncompliance. Given the homogeneity assumption the population of farmers adopts a monomorphic behaviour characterized by full compliance in the sense that all the farmers adopt the optimal compliance decision. In the opposite case, if monitoring effort is less than $\beta^{\min}$ then the inspection probability is not high enough to stimulate compliance. The optimal noncompliance decision exists and the optimum response of the population of farmers is $n^* = n_o$, meaning that no farmer complies with the Directive.

If the structure of the policy regime is not modified over time and the environmental agency precommits to the chosen monitoring effort then the population takes at a given time t a "once and for all" decision, that is retained in the future, implying either full compliance or noncompliance with the statutory environmental requirements of the Directive. This requires that the examined public voluntary agreement has "non-surprise" features in the sense that both the environmental agency and the policy maker[158] offer assurances to regulated agents that they will not change the terms of the agreement $(i.e.\, \beta, \mathbf{g})$, in response to changing environmental protection needs (Langpap and Wu, 2004). Therefore, it holds that:

Proposition 1: *If monitoring effort is chosen arbitrarily, based on the assumption that farmers decide about complying or not by using profit maximizing behaviour, then the entire population of farmers adopts a monomorphic behaviour which persists in the long-run. If* $\beta > \beta^{\min}$ *then the optimum compliance decision* $n^* = n_D$ *is undertaken and there is full compliance of the population, while if* $\beta < \beta^{\min}$ *the optimum noncompliance decision* $n^* = n_o$ *is undertaken and there is noncompliance of the population.*

3.1.2 Compliance Decisions under Imitating Behavioural Rules

Under bounded rationality farmers ignore the exact structure of payoffs and form anticipations about the policy impacts. At a given time t the population of farmers is divided in two groups, following different strategies concerning compliance with the Directive. Let $x(t)$ be the proportion of agents adopting the compliant strategy at time t, while $x_N(t)$ the remaining proportion deviating from defined standards and retaining the profit maximizing nitrogen usage level n_o, with $x(t) + x_N(t) = 1$.

The proportion of farmers complying with the provisions of the Directive evolves in time given the fact that farmers learn the true structure of payoffs via their interaction.

[158] The policy maker defines the range of the policy parameters $\mathbf{g} = (\gamma, s^n, F, n_D^*, q)$.

If farmers perceive that the optimal compliant decision $n^* = n_D$ involves higher profits, then it is imitated by other farmers and met more frequently in the population, otherwise the share of compliant farmers decreases and the optimal noncompliant decision $n^* = n_o$ is met more frequently. Based on the replicator dynamics framework described previously, the equation describing the motion of the group of compliant agents x over time is modelled by:

$$\dot{x} = \kappa\delta\, x(1-x)[z(\mathbf{g},\beta) - \Delta\Pi_D^o] \qquad (10)$$

where $\kappa\delta$ are constant factors that affect the rate of adjustment to stationarity and are often set equal to unit without affecting the stability analysis. The expression $[z(\mathbf{g},\beta) - \Delta\Pi_D^o] = \Omega(\beta)$ represents the divergence of profit losses under the deviating and compliant strategy compared to the no regulation case, defined as $z(\mathbf{g},\beta) = (\Pi^o(n_o) - E\Pi^{nc}(n_o))$ and $\Delta\Pi_D^o = (\Pi^o(n_o) - \Pi^D(n_D))$.

By setting $\dot{x} = 0$ in (10) we obtain the steady states of the replicator dynamic. It follows that in the long-run the population of farmers converges to a monomorphic critical point characterized either by full compliance $(x_1^* = 1)$ or noncompliance $(x_2^* = 0)$ with the Directive. To show this consider the stability condition

$$\frac{d\dot{x}}{dx} = (1-2x)\Omega(\beta) \qquad (11)$$

This condition implies that full compliance is the evolutionary stable steady state, in the sense that $\left.\frac{d\dot{x}}{dx}\right|_{x_1^*=1} < 0$, if the divergence of profit losses $\Omega(\beta)$ is positive. The mechanism operates in the following way. Assume that there is a critical value of monitoring effort $(\tilde{\beta})$ setting the profit loss divergence equal to zero and thus making farmers indifferent between the considered strategies:

$$\tilde{\beta} : \Omega(\tilde{\beta}) = 0$$

This critical value is similar to the minimum monitoring effort value $\beta^{\min}$ defined under unbounded rationality, and behaves as a bifurcation parameter since the sign of Ω and thus the stability of the steady states, depend on the magnitude of the undertaken monitoring effort β relative to the critical value $\widetilde{\beta}$. Therefore the imposition of the more costly noncompliance sanctions, which are reflected in $z(\mathbf{g},\beta)$, becomes more likely if the undertaken monitoring effort β, exceeds the critical value $\widetilde{\beta}$. In such a case the profit losses that compliance entails are preferred to losses involved by detected noncompliance, inducing in the long run the entire population of farmers to adopt the optimum compliance decision $n^* = n_D$, in the sense that $\lim_{t\to\infty} x = 1$.

Therefore, when the environmental agency precommits itself to an announced fixed monitoring effort β it holds:

Proposition 2: *If monitoring effort is chosen arbitrarily based on the assumption that farmers decide about complying or not by following proportional imitation rules then the population of farmers converges always to a monomorphic steady state. If* $\beta > \tilde{\beta}$ *then the share of compliant farmers increases over time resulting eventually into full compliance* $x_1^* = 1$ *with the Directive, while if* $\beta < \tilde{\beta}$ *then the proportion of complying farmers diminishes over time resulting into noncompliance* $x_2^* = 0$.

The total differential of $\Omega(\mathbf{g},\widetilde{\beta}) = 0$ with respect to the policy parameters $\mathbf{g}$ indicates that given the costs of monitoring effort the target of full compliance can be attainable through less monitoring effort if the "mixed" policy is characterized by a laxer performance standard (n_D^*), an increased rural development subsidy (s^n) and / or a stricter enforcement mechanism (q, F, γ), as can be seen by the derivatives:

$$\frac{d\widetilde{\beta}}{dn_D^*} = -\frac{p(\widetilde{\beta})s^n\gamma}{dz/d\beta} < 0 \text{ and } \frac{d\widetilde{\beta}}{ds^n} = -\frac{(n_D^* - n_D)p(\widetilde{\beta})\gamma}{dz/d\beta} < 0$$

$$\frac{d\widetilde{\beta}}{dq} = -\frac{dz/dq}{dz/d\beta} < 0,\ \frac{d\widetilde{\beta}}{dF} = -\frac{dz/dF}{dz/d\beta} < 0 \text{ and } \frac{d\widetilde{\beta}}{d\gamma} = -\frac{dz/d\gamma}{dz/d\beta} < 0$$

This implies that under the proper design of the policy parameters $\mathbf{g}$ the range of monitoring effort values β that induce full compliance can become wider, allowing the environmental agency to achieve full compliance by committing to a lower monitoring effort value and thus incurring less monitoring expenses. In this sense there is trade-off between the different policy instruments for attaining full compliance.

Under the replicator dynamics imitation rule the aggregate nitrate emissions are affected by the decisions to comply with the Directive. Therefore equation (1) is further specified as:

$$N = v\{xn_D + (1-x)n_o)\} \tag{12}$$

It is notable that if the environmental agency chooses the monitoring effort value (or inspection probability) based on observations of compliance fraction x and / or aggregate emissions N (or equivalently the aggregate nitrogen input usage n), then the inspection probability (7) with joint dependence on compliance status x and stocks would be:

$$p(t) = p\left(\beta\left(x,N\right),\omega_c\right) \;\; with \;\; \frac{\partial p}{\partial x} < 0 \text{ and } \frac{\partial p}{\partial N} > 0$$

Under such a generalised inspection probability, the replicator dynamic equation (10) is redefined as:

$$\dot{x} = \kappa\delta \; x(1-x)[z\left(\mathbf{g},\beta\left(x,N\right)\right) - \Delta\Pi_D^o]$$

where the associated stability condition is:

$$\frac{d\dot{x}}{dx} = (1-2x)\Omega\left(\beta\left(x,N\right)\right) + x(1-x)\frac{\partial p}{\partial \beta}\frac{\partial \beta}{\partial x}\Upsilon$$

Under an inspection probability dependent on $\left(x,N\right)$, the replicator dynamic equation defines two monomorphic equilibrium points, $x_1^* = 1$ and $x_2^* = 0$. Nevertheless, there is a potential third equilibrium point $x_3^* \in \left(0,1\right)$, which satisfies the equilibrium condition $\dot{x} = 0$ and involves partial compliance of the regulated population. This steady state is determined by a critical pair of compliance fraction and aggregate emissions that sets divergence of profit losses equal to zero, defined as $\left(\hat{x},\hat{N}\right) : \Omega\left(\beta\left(\hat{x},\hat{N}\right)\right) = 0$. The existence of the polymorphic steady state and thus the type of the prevailing equilibrium under this generalized case, depends on the magnitude of the critical pair $\left(\hat{x},\hat{N}\right)$ and the monomorphic pair values, $\left(x_1^*,N_1^*\right)$ and $\left(x_2^*,N_2^*\right)$.

Given the assumptions that $\partial\beta/\partial x<0$ for $x\in[0,1]$ and $\partial\beta/\partial N>0$, it holds that $\Omega>0$ for any $(x,N)<\left(\hat{x},\hat{N}\right)$ and that $\Omega<0$ for any $(x,N)>\left(\hat{x},\hat{N}\right)$. Hence, if the critical pair $\left(\hat{x},\hat{N}\right)$ lays in the interval $(0,1)$, in the sense that $\left(x_1^*,N_1^*\right)>\left(\hat{x},\hat{N}\right)>\left(x_2^*,N_2^*\right)$, the associated stability conditions are:

$$\left.\frac{d\dot{x}}{dx}\right|_{x_1^*=1},\left.\frac{d\dot{x}}{dx}\right|_{x_2^*=0}>0 \text{ and } \left.\frac{d\dot{x}}{dx}\right|_{x_3^*\in(0,1)}<0$$

involving that both monomorphic equilibria are unstable, while the polymorphic equilibrium x_3^* is stable. In the opposite case that $\left(\hat{x},\hat{N}\right)$ lies outside the interval $(0,1)$, meaning that either $\left(\hat{x},\hat{N}\right)>\left(x_1^*,N_1^*\right)>\left(x_2^*,N_2^*\right)$ or $\left(x_1^*,N_1^*\right)>\left(x_2^*,N_2^*\right)>\left(\hat{x},\hat{N}\right)$, the population converges to a monomorphic steady state involving either full or no compliance of the population with the Directive.

It is underlined that under an inspection probability defined either as $p(\beta(x))$ or $p(\beta(N))$, the long-run behavior of the population is identical to the behavior under the under the generalized inspection probability $p(\beta(x,N))$.[159]

It can be concluded thus that:

Proposition 3: *If monitoring effort is chosen arbitrarily based on the imitation dynamics rule and the state variables of the problem, the regulated population converges either to a polymorphic or monomorphic steady state.*

[159] In the case of $p(\beta(x))$ there is a critical compliance fraction defined as $\hat{x}$ setting $\Omega=0$, while in the case of $p(\beta(N))$ there is a critical value of aggregate emissions $\hat{N}$ setting $\Omega=0$ respectively. In each case the type of the evolutionary stable critical point depends on the relation between the critical value and the associated monomorphic values. Hence, the population converges to a polymorphic steady state either if $x_1^*>\hat{x}>x_2^*$ or $N_1^*>\hat{N}>N_2^*$.

Finally, it is worth mentioning that under the proper design of the policy parameters $\mathbf{g}$ the polymorphic steady states can be driven closer to the full compliance steady state.[160]

3.2 Optimal Regulation Design

Even though the unintended generation of nitrates emission flows offers private benefits to individual farmers, their decisions create external costs for the rest of society (Chambers and Quiggin, 1996) in terms of both natural environment and human health consequences. Let $D(N)$ be the social damage caused by nitrates leaching that is assumed to be a linear function of aggregate nitrates leaching. Given the assumed direct, one-to-one relation between individual nitrate leaching N_i and nitrogen input n_i, social damages are given by:[161]

$$D(N) = \alpha N = a \sum_{i=1}^{v} n_i = avn$$

where $\alpha > 0$ represents the constant marginal damage of aggregate emission flows.

Monitoring effort β required to verify compliance is also costly to society since it requires resources. It is usually financed by social funds raised through taxes and furthermore involves transaction costs to the environmental agent. The associated monitoring costs are:

$$m(\beta) \;\; with \;\; \frac{\partial m(\beta)}{\partial \beta} > 0 \;\; and \;\; \frac{\partial^2 m(\beta)}{\partial \beta^2} > 0$$

characterized by $\partial m(0)/\partial \beta > 0$.

Consider that the environmental agency selects the monitoring effort level in an optimal way in order to minimize the aggregate social costs SC, defined as the sum of monitoring costs and environmental damages from nitrates leaching:

[160] For the analysis of regulation in common pool resources under imitation dynamics see Xepapadeas (2005).

[161] Given the homogeneity assumption we can drop the index i in the social damage expression.

$$\min_{\beta} SC = \min_{\beta}\{m(\beta)+D(n)\} \tag{13}$$

conditional to the expression of aggregate nitrates emission flows and the behavioural rule considered each time.

3.2.1 Fully Rational Compliance Decisions

If the environmental agent considers that farmers are fully rational then the minimization problem is conditional to the compliance constraint (9). Under this context the problem is static and given by:

$$\begin{aligned}
&\min_{\beta} \ \{m(\beta)+\alpha vn)\} \\
&\text{s.t.} \\
&\quad \Pi^{D}(n_D) = E\Pi^{nc}\left(n_o\right) \\
&\quad n = \sum_{i=1}^{v} n_i = vn
\end{aligned}$$

The Lagrangean of the problem is:

$$L(\beta,x,\mu) = m(\beta)+\alpha vn + \mu\left\{E\Pi^{nc}\left(n_o\right)-\Pi^{D}(n_D)\right\}$$

where μ is the Langrangean multiplier denoting the impact of a marginal change in the payoff of complying agents on the value function J^* of aggregate social cost and is considered to represent a marginal cost $(i.e.\ \mu>0)$.

The associated first-order-optimality conditions involve:

$$\frac{\partial L}{\partial \beta} = \frac{\partial m(\beta)}{\partial \beta} - \mu\frac{\partial p(\beta)}{\partial \beta}(qF\gamma + s^{n}(n_D^{*}-n_D)) = 0 \tag{14a}$$

$$\frac{\partial L}{\partial \mu} = E\Pi^{nc}\left(n_o\right)-\Pi^{D}(n_D) = 0 \tag{14b}$$

$$\begin{aligned}
\Pi^{D}(n_D) &= \left[pf(\mathbf{x},n)-\mathbf{wx}-w^{n}n+s^{n}(n_D^{*}-n_D)\right] \\
E\Pi^{nc}(n_o) &= \Pi^{o}\left(n_o\right)+s^{n}(n_D^{*}-n_D)\left(1-p(\beta)\gamma\right)-p(\beta)qF
\end{aligned}$$

In the absence of a budget constraint, the compliance constraint (14b) determines the optimal β : $\beta^{*}=\beta^{\min}$. Then the Lagrangean multiplier μ is determined by (14a) for

$\beta = \beta^*$. Since $\partial E\Pi^{nc}(n_o)/\partial\beta < 0$, if the regulator actually applies monitoring effort $\widehat{\beta} = \beta^* + \varepsilon = \beta^{\min} + \varepsilon,\ \varepsilon > 0$, full compliance is attained. This is a "knife-edge" result induced by the fully rational behaviour of the farmers regarding their compliance decisions. If an effective budget constraint of the form $m(\beta) \leq B$ is present, then monitoring effort will be chosen at a level $\beta(B)$: $m(\beta) = B$. If $\beta(B)$ is less than the minimum value $\beta^{\min}$ required to induce compliance, then the compliance incentives are inadequate and the entire population of farmers ends up adopting the noncompliance decision rule $n^* = n_o$. In the opposite case the compliance strategy is the prevailing strategy and the population is characterized by full compliance with the Directive and the optimum compliance decision $n^* = n_D$ occurs in the long-run.

Proposition 4: *If monitoring effort is selected optimally based on the assumption that farmers decide about complying or not by using profit maximizing behaviour, then the population always adopts a monomorphic strategy. If a budget constraint is not effective, then full compliance is attained by choosing* $\widehat{\beta} = \beta^{\min} + \varepsilon$. *If a budget constraint is effective, then if* $\beta(B) > \beta^{\min}$ *the optimal compliance decision is adopted and the population is characterized by full compliance, while if* $\beta(B) < \beta^{\min}$ *the optimal noncompliance decision is adopted and noncompliance emerges.*

3.2.2 Compliance Decisions under Imitating Behavioural Rules

Under imitating behavioural rules modelled by replicator dynamics (10), the regulator's problem is:

$$\min_{\beta} \int_0^\infty \exp(-\rho t)\{m(\beta) + \alpha\widehat{n}\}$$

s.t.

$$\dot{x} = x(1-x)\left[z(\mathbf{g}, \beta) - \Delta\Pi_D^o\right]$$

$$\widehat{n} = \sum_{i=1}^{v} n_i = v[xn_D + (1-x)n_o]$$

The Hamiltonian of the problem is:

$$H(\beta, x, \lambda) = m(\beta) + \alpha v[xn_D + (1-x)n_o] + \lambda x(1-x)\left[z(\mathbf{g}, \beta) - \Delta\Pi_D^o\right] \qquad (15)$$

where λ is the associated costate variable reflecting the impact of a marginal change in the proportion of complying agents on minimum discounted social cost J^*:

$$\lambda = \frac{\partial J^*}{\partial x}$$

and represents the dynamic social shadow value of compliance. This value is expected to be negative since an increase in compliance reduces social costs $(i.e.\ \lambda < 0)$.

The Pontryagin maximum principle[162] implies for $x \in (0,1)$:[163]

$$\frac{\partial H(\cdot)}{\partial \beta} = \frac{\partial m(\beta)}{\partial \beta} + \lambda x(1-x)\frac{\partial p(\beta)}{\partial \beta}\Upsilon = 0 \text{ if } \beta^* > 0 \qquad (16a)$$

$$\text{if } \frac{\partial H(\cdot)}{\partial \beta} > 0,\ \beta^* = 0$$

$$\dot{\lambda} = \rho\lambda - \frac{\partial H(\cdot)}{\partial x} = \lambda[\rho - (1-2x)\Omega(\beta)] - \alpha v[n_D - n_o] \qquad (16b)$$

The associated Arrow-type transversality conditions imply:

$$\lim_{t\to\infty} \exp(-\rho t)\lambda(t) \geq 0 \quad and \quad \lim_{t\to\infty} \exp(-\rho t)\lambda(t)x(t) = 0$$

Assume that condition (16a) determines an interior solution $(i.e.\ \beta^* > 0)$. From the Implicit Function Theorem the optimal monitoring effort β^* minimizing the discounted aggregate social costs is:

$$(16a): \quad \Rightarrow \beta^* = \widehat{\beta}(x, \lambda, \mathbf{g}) = \widehat{\beta}(x, \lambda, \gamma, s^n, F, n_D^*, q) \qquad (17)$$

At the monomorphic steady states the value of β depends on the magnitude of the policy parameters $\mathbf{g}$, while it is independent of the state and costate variables of the problem. Hence, for $x = x_1^* = 1$ or $x = x_2^* = 0$, we assume that $\beta = \beta_\varsigma^*$, $\varsigma = 1,2$ is

[162]The second-order-condition $H_{\beta\beta}(\beta, x, \lambda)$ is positive implying that the optimal β^* minimizes the Hamiltonian $H(\beta, x^*, \lambda)$.

[163]Note that $\Upsilon = \left[qF + s^n\gamma(n_D^* - n_D)\right]$.

chosen such that both full compliance and no compliance are conditionally attracting for the replicator dynamic equation.[164] In particular, β_1^* is selected to set the divergence of profit losses $[z\left(\mathbf{g},\beta_1^*\right)-\Delta\Pi_D^o]=\Omega(\beta_1^*)$ positive, in the sense that the compliant strategy is preferable in terms of profit losses, so that once the population converges to the full compliance steady state it does not diverge. On the other hand, β_2^* is selected to set the divergence of profit losses $[z\left(\mathbf{g},\beta_2^*\right)-\Delta\Pi_D^o]=\Omega(\beta_2^*)$ negative, so as to set profit losses under the deviating strategy preferable to the losses involved by the compliant strategy.

By substituting (17) into (10) and (16b) the modified Hamiltonian dynamic system (MHDS) in the state-costate space is defined as:

$$\dot{x}=x(1-x)\left[z(\mathbf{g},\widehat{\beta}(x,\lambda,\mathbf{g}))-\Delta\Pi_D^o\right] \tag{18}$$

$$\dot{\lambda}=\lambda\left(\rho-(1-2x)\left[z(\mathbf{g},\widehat{\beta}(x,\lambda,\mathbf{g}))-\Delta\Pi_D^o\right]\right)-\alpha v\Delta(n)_o^D \tag{19}$$

where $[n_D-n_o]=\Delta(n)_o^D$. The solution of the MHDS determines the socially-optimal time paths $\left(x^*(t),\lambda^*(t)\right)$ and the socially-optimal steady state equilibrium point $(x^\infty,\lambda^\infty)$ for the compliance fraction x and its shadow value λ, along with the corresponding socially-optimal monitoring effort path $\beta^*(x^*(t),\lambda^*(t))$.

By setting $\left(\dot{x}=\dot{\lambda}=0\right)$, two types of possible steady states are determined for the long-run equilibrium compliance fraction:

$$\begin{aligned}&\text{Monomorphic}: \ x_1^*=1,\ x_2^*=0\\&\text{Polymorphic}: \ x_3^*\in\left(0,1\right): \ z(s^n,n_D^*,\gamma,q,F,\widehat{\beta}(x,\lambda,\mathbf{g}))=\Delta\Pi_D^o\end{aligned}$$

Monomorphic critical points involve either full compliance (x_1^*) or full noncompliance (x_2^*) with the Directive. They are depicted by two isoclines vertical to the horizontal axis (figure 1).

[Figure 1]

[164] Both assumptions for the values of $\Omega\left(\beta_1^*\right)$ and $\Omega\left(\beta_2^*\right)$ are necessary for the definition of the stability properties of the monomorphic steady states. For further details see Appendix I.

The polymorphic steady state (x_3^*) is characterized by partial compliance and is implicitly defined by an isocline $x(\lambda)|_{\dot{x}=0}$ with the property:

$$\lambda(x)|_{\dot{x}=0} \ : \ \Omega(x,\lambda) = \left[z(s^n, n_D^*, \gamma, q, F, \widehat{\beta}(x,\lambda,\mathbf{g})) - \Delta\Pi_D^o \right] = 0 \qquad (20)$$

All the combinations (x,λ) along the $\lambda(x)|_{\dot{x}=0}$ isocline satisfy $\Omega(x,\lambda)=0$. For combination (x,λ) outside this isocline $\Omega \neq 0$. For combinations located above the isocline $\Omega > 0$, while combinations located below are characterized by $\Omega < 0$.[165]

The $\lambda(x)|_{\dot{x}=0}$ expression is illustrated by an inverse "U" shaped isocline with maximum at $x = 1/2$, (figure 1) since its slope is:[166]

$$\left.\frac{d\lambda}{dx}\right|_{\dot{x}=0} = -\frac{\partial\beta^* / \partial x}{\partial\beta^* / \partial\lambda} = \begin{cases} \left.\frac{d\lambda}{dx}\right|_{\dot{x}=0} > 0 & for \ \ x \in (0,1/2) \\ \left.\frac{d\lambda}{dx}\right|_{\dot{x}=0} < 0 & for \ \ x \in (1/2,1) \end{cases}$$

The slope can be interpreted as reflecting the relative variability of the monitoring effort β due to changes in the levels of the state and costate variables.[167]

By setting (19) equal to zero and substituting the steady-state equilibria of (18), the corresponding steady state shadow values of compliance are defined as:

$$\lambda^*\Big|_{x_1^*=1} = \frac{\alpha v \Delta(n)_o^D}{\rho + \Omega(\beta_1^*)}, \ \lambda^*\Big|_{x_2^*=0} = \frac{\alpha v \Delta(n)_o^D}{\rho - \Omega(\beta_2^*)} \ \text{ and } \lambda^*\Big|_{x_3^* \in (0,1)} = \frac{\alpha v \Delta(n)_o^D}{\rho}$$

By the assumptions for the values of $\Omega(\beta_1^*)$ and $\Omega(\beta_2^*)$ and the fact that $\alpha v \Delta(n)_o^D < 0$, it holds that λ is negative at all steady states and that $\lambda^*\Big|_{x_3^* \in (0,1)}$ is greater than

[165] It is assumed that $\Omega(\beta_1^*)$ is positive, while $\Omega(\beta_2^*)$ is negative, so that both full compliance and no compliance are conditionally attracting for the replicator dynamic equation.

[166] This isocline does not intersect with the monomorphic isoclines of (18).

[167] From the partial derivative $d\beta^*/dx = (-H_{\beta\beta})^{-1}\left[\lambda(1-2x)\frac{\partial p(\beta)}{\partial\beta}\Upsilon\right]$, it is evident that $d\lambda/dx > 0$ for $x \in (0,1/2)$ and $d\lambda/dx < 0$ for $x \in (1/2,1)$.

$\lambda^*\big|_{x_1^*=1}$ and $\lambda\big|_{x_2^*=0}$. Therefore the monomorphic steady state shadow values λ_1^* and λ_2^* are below the $\lambda(x)\big|_{\dot{x}=0}$ isocline (see figure 1).

The behaviour of the $\dot{\lambda}=0$ isocline in the (x,λ) space is ambiguous given that the sign of the slope:

$$\frac{d\lambda}{dx}\Big|_{\dot{\lambda}=0} = -\lambda\left\{2\Omega(\beta)-(1-2x)\frac{\partial p}{\partial \beta}\frac{\partial \beta}{\partial x}\Upsilon\right\}\Bigg)\left\{\rho-(1-2x)\left[\Omega+\lambda\frac{\partial p}{\partial \beta}\frac{\partial \beta}{\partial \lambda}\Upsilon\right]\right\} \quad (21)$$

can be determined only in the neighbourhood of the steady-states and around the compliance value $(x=1/2)$ (see figure 1).[168] Whether the $\dot{\lambda}=0$ curve is continuous or not at the monomorphic values of λ depends on the assumptions for the optimal values β_1^* and β_2^*. In particular $\lambda_1^*(\beta_1^*)$ and $\lambda_2^*(\beta_2^*)$ are continuity points if:

$$\lim_{x\to 1}\widehat{\beta}(x,\lambda,\mathbf{g})=\beta_1^* \text{ and } \lim_{x\to 0}\widehat{\beta}(x,\lambda,\mathbf{g})=\beta_2^* \quad (22)$$

simultaneously occur. However, it is more natural to assume that the hair-line case of (22) is not satisfied and that the monomorphic values of λ are isolated points of $\dot{\lambda}=0$.

Depending on the shape of $\dot{\lambda}=0$ and $\lambda(x)\big|_{\dot{x}=0}$ in the (x,λ) space, the $\dot{\lambda}=0$ isocline can be depicted in several ways. If the two isoclines do not intersect, then $\dot{\lambda}=0$ represents either a "U" shaped curve, or a curve with decreasing and increasing parts (figure 2). On the other hand, if $\dot{\lambda}=0$ intersects the $\Omega(x,\lambda)=0$ once for $x\in(0,1)$, then it assigns a fixed value to λ for the monomorphic steady state of (18) and defines a curve with decreasing and/or increasing parts for the remaining x values (see figure 3). Finally, in the "knife-edge" case where the $\dot{\lambda}=0$ isocline is symmetric

[168]Around the monomorphic equilibrium points the slope is $\frac{d\lambda}{dx}\Big|_{\dot{\lambda}=0}^{x_1^*}>0$ and $\frac{d\lambda}{dx}\Big|_{\dot{\lambda}=0}^{x_2^*}<0$. For $x=1/2$ it holds $\frac{d\lambda}{dx}\Big|_{\dot{\lambda}=0}^{x_2^*}<0$, while around the polymorphic steady states it can be seen that $\frac{d\lambda}{dx}\Big|_{\dot{\lambda}=0}^{x_3^*}>0$ if $x_3^*\in(0,1/2)$ and $\frac{d\lambda}{dx}\Big|_{\dot{\lambda}=0}^{x_3^*}<0$ if $x_3^*\in(1/2,1)$. At intermediate compliance values the slope sign is uncertain.

around $x = 1/2$ and intersects the $\Omega(x,\lambda) = 0$ twice, it is defined by an inverse "U" shaped curve (see figure 4).[169]

[Figure 2]

[Figure 3]

[Figure 4]

The intersection of $\dot{\lambda} = 0$ and $\dot{x} = 0$ isocline defines the long-run equilibrium for x and λ. The total number and type of feasible socially-optimal equilibrium steady states (x_i^*, λ_i^*) depends on the shape of $\dot{\lambda} = 0$ and $\lambda(x)|_{\dot{x}=0}$ in the (x,λ) space. If $\dot{\lambda} = 0$ does not intersect with $\lambda(x)|_{\dot{x}=0}$, then the MHDS involves only two monomorphic steady states indicating full or non compliance (figure 2). On the other hand, if they intersect then the system is characterized by the two monomorphic equilibria and one polymorphic critical point (figure 3), given the fact that $\dot{\lambda} = 0$ meets $\lambda(x)|_{\dot{x}=0}$ only once, either at its increasing or decreasing part.[170] In this case if $\dot{\lambda} = 0$ and $\lambda(x)|_{\dot{x}=0}$ intersect at the increasing part of $\lambda(x)|_{\dot{x}=0}$, then the polymorphic rest point involves a small fraction of compliant farmers (*i.e.* $x_3^* \in (0,1/2)$), while if they intersect at its decreasing part then it involves high proportion of compliant farmers (*i.e.* $x_3^* \in (1/2,1)$).[171]

Given that monitoring effort is optimally chosen, the MHDS is characterized by multiple equilibria involving either full compliance (x_1^*, λ_1^*), noncompliance (x_2^*, λ_2^*) and/or partial compliance (x_3^*, λ_3^*) with the aims of the Directive. The stability properties of each critical point are examined in detail in Appendix I. Stability analysis suggests that the system is characterized by multiple saddle points potentially

[169]It is worth mentioning that the $\dot{\lambda} = 0$ isocline cannot intersect with the monomorphic isoclines of (18) in the area defined above the $\lambda(x)|_{\dot{x}=0}$ isocline due to the fact that both $\lambda_1^* < \lambda_3^*$ and $\lambda_2^* < \lambda_3^*$. Furthermore, we exclude hairline cases where the $\dot{\lambda} = 0$ isocline is tangent to the $\Omega(x,\lambda) = 0$ curve.

[170]The slope at the polymorphic steady states is known, since the MHDS can not have multiple polymorphic steady states.

[171]In the special case that $\dot{\lambda} = 0$ is symmetric around $x = 1/2$ and intersects the $\Omega(x,\lambda) = 0$ twice, the MHDS has two polymorphic critical points, with the same shadow value for λ (figure 4).

connected by heteroclinic orbits (see Figures 5a,b). In particular, both monomorphic rest points and the polymorphic steady state involving a high level of compliance (*i.e.* $x_3^* \in (1/2,1)$) satisfy the saddle point property, implying that for any initial compliance x^0, there exists an initial costate variable λ^0 such that the system converges to one of these steady states as $t \to \infty$. Convergence to a specific monomorphic or a polymorphic state depends on the specific initial compliance state. In this sense the emerging long run steady state exhibits history dependence.

[Figure 5a]

[Figure 5b]

Stability analysis also indicates that depending on the relative magnitude of marginal social benefits and costs the steady states may include one stable and one unstable polymorphic steady states, with the stable steady state involving low level of compliance $\left(i.e.\ x_3^* \in \left(0,1/2\right)\right)$. If the structure of marginal social benefits and costs is such that the trace $Tr\left(J^*\right)$ of the Jacobian matrix J^* of the MHDS evaluated at the low compliance steady state $\left(x_3^*, \lambda_3^*\right)$:

$$Tr\left(J_3^*\right) = \rho + \frac{\partial p}{\partial \beta}\Upsilon\left\{x_3^*(1-x_3^*)\frac{\partial \beta^*}{\partial x} - \lambda_3^*(1-2x_3^*)\frac{\partial \beta^*}{\partial \lambda}\right\}$$

is negative, then (x_3^*, λ_3^*) is a stable steady state. Furthermore, depending on the sign of the associated discriminant Δ, this steady state can be a stable focus where the approach path is characterised by oscillations (see figure 6) or a stable node without spilaring trajectories. In the special case that $Tr\left(J_3^*\right) = 0$ and $\Delta < 0$, then the polymorphic steady state is center where the system fluctuates around the rest point.

[Figure 6]

It is worth mentioning that when the low compliance steady state is unstable, then there is a possibility that a limit cycle with counterclockwise movement exists around the given critical point (see figure 7). Given that the flow of the vector field (18) - (19) points outwards around the unstable steady state, a limit cycle denoted by L exists if a compact positively invariant region R exists such that the flow of the vector field is pointing inwards on its boundary.[172] In such a case all the (x, λ) combinations along the limit cycle L are stable states and under particular initial conditions the system can be trapped in a low level compliance area characterised by oscillating dynamics.

[Figure 7]

Hence, it can be concluded that:

Proposition 5: *If monitoring effort is chosen optimally based on the assumption that farmers decide about complying or not by following proportional imitation rules, then depending on the initial compliance state* x_0*, the population converges either to a monomorphic steady state involving full compliance* (x_1^*, λ_1^*) *or full noncompliance* (x_2^*, λ_2^*)*, or to a polymorphic steady state involving low or high levels of partial compliance* (x_3^*, λ_3^*)*. Depending on the topological properties of the resulting evolutionary equilibrium point, the approach dynamics can either be monotonic or oscillating.*

The slope of examined isoclines influences the discrepancies between the equilibrium compliance proportions associated with the polymorphic and monomorphic steady states. If the monitoring effort is more sensitive to changes in the compliance fraction (x), or alternatively less sensitive to changes in the shadow value of compliance (λ), then the isocline $\lambda(x)|_{\dot{x}=0}$ becomes steeper and the discrepancy between the polymorphic and monomorphic steady states increases, leading the polymorphic steady state closer to the central compliance proportion, $x = 1/2$.[173]

The short-run and the steady-state comparative statics analysis indicates that even though a reduced rural development (RD) subsidy (s^n), a lax enforcement mechanism (q, F, γ) and a stringent performance standard (n_D^*) induce a reduction in the short-run socially optimal monitoring effort in the polymorphic compliance range

[172] For further details see Xepapadeas (2005). For technical details see Sastry (1999).

[173] In the opposite case the $\lambda(x)|_{\dot{x}=0}$ isocline is flatter and the discrepancies between the rest points decrease.

$x \in (0,1)$, [174] their impact on the steady-state monitoring effort value $\beta_i^{\infty} = \widehat{\beta}_i(x_i^{\infty}, \lambda_i^{\infty}, \mathbf{g})$ is ambiguous and crucially dependent on the relative magnitude of their short-run and long-run impacts on β.[175] Finally, it is worth mentioning that the short-run and steady-state monitoring effort values at the monomorphic compliance values are left unaffected by variations of the policy parameters $\mathbf{g} = (\gamma, s^n, F, n_D^*, q)$.

4. Implementation of the Directive under Accumulation of Monitoring Capital

According to the European Commission (2002), the performance of action programs is assessed through a network of sampling stations[176] which monitor nitrogen in soil, rootzone level, pilot fields and / or small watersheds. Henceforth, besides the occasional random spot-checks (β), the environmental agent also engages in the installation of monitoring capital to facilitate the detection of deviating performance and thus the stimulation of compliance with the public voluntary program.

Let I represents investment in capital in the form of field monitoring systems, laboratory equipment and scientific personnel that accumulates in time defining monitoring capital k. The net capital formation is described by:[177]

$$\dot{k} = I - \delta k \tag{23}$$

[174]The short-run comparative statics analysis results are summarized in:

	x	λ	γ	s^n	n_D^*	q	F
β^*	?	$(-)$	+	+	+	+	+

where for compliance fraction values lying within the range $x \in (0,1/2)$, it holds that $(d\beta^*/dx) > 0$, while for $x \in (1/2,1)$ then $(d\beta^*/dx) < 0$.

[175]The steady-state comparative statics of monitoring effort with respect to parameters g are given by: $\frac{\partial \beta_i(\infty)}{\partial \mathbf{g}} = \left[\frac{\partial \widehat{\beta}_i(\infty)}{\partial x}\frac{\partial x_i^{\infty}}{\partial \mathbf{g}} + \frac{\partial \widehat{\beta}_i(\infty)}{\partial \lambda}\frac{\partial \lambda_i^{\infty}}{\partial \mathbf{g}}\right] + \frac{\partial \widehat{\beta}_i(\infty)}{\partial \mathbf{g}}$, where $\frac{\partial \widehat{\beta}_i(\infty)}{\partial \mathbf{g}}$ and $\left(\frac{\partial \widehat{\beta}_i(\infty)}{\partial x}\frac{\partial x_i^{\infty}}{\partial \mathbf{g}} + \frac{\partial \widehat{\beta}_i(\infty)}{\partial \lambda}\frac{\partial \lambda_i^{\infty}}{\partial \mathbf{g}}\right)$ are the short-run and long-run powers exercised by policy parameters g.

[176]One station for 100-200 Km^2 is recommended (EC, 2002).

[177]It is considered that due to technological and / or budgetary restrictions the accumulated monitoring capital does not alter the problem of non-point-source pollution into a point-source problem, in the sense that full observability is unattainable.

where $\delta \geq 0$ is the exponential depreciation rate of monitoring capital k.

The inspection probability (7) is redefined as a positive function of both monitoring effort and accumulated monitoring capital:

$$p(t) = p(\beta, k, \boldsymbol{\omega}_v) \quad with \frac{\partial p}{\partial k} > 0, \ \frac{\partial^2 p}{\partial k^2} < 0 \ and \ \frac{\partial^2 p}{\partial k \partial \beta} > 0$$

with diminishing returns both in β and k. Note that complementarity is assumed to exist between the monitoring effort and monitoring capital.

In this context the expected deviating payoff (8) is rewritten as:

$$E\Pi^{nc}(n_o) = \Pi^o(n_o) - z(\beta, k, \mathbf{g})$$

It is evident that a farmer's decision to comply or not depends on both the magnitude of monitoring effort and accumulated monitoring capital. This implies that in addition to the level of undertaken monitoring effort, the environmental agent must select the level of realized investment in monitoring capital (I) that ensures that the accumulated monitoring capital k is sufficient enough to stimulate full or at least partial compliance of the regulated population with the aims of the Nitrates Directive.

4.1 Arbitrary Regulation Design

Accordingly to the perceived rationality context, the investment level must be set higher than the value that satisfies with equality the associated indifference conditions:[178]

$$\begin{aligned} &Full\ rationality: && I^{\min} \to k^{\min} && so\ that\ \ \Pi^D(n_D) = E\Pi^{nc}\left(n_o, \beta^{\min}, k^{\min}\right) \\ &Bounded\ rationality: && \tilde{I} \to \tilde{k} && so\ that\ \ \Omega(\tilde{\beta}, \tilde{k}) = 0 \end{aligned}$$

Under the assumption that there is no binding budget constraint to restrain the value of realised investment in monitoring capital and given that $\beta > \beta^{\min}$ $(or \ \tilde{\beta})$, the entire population of regulated farmers is eventually induced to adopt the optimum

[178]The selection criteria of monitoring effort β are not modified.

compliance decision if $I > I^{\min}$ $(or\ \widetilde{I})$ so that the accumulated monitoring capital k exceeds the minimum value $k^{\min}$ $\left(or\ \widetilde{k}\right)$.

The fact that capital depreciates over time $\left(i.e.\ \delta \geq 0\right)$ must also be taken into account in the selection process of monitoring capital investment. An investment level that retains capital invariant over time exists:

$$I^{\#}\ :\ \dot{k} = 0$$

Thus independently of the considered behavioural rule, the investment level I must be set at least equal to $I^{\#}$ to ensure that the inspection probability $p(\beta,k)$ (via the accumulated monitoring capital) and thus the compliance incentives do not decline over time.[179]

Henceforth, when it comes to choosing the undertaken investment level I, the environmental agent must select a value higher than the maximum of $I^{\min}$ $(or\ \widetilde{I})$ and $I^{\#}$ to simultaneously ensure that the accumulated monitoring capital k does not decline over time and that the compliant strategy $\left(n_D\right)$ is the optimal decision.[180] Given that $\beta > \beta^{\min}$ or $\beta > \widetilde{\beta}$, it is concluded that:

Proposition 6: *If investment in monitoring capital is chosen arbitrarily and the budget constraint is not effective, then full compliance of the regulated population is attained if under the full rationality behavioural rule* $\widehat{I} > \max\left\{I^{\min}, I^{\#}\right\}$ *or* $\widehat{I} > \max\left\{\widetilde{I}, I^{\#}\right\}$ *under the bounded rationality behavioural rule.*

However, given (23), the accumulation of the required monitoring capital

$$\widehat{k} > \max\left\{k^{\min}, k^{\#}\right\}\ or\ \widehat{k} > \max\left\{\widetilde{k}, k^{\#}\right\}$$

[179] If $I < I^{\#}$ then $\dot{k} < 0$ and given that $\left(\partial p/\partial k\right) > 0$ the inspection probability declines over time so that eventually $\Pi^{D}(n_D) > E\Pi^{nc}\left(n_o, \beta^{\min}, k^{\min}\right)$ and $\Omega(\widetilde{\beta}, \widetilde{k}) < 0$.

[180] It is stressed that if $I > I^{\min}$ $(or\ \widetilde{I})$ but $I < I^{\#}$ then the deviating strategy eventually becomes more profitable, given that k and $p(\beta,k)$ decline over time.

is a time-consuming process depending on the size of undertaken investment $\left(\hat{I} < \bar{I}\right)$ and depreciation rate (δ).[181] The notion of time appears in the attainment of the desired long-run behaviour. In particular, under the context of full rationality the critical capital level behaves as a bifurcation parameter since for lower values no farmer complies with the Directive's provisions, but as soon as $\hat{k}$ is reached and exceeded there is an automatic switch of all the members of the population to the compliant strategy.[182] Such a direct convergence to the full compliance critical point is not expected under the bounded rationality context where the dynamics of the farmers' population appear quite differentiated. For capital values less than $\hat{k}$ the share of compliant farmers declines over time leading eventually to the full noncompliance steady state $\left(x_2^* = 0\right)$, while for values that exceed $\hat{k}$ the share of compliant farmers increases over time and there is gradual and not instant convergence to the full compliance steady state $\left(x_1^* = 0\right)$.

4.2 Optimal Investment Policy

Investment in monitoring capital is costly to society since it involves purchase and adjustment costs for the environmental agency. In such a case the function of monitoring cost (CM) is given by a separable function of the form:

$$CM = m(\beta) + bI + q(I)$$

where b is the per unit purchase price of monitoring capital and $q(I)$ the convex adjustment costs including installation costs and personnel training (Xepapadeas, 1992b).

Hence, the agent pursues the minimum present value of the augmented aggregate social costs SC' by defining the optimal path of both monitoring effort and monitoring investment conditional to aggregate nitrates emission flows, the capital accumulation differential equation (23) and the behavioural rule at each point in

[181] Even though there is an investment level $(\bar{I})$ that guarantees the instant accumulation of the required capital and thus the direct convergence to the desired long-run equilibrium, such a size of investment is unfeasible due to apparent budgetary and /or technological restrictions.

[182] If $\hat{I} > \bar{I}$ then there is automatic convergence to the full compliance critical point.

time. [183] Even though the minimization problem [184] under the full rationality behavioural rule is no longer static, there is no modification in the dynamics of the farmers' population since the regulated population retains a monomorphic behaviour regarding compliance or not with statutory requirements, which depends on the magnitude of the applied optimum monitoring elements $\left(\beta^*, I^*\right)$ compared to the critical values $\left(\beta^{\min}, \hat{I}\right)$. However, under the imitating behavioural rule the topological properties of the polymorphic steady state involving high compliance levels ($x_3^* \in (1/2,1)$) are altered, since it no longer satisfies the saddle point property. Depending on the structure of the associated marginal social benefits and costs this steady state exhibits identical properties to the low compliance steady state $\left(x_3^* \in (0,1/2)\right)$. It can be a stable steady state with monotoning approach dynamics or spilaring trajectories, as well as a center equilibrium point, or an unstable critical point associated with a limit cycle where the system can be trapped in a high level compliance area with oscillating dynamics. Finally, it is worth referring to the possibility of an extreme case where both polymorphic steady states are unstable and around them there is a limit cycle.

5. Conclusions

The non-point-source characteristics of agricultural pollution problems undermine the effectiveness of regulation to induce compliance with environmental considerations, rendering essential the existence of a substantial monitoring mechanism. Both the Council Nitrates Directive (91/676/EEC) and the agri-environmental programs of the second pillar of CAP have incorporated such mechanisms in their policy design in order to verify that regulated farmers are complying with statutory nitrogen usage standards, and that foreseen sanctions are enforced whenever noncompliant behaviour is detected. The intention of the present paper was to examine whether the compliance incentives associated with monitoring and enforcement under 91/676/EEC and the second pillar of CAP, are adequate enough to induce the majority or even the entire

[183] Where $SC' = m(\beta) + bI + q(I) + D(n)$.

[184] To avoid complexities the compliance criterion (9) is considered to be satisfied with strict inequality (>).

population of farmers to restrict, in the long-run, the nitrogen input usage to the level suggested by a regulatory regime combining both the aims of the Directive and the compensation payments of CAP. To do so, we considered a homogeneous population of farmers who in their decision of whether to comply or not with the provisions of regulation, may follow two alternative behavioural rules according to their rationality characteristics. The selection of the monitoring and enforcement scheme by the regulator, is characterized under two assumptions, regarding farmers' compliance: (i) the optimizing behavioural rule which occurs under full rationality, and (ii) the evolutionary imitation rule which occurs under bounded rationality.

Our results suggest that the compliance incentives of a given population of farmers are affected by both the rule for selecting monitoring effort by the regulator and the behavioural rules under which farmers decide their compliance strategy. If monitoring effort is chosen by the regulator arbitrarily, based either on farmers' profit maximizing behaviour or on farmers' proportional imitation rule, then the entire population of farmers adopts a monomorphic behaviour, involving either full compliance or full noncompliance. Full compliance can be guaranteed if the environmental agency precommits to a monitoring effort value set higher than the critical value which makes farmers indifferent between compliance and deviation under both behavioural rules. If monitoring effort level is chosen optimally via the minimization of a social welfare criterion, then the same monomorphic behaviour emerges if the problem is constrained by the farmers' optimizing behavioural rule regarding compliance. If the social welfare criterion is minimized conditional to the farmers' imitation behavioural rule regarding compliance, then the population may also adopt a polymorphic behaviour involving partial compliance. A further difference between the optimality and imitation behavioural rule is the time occurrence of the long-run behaviour. When farmers are fully rational in deciding about their compliance strategy, then there is an immediate switch to full compliance or not, since the population takes a "once and for all" decision. Under the replicator dynamics imitation rule there is a gradual change in the composition of the population, depending on the revealed information via the farmers' interaction over time. Finally, the enforcement problem of the given regulation was reexamined under the presence of an additional choice variable - investment in monitoring capital - indicating identical properties with the previous analysis regarding population dynamics.

CHAPTER II: Modelling of Agricultural Behavior under the CAP Regime: Assessment of Environmental Impacts and Policy Effectiveness

The structure of farming activity under the provisions of the generalized regime of the Common Agricultural Policy involving both the first and second pillar elements is modelled. Independently of whether regulated agents exhibit unbounded or bounded rationality, the impact of the different type of CAP measures, as prescribed by Agenda 2000, in the decision making - and thus on the environmental performance of a homogeneous population of farmers - are discussed. The problem of a representative farmer is used for this purpose. After assessing the environmental effectiveness of the various CAP regimes, the mechanism that provides the type of CAP instruments that safeguard the collective attainment of a social environmental target, along with the type of interdependence characterizing them, is defined under the analytical framework of unboundedly and boundedly rational agents respectively. The problem of the optimal regulation of an unboundedly rational population of farmers is discussed in both a static and a dynamic context. The long-run viability of the Agenda 2000 CAP reform is also examined under the assumption of bounded rationality by employing the evolutionary framework of replicator dynamics.

Given that the aim of this Chapter is twofold, it is divided into two sections, with section II.1 being dedicated to the assessment of the relative environmental impacts of the various CAP subregimes of Agenda 2000, whilst section II.2 addresses the design of optimal policy under alternative contexts regarding assumptions about the rationality of the regulated agents.

European Environment under the CAP Regime

Despite their beneficial environmental services, European agriculture is associated with a series of adverse environmental effects.[185] Among the factors creating the

[185] Among the beneficial services are classified the decline of greenhouse emissions and the gains to biodiversity, while among the adverse services are the loss of landscape diversity and quality, as well

unbalance between agriculture and environment, CAP measures are considered of primary importance.[186] Supports linked with output levels (coupled payments) increased production to levels that would not have occurred otherwise, resulting into intensification, specialization, expansion of cultivated areas and rise in livestock numbers (Baldock et al., 2002). Even though coupled payments have not yet been cancelled by EU market policy (Pillar I), the Commission circularly admitted in 1988 that such a price policy is liable for environmental damages (Fennel, 1997) and decided to reorganize CAP as a response to the wider demand for an environmentally oriented CAP.

The major element of the 1992 or *McSharry CAP reform* was the gradual reduction or even elimination of production subsidies and the introduction of direct aid payments, provided per hectare (decoupling) to compensate farmers for support price cuts (EC, 2003). The substitution of price support measures by decoupled payments was continued by the 1999 or *Agenda 2000 reform*, which makes direct aid payments conditional to environmental aims (i.e. horizontal regulation). A long-term set-aside mechanism[187] was proposed and a package of *rural development measures* (Pillar II)[188] was promoted to complement reforms of common market organizations (CMOs) and internalize major environmental considerations. To maximize environmental benefits, both direct and pillar II payments are subject to the *cross-compliance principle*, a sanctioning approach incorporated in horizontal regulation that involves proportionate penalties for environmental infringements entailing, where appropriate,

as the deterioration of important habitats. For further details about the beneficial and adverse environmental services of agriculture, see the introductory chapter in Part I.

[186]The driving forces of such an unbalance are: (i) changes in market conditions (i.e. input prices), (ii) commercial considerations (i.e. profit maximization), (iii) institutional changes, (iv) technology development, (v) economic and social changes in rural areas (i.e. cost of labour, population mobility), (vi) independent and partly endogenous environmental changes (i.e. global warming), as well as (vii) public policy measures of CAP or in different policy realms (i.e. land ownership, food safety) (Baldock et al., 2002). Furthermore, among the factors that contribute to agricultural pollution are also classified the imperfect knowledge about the (i) land attributes (i.e. soil moisture and fertility level) (Johnson et al., 1991), (ii) location physical attributes (Wu and Babcock, 2001), as well as (iii) the operating characteristics of the activity (i.e. farming experience, education) (Wu and Babcock, 2001).

[187]Farmers setting-aside their arable land for ten years are eligible for direct payments dependent on this requirement. Non-food crops (i.e. energy crops) can be cultivated on this land (EC, 2004a).

[188] Under Pillar II, aid is provided for (i) early retirement, (ii) set-up of young farmers, (iii) reafforestation of agricultural land, (iv) compensatory payments for mountainous and other less-favoured areas, (v) agri-environmental programs, (vi) vocational training, (vii) improving processing and marketing of agricultural products, and (viii) investment in agricultural holdings (EC, 2004a).

partial or full removal of aid in the event of deviation from certain farming standards (EC, 1999). Finally, *dynamic modulation* involves the transfer of funds released from the compulsory reduction of market policy payments to rural development measures contributing to environmentally benign practices. The reforms were strengthened by the 2003 or Mid-term review CAP reform, which introduced a single payment scheme based on direct payments received during the period 2000-2002 and the hectares entitled for those payments, as well as redefining the cross-compliance principle to make it dependent on the detected noncompliance type (EC, 2004b).[189]

Agenda 2000 is known as the "*Green CAP*" because of the belief that it brings greater quality to environmental integration. However, the theoretical analysis of this regime has been rather limited and its environmental impacts have not yet been fully assessed to justify such a characterization. Hence, the intention of this section is to assess the impact of the various pillar I and pillar II policy instruments, as foreseen by the 1999 CAP reform, on the environmental performance of a homogeneous population of farmers defined in terms of equilibrium production choices of a representative farmer. Moreover, it aims at evaluating the effectiveness of the given CAP reform to stimulate compliance of an entire population of either unboundedly or boundedly rational farmers with a socially desirable environmental target. This is achieved by considering the mechanism that provides the type of the CAP instruments, along with the type of interdependence characterizing them which guarantees the achievement of such a target.[190]

To do so a conceptual, theoretical framework describing farming behaviour under the Agenda 2000 provisions is developed, by considering a homogeneous population of farmers where each farmer is eligible for a production subsidy and two types of direct payments provided for alternative land treatments: (i) cultivation and (ii) set-aside. The given financial provisions are granted to each European farmer through a public

[189]Particularly, if a farmer fails to comply with standards due to negligence, then the reduction of payments varies between 5% and 15%, while payments are reduced by at least 20% and may also be completely withdrawn in the event of deliberate noncompliance.

[190] Under unbounded rationality agents adopt an optimizing behavioural rule and behave as if they had all the necessary data and skills to calculate the optimum response (Binmore, 1992), while under bounded rationality agents have imperfect information about payoffs, they are unable to compute the optimal strategy and choose between predetermined strategies (Noailly et al., 2003).

voluntary program, [191] in the form of a formal contract between the entitled farmer and the Commission. Given the attainment costs of environmental requirements incorporated in direct payments, two strategies are considered: compliance with and deviation from farming standards. A deviating strategy can be detected via random inspections,[192] given the non-point-source characteristics of agricultural pollution, and deterred via the enforcement of the cross-compliance principle.

Given the generalized nature of the provided farm model, the different CAP regimes associated with common market organizations are reproduced under the proper simplifying assumptions, allowing comparisons between regimes in terms of farmers' equilibrium production choices, independent of the rationality assumptions. The examined CAP regimes associated with CMOs are: (i) *full coupling regime* that involves only production subsidies independent of environmental requirements, (ii) *partial decoupling regime*, involving coupled and decoupled payments, and (iii) *full decoupling regime*, that provides only direct payments. The unregulated regime, providing neither coupled nor decoupled payments, is employed as a benchmark regime. To assess whether and how production choices are altered by the introduction of farming standards and the cross-compliance principle, the partially and fully decoupled regimes are examined under the absence and presence of such considerations. Likewise the compliant and deviating strategy is compared in terms of equilibrium input and land usage values.

To examine the Commission's perception that rural development measures enhance further the "green" character of Agenda 2000, it is considered that the land quality target is attained either by restricting main production choices (inputs, land and labour) or by treating them in an environmentally benign way through secondary production choices (treatments on input usage etc.). Such treatments can either be self-financed fully or partially through an RD program - that is actually a public voluntary program - providing a set of subsidies per unit of established treatments subject to farming standards and the cross-compliance principle. The extended farm model is employed to examine the environmental performance of farmers' population

[191] For further details about the elements of the particular voluntary programs, see EC (2004b; 2007) or visit the official site of the European Commission: www.europa.eu/pol/agr/index_en.htm
[192]The simultaneous inspection of the entire population of farmers within a given geographical region is a technically very demanding task and potentially prohibitively costly.

when CAP regimes are extended with Pillar II payments (i.e. extended full coupling, partial and full decoupling regime).

The problem of optimal regulation is also discussed. This problem provides the socially optimal CAP instruments associated with common markets organizations, by comparing the optimality conditions of the regulator and a representative unboundedly rational non-complying farmer in a static and dynamic context. Given that in our setup the number of instruments is higher than the number of externalities, optimal instruments are defined for fixed values of the remaining CAP instruments. The type of interdependence between the various CAP instruments and the optimal instrument, as well as the conditions under which a given CAP regime is optimal, are also provided. After defining the dynamic socially optimum CAP instruments, the effectiveness of Agenda 2000 is assessed in the context of boundedly rational agents which behave under evolutionary imitation dynamics. The replicator dynamics framework is employed to define: (i) the selection mechanism of optimal CAP instruments and thus examine whether the current structure of the reformed CAP can induce the majority, or even all, of the population of farmers to adopt a complying strategy, and (ii) the type and the range of values of the various CAP instruments that render feasible the attainment of such a target. Finally, the policy effectiveness of Agenda 2000 is further assessed when extended with RD payments by evaluating the type of static and dynamic socially optimal Pillar II CAP measures.

The perception that CAP, as shaped by Agenda 2000, achieves the integration of environmental considerations into individual and thus collective farming behaviour is not supported strongly by the results of our analysis. Comparative static analysis shows that even though the reduction of coupled payments and the incorporation of environmental constraints induce the population of potentially deviating farmers to restrict production choices, the final impact of direct payments and the compliance enforcement mechanism on these choices is ambiguous. The comparison of strategies also indicated that direct payments and the compliance enforcement mechanism may not be sufficient to induce deviating farmers to alter their production choices and adopt a strategy approaching (or even matching with) the compliant strategy.

Nonintervention is preferable on environmental grounds to intervention via production subsidies, justifying the wide criticism of coupled payments. However, the environmental performance of the regulated farmers under the Agenda 2000 regimes (partial or full decoupling) can not be clearly shown to be superior to the performance resulting under the unregulated and full coupling regime both under the compliant and non-compliant strategy. Even though both the partial and full decoupling regimes involve less input usage, there is uncertainty about their relative impact on the set-aside decision of farmers' population given that direct payments are provided on conflicting land usages. The fully decoupled regime is environmentally superior in terms of both production choices (i.e. input and land usage) to the regime involving both coupled and decoupled payments, justifying the Commission's decision to proceed with the full cancellation of coupled payments. However, the relative environmental performance of the regulated population under these intervention regimes becomes ambiguous when examined in terms of both main and secondary production choices. The prospect that the transition from the partial and full decoupling regime to the rural development regime may forestall the further deterioration of the agricultural environment and proceed further in the reconstruction of the quality of the agricultural landscape, as indicated by the Mid-term review, is not verifiable by our theoretical model.

The environmental performance of the population of farmers under the partially and fully decoupled regimes can be further enhanced by the incorporation of environmental considerations and rural development payments, justifying the Commission's decision to embody pillar II in CAP. The assessed static and dynamic socially optimum CAP measures associated with common markets organizations and rural development indicated that it may be socially desirable to maintain coupled payments and extend the compliance enforcement mechanism with a set of charges on crop yields, land-usage, set-aside-land and / or secondary production choices. Given the current structure of CAP, such measures are not foreseen and both Agenda 2000 and the Mid-term review can be regarded as ex-ante suboptimal.

II.1 Assessment of Environmental Impacts

The structure of farming activity under the provisions of the generalized CAP regime involving both the first and second pillar elements is modelled, where independent of the considered degree of rationality the impacts of the different type of CAP measures in the decision making - and thus on the environmental performance - of a homogeneous population of farmers are discussed through the problem of a representative farmer.

1. The Farm Model under the CAP Regime associated with Common Markets Organizations

Consider a farmer i producing a single crop and possessing $\overline{L}_i$ gross land that is decomposed into:

$$\overline{L}_i = \left(1 - b_i^F\right)\overline{L}_i + b_i^F \overline{L}_i$$

where $\left(1 - b_i^F\right)$ is the fraction of gross land used for cultivation and b_i^F the remaining fraction voluntarily set aside (non-production case). For simplicity let $\left(1 - b_i^F\right)\overline{L}_i = L_i^c$.

Crop yields are given by:

$$y_i = f(\mathbf{x}_{ij}, L_i^c) \quad (1)$$

where $\mathbf{x}_{ij}$ is the vector of input choices among a set of $j = 1,...,m$ inputs.[193]

Farming activity i is associated with unintended generation of emission flows (e.g. nitrates leaching):

$$e_i = e(\mathbf{x}_{ij}, L_i^c) \quad (2)$$

that is positively correlated to production.[194]

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[193]It holds $f_x, f_{L^C} > 0$ and $f_{xx}, f_{L^C L^C} < 0$, indicating that crop yields are increasing both in input and land usage, whilst display diminishing returns in both x and L^C. It is considered that $\mathbf{x}_{ij}$ and L^c are complements, in the sense that $f_{x L^C} > 0$, a fact that involves that the marginal product of x is increasing to increases of L^C. Alternatively $f_{b^F} < 0$ and $f_{b^F b^F} > 0$.

In the absence of regulatory intervention the payoff function is:

$$\pi_i = Pf(\mathbf{x}_{ij}, L_i^c) - \mathbf{w}_j \mathbf{x}_{ij}$$

where P is the output price and $\mathbf{w}_j$ the vector of input prices in the competitive market respectively.[195]

Under Agenda 2000 the given crop is eligible both for a production subsidy (s) and two types of direct aid payments (DPs) coupled with the alternative and conflicting land usages, distinguished into:

- A direct payment DP_1 granted on the basis of cultivated land

$$L_i^c \ : \ DP_1 = \sigma_1 L_i^c = \sigma_1\left(1 - b_i^F\right)\overline{L}_i$$

where σ_1 is the premium provided per hectare of cultivated land.

- A direct payment DP_2 granted on the basis of set-aside land

$$\left(\overline{L}_i - L_i^c\right) \ : \ DP_2 = \sigma_2\left(\overline{L}_i - L_i^c\right) = \sigma_2 b^R \overline{L}_i$$

where σ_2 is the premium granted per hectare of set-aside land and $\left(\overline{L}_i - L_i^c\right)$ the size of voluntarily set-aside land. The Commission has defined a certain fraction of land to be compulsory set-aside $\left(b^R\right)$. Hence, farmers setting-aside more land are not eligible for a premium for the additional range $\left(b_i^F - b^R\right)$.[196]

Based on the horizontal regulation, direct payments are conditional on environmental requirements:

- DP_1 is subject to an individual land quality standard, assumed to be expressed by the following constraint:

$$Q_i(e_1, e_2, ..., e_n) \geq \overline{Q}_i \qquad (3)$$

[194] It holds $e_x, e_{L^C} > 0$ and $e_{xx}, e_{L^C L^C} > 0$, with $e_{x L^C} > 0$ given that $\mathbf{x}_{ij}$ and L^c are treated as complements. Alternatively $e_{b^F} < 0$ and $e_{b^F b^F} > 0$.

[195] Land is not included in the vector since it is owned by the farmer.

[196] The additional range can be eligible for a *DP* through an RD program, providing compensation for the afforestation of agricultural land (EC, 2004a).

where Q_i is a decreasing function of emissions' flows,[197] indicating the possibility of strategic interactions among farmers within a geographical area. A typical example of such interaction is the upstream and downstream farmer.[198]

- DP_2 is conditional to a land usage constraint:

$$b^F \geq b^R \text{ or } L_i^c \leq \widetilde{L}^c \qquad (4)$$

where the constraint constant $\widetilde{L}^c = (1-b^R)\overline{L}_i$ represents the maximum permissible size of cultivated land.

Incentives not to attain environmental requirements arise from the non-point-source character of agricultural pollution. The fact that individual production choices are not directly observed by a third party (i.e. regulator) allows individual farmers to retain production choices unchanged and thus avert profit losses that compliance with (3) and (4) entails.[199] Such a deviation from given performance standards cannot always be attributed to deliberate actions but rather sometimes to farmers' negligence to comply. In any case deliberate and negligent deviating behaviour can be detected via the realization of a number of random inspections, given the regulator's inability to inspect simultaneously the entire population of farmers receiving direct payments.

Such a deviating behaviour can be detected under a certain probability p and further deterred via the principle of cross-compliance, which involves reduction or even cancellation of provided direct payments by the amounts:

$$DP_1\gamma(\overline{Q}_i - Q_i) \text{ and } DP_2\gamma(L_i^c - \widetilde{L}^c)$$

where $\gamma \in [0,1]$ denotes the reduction rate. The final reduction of DPs is proportional to deviations from the constraint constant. Hence the higher the deviation is, the more

[197] Given that $Q_{e_i}, Q_{e_i e_i} < 0$ it holds that $Q_x, Q_{L^C} < 0$ and $Q_{xx}, Q_{L^C L^C} < 0$, with $Q_{xL^C} > 0$. Alternatively, $Q_{b^F} > 0$ and $Q_{b^F b^F} < 0$.

[198] Note that in an area characterised by a steep slope the land quality valuation of a farmer located on the top of a hill cannot be adversely affected by the emission flows of a farmer located at the bottom.

[199] The attainment of the land quality target requires the restricted use of inputs $\mathbf{x}_{ij}$ and / or of cultivated land L^c, resulting in a reduction in crop yields. Similarly, the attainment of the land usage target imposes restrictions on the size of cultivated land, also involving reduction in crop yields.

evident deliberate noncompliance, justifying the higher reduction of *DPs* as foreseen by the 2003 CAP reform.

2. Behavioural Strategies under the CAP Regime

Under a CAP regime involving performance standards and a compliance enforcement mechanism, two behavioural rules can be distinguished, depending on farmers' attitude towards environmental constraints. If constraints (3) and (4) enter farmer i's profit maximization problem, then the compliant strategy is considered, while if the constraints do not enter the problem, the possibility of noncompliance with environmental standards is considered and the deviating strategy occurs.

The two maximization problems are:[200]

- **Compliant Strategy**.

$$\max_{\mathbf{x},b^F} \pi_i^C = P(1+s)f(\mathbf{x}_{ij}, L_i^c) - \mathbf{w}_j \mathbf{x}_{ij} + \sigma_1 L_i^c + \sigma_2\left(\overline{L}_i - L_i^c\right) \qquad (5)$$

subject to

$$L_i^c \leq \widetilde{L}^c$$

$$Q_i(e_1, e_2, ..., e_n) \geq \overline{Q}_i$$

- **Deviating Strategy**.

$$\max_{\mathbf{x},b^F} \pi_i^{NC} = P(1+s)f(\mathbf{x}_{ij}, L_i^c) - \mathbf{w}_j \mathbf{x}_{ij} + \sigma_1 L_i^c \left\{1 - p\gamma\left(\overline{Q}_i - Q_i\right)\right\} \qquad (6)$$

$$+\sigma_2\left(\overline{L}_i - L_i^c\right)\left\{1 - p\gamma(\widetilde{L}^c - L_i^c)\right\}$$

where $\left\{1 - p\gamma\left(\overline{Q}_i - Q_i\right)\right\}$ and $\left\{1 - p\gamma(L_i^c - \widetilde{L}^c)\right\}$ represent the net percentage of direct payments provided after the detection of deviation from the imposed constraints and the enforcement of cross-compliance principle.

[200] In the absence of farming standards there is no distinction between compliant and deviating farmer. The maximization problem reduces into: $\max_{\mathbf{x},b^F} \pi_i = P(1+s)f(\mathbf{x}_{ij}, L_i^c) - \mathbf{w}_j \mathbf{x}_{ij} + DP_1 + DP_2$, where Pillar I payments (s, σ_1, σ_2), environmental considerations $\left(\overline{Q}_i, \widetilde{L}^c\right)$ and the compliance enforcement mechanism (p, γ) are considered to be uniform for every farmer.

The generalized nature of the described CAP regime[201] allows the definition of the different CAP regimes via the proper simplifying assumptions. Hence, the environmental performance of the homogeneous population of farmers can be examined in terms of set-aside decision $\left(b_i^F\right)$ and inputs usage $\left(\mathbf{x}_{ij}\right)$ through the problem of a representative farmer i. The analyzed CAP regimes are:

- *Unregulated competitive regime*: $s=0$ and $\sigma_1,\sigma_2=0$. It is the *prior-CAP regime* or a CAP regime characterized by nonprovision of Pillar I payments.
- *Full coupling regime*: $s>0$ and $\sigma_1,\sigma_2=0$. It is the *old regime* providing coupled payments independent of farming standards.
- *Partial decoupled regime*: $s>0$ and $\sigma_1,\sigma_2>0$. It is the *current regime* involving both coupled and decoupled payments, the performance of which is examined under:[202]
    - Absence of land quality and land usage constraints.[203]
    - Existence of land quality and land usage constraints.

  to verify the perception that the link of decoupled payments with environmental constraints restrains farmers' production choices.
- *Full decoupled regime*: $s=0$ and $\sigma_1,\sigma_2>0$. It is the *forthcoming regime*, involving complete cancellation of coupled payments and provision only of direct payments.[204] Its performance is examined both under the (a) absence and (b) existence of farming standards.[205]

[201]It is the regime of partial decoupling denoted below by the indication (3b).

[202]Limited production aid and a supplementary per hectare aid is foreseen for some crop types such as rice, nuts and some protein crops (EC, 2004a).

[203]When examing the performance of the given CAP regime under the deviating rule, the subcase a) is analogous to examining the case of nonenforcement of environmental standards in the sense either that no farmer is inspected $\left(i.e.\ p=0\right)$, or if inspected and found to be deviating from given standards, then no reduction of DPs occurs $\left(i.e.\ \gamma=0\right)$.

[204]This regime already applies for cereals, oilseeds, protein crops, grain legumes, potatoes for starch production, beef, veal and sheepmeat (EC, 2004a).

[205]The Mid-term CAP regime is identical to the full decoupling regime since it involves the provision of DP_s and a single farm payment that is a fixed amount given that it depends on direct payments

2.1 The Maximization Problem under the Compliant Strategy

Given the production choices of the other farmers, farmer i considers, given the choices of the rest farmers, the problem (5) and maximizes the Langrangean function:

$$L(\mathbf{x}_{ij}, b^F, \lambda_1, \lambda_2) = P(1+s) f(\mathbf{x}_{ij}, L_i^c) - \mathbf{w}_j \mathbf{x}_{ij} + \sigma_1 L_i^c + \sigma_2 \left(\overline{L}_i - L_i^c\right)$$
$$+\lambda_1 \left[Q_i(e_1, e_2, ..., e_n) - \overline{Q}_i\right] + \lambda_2 \left[\widetilde{L}^c - L_i^c\right]$$

The Kuhn-Tucker necessary conditions of the problem are given by:

$$FOC_{x_j} : P(1+s)\frac{\partial f(\mathbf{x}_{ij}^*, L_{i*}^c)}{\partial x_{ij}} - w + \lambda_1 \frac{\partial Q_i}{\partial e_i}\frac{\partial e_i\left(\mathbf{x}_{ij}^*, L_{i*}^c\right)}{\partial x_{ij}} = 0 \text{ if } x_{ij}^* > 0 \quad (7)$$

$$\text{or } \frac{\partial L\left(\mathbf{x}_{ij}^*, b_{i*}^F, \lambda_1, \lambda_2\right)}{\partial x_{ij}} < 0 \quad \text{if } x_{ij}^* = 0$$

$$FOC_{b_i^F} : \lambda_2 - \lambda_1 \frac{\partial Q_i}{\partial e_i}\frac{\partial e_i(\cdot)}{\partial L_i^c} - P(1+s)\frac{\partial f(\cdot)}{\partial L_i^c} - \sigma_1 + \sigma_2 = 0 \text{ if } b_{i*}^F > 0 \quad (8)$$

$$\text{or } \frac{\partial L\left(\mathbf{x}_{ij}^*, b_{i*}^F, \lambda_1, \lambda_2\right)}{\partial b_i^F} < 0 \quad \text{if } b_{i*}^F = 0$$

$$FOC_{\lambda_1} : Q_i(e_1, e_2, ..., e_n) - \overline{Q}_i = 0 \quad \text{if } \lambda_1 > 0$$
$$\text{or } Q_i(e_1, e_2, ..., e_n) - \overline{Q}_i > 0 \quad \text{if } \lambda_1 = 0$$
$$FOC_{\lambda_2} : \widetilde{L}^c - L_{i*}^c = 0 \quad \text{if } \lambda_2 > 0$$
$$\text{or } \widetilde{L}^c - L_{i*}^c > 0 \quad \text{if } \lambda_2 = 0$$

By the Envelop Theorem the Langrangean multipliers λ_1 and λ_2 express the marginal cost and benefit resulting from a change in the land quality and usage constraint constant, $\overline{Q}_i$ and $\widetilde{L}^c$ respectively.

Conditions (7) and (8) provide the Nash equilibrium input usage x_{ij}^* and set-aside b_{i*}^F values under the compliant behavioural rule, assuming that such a Nash equilibrium exists, as:[206]

received during the period 2000-2002 and the number of hectares eligible for those payments, leaving thus the analysis unaffected.

[206]The sufficient conditions for maximum are considered to be satisfied.

$$x_{ij}^{*}(P,\mathbf{w}_j,s,\sigma_1,\sigma_2) \text{ and } b_{*}^{F}(P,\mathbf{w}_j,s,\sigma_1,\sigma_2)$$

According to condition (7) farmer i applies input x_{ij} up to the point where the marginal revenues from production equate with the marginal costs from the purchase of the j input and the nonattainment of the land quality constraint $\left(\frac{\partial Q_i}{\partial e_i}\frac{\partial e_i}{\partial x}\lambda_1\right)$. In the same context condition (8) equates marginal revenues in terms of set-aside premium, shadow savings due to compliance with the land quality and the set-aside constraint constants, $\left(-\lambda_1\frac{\partial Q_i}{\partial e_i}\frac{\partial e_i}{\partial L_i^c}+\lambda_2\right)$, with marginal costs in terms of foregone market revenues and foregone land usage premium.

Comparative static analysis indicated that changes in the value of provided CAP payments leave unaffected the optimum production choices $\left(\mathbf{x}_{ij}^{*}, L_{i*}^{c}\right)$ if constraints (3) and (4) are binding. On the other hand, if constraints are nonbinding then the optimum production choices of the population of compliant farmers are affected by marginal changes in the magnitude of coupled and decoupled direct premiums. Particularly:

Proposition 1: *The environmental performance of the population of compliant farmers is enhanced if the CAP regime is characterised by (i) a reduced production subsidy, (ii) reduced land-usage payments, and (iii) an increased land-aside direct premium, facts that restrict the optimum production choices under the compliant strategy.*

Indeed the gradual reduction of both production subsidies and land usage direct payments is foreseen by the current structure of CAP via the principle of dynamic modulation. However, the same principle also involves gradual reduction of set-aside direct payments, introducing uncertainty about the final impact of the current structure of CAP on the environmental performance of the representative compliant farmer and thus on the performance of the associated population.

2.2 Profit Maximization under the Deviating Behaviour

Under the deviating strategy the Kuhn-Tucker conditions are:

$$FOC_{x_{ij}} : P(1+s)\frac{\partial f(\mathbf{x}_{ij}^{\#}, L_{i\#}^{c})}{\partial x_{ij}} - w_j + \sigma_1 L^c p\gamma \frac{\partial Q_i}{\partial e_i}\frac{\partial e_i^{\#}}{\partial x_{ij}} = 0 \quad \text{if} \quad x_{ij}^{\#} > 0 \quad (9)$$

$$\text{or}\ \frac{\partial \pi_i^{NC}}{\partial x_{ij}} < 0 \quad \text{if}\ x_{ij}^{\#} = 0$$

$$FOC_{b^f} : -P(1+s)\frac{\partial f^{\#}}{\partial L_i^c} - \sigma_1\left\{1 - p\gamma\left[\left(\overline{Q}_i - Q_i^{\#}\right) - \frac{\partial Q_i}{\partial e_i}\frac{\partial e_i^{\#}}{\partial L_i^c}L^c\right]\right\} \quad (10)$$

$$+\sigma_2\left\{1 - p\gamma\left(\left(\overline{L}_i - \widetilde{L}^c\right) - 2\left(\overline{L}_i - L_{\#}^c\right)\right)\right\} = 0 \quad \text{if}\ b_{i\#}^F > 0$$

$$\text{or}\ \frac{\partial \pi_i^{NC}}{\partial b_i^F} < 0 \quad \text{if}\ b_{i\#}^F = 0$$

Given the actions of the other farmers, the Nash equilibrium input usage $x_{ij}^{\#}$ and set-aside $b_{i\#}^F$ values under the deviating behavioural rule, as provided by conditions (9) and (10), are given by:[207]

$$x_{ij}^{\#}(P, \mathbf{w}_j, s, \sigma_1, \sigma_2, \gamma, b^R, \overline{Q}_i, p) \text{ and } b_{\#}^F(P, \mathbf{w}_j, s, \sigma_1, \sigma_2, \gamma, b^R, \overline{Q}_i, p)$$

According to condition (9) inputs are applied up to the point where marginal revenues from production equal the marginal costs from input purchase and the reduction of DP_1 due to both detection of deviation from the land quality constraint and enforcement of the cross-compliance principle. Similarly condition (10) defines the set-aside fraction that equates marginal revenues from nonproduction and enhanced land quality defined as the preserved amount of DP_1 payment $\left(\sigma_1 p\gamma\left[\left(\overline{Q}_i - Q_i\right) - \frac{\partial Q_i}{\partial e_i}\frac{\partial e_i}{\partial L_i^c}L_i^c\right]\right)$, with marginal costs in terms of foregone market revenues and land usage premium. The last term can either reflect a marginal cost or revenue depending on the relative size of the voluntary $\left(\overline{L}_i - L_i^c\right)$ and compulsory set-aside land $\left(\overline{L}_i - \widetilde{L}^c\right)$.

Comparative statics analysis indicated that the final impact of the current structure of CAP on the environmental performance of the population of deviating farmers is

[207]It is assumed that the second-order sufficient conditions are satisfied.

ambiguous due to the opposing impact on production choices $\left(\mathbf{x}_{ij}^{\#}, b_{i\#}^{F}\right)$ of the various measures of the Agenda 2000 CAP reform. Even though a reduced production subsidy, along with increased constraint constants b^R and $\overline{Q}_i$, restricts the equilibrium production choices under the deviating strategy,[208] the impact of direct premiums (σ_1, σ_2) and the compliance enforcement mechanism (p, γ) is ambiguous. Hence:

Proposition 2: *The environmental behaviour of the population of deviating farmers is enhanced if the structure of CAP is characterised by:*

i) *An increased land set-aside premium and a stringent compliance enforcement mechanism if the condition* $\left(\overline{L} - L_{\#}^{c}\right) \geq \left(\left(\overline{L} - \widetilde{L}^{c}\right)\right)/2\right)$ *holds.*

ii) *An invariant land set-aside premium and compliance enforcement mechanism if the condition* $\left(\overline{L} - L_{\#}^{c}\right) < \left(\left(\overline{L} - \widetilde{L}^{c}\right)\right)/2\right)$ *holds.*

iii) *An invariant land-usage premium independent of the relative magnitude of* $\left(\overline{L}_i - L_{\#}^{c}\right)$ *and* $\left(\overline{L}_i - \widetilde{L}^{c}\right)$.

If the inspections to verify compliance with environmental standards b^R and Q_i are realized by independent regulatory bodies, then both the inspection probability p and the cross-compliance reduction rate γ may be differentiated across the direct payments of CAP, DP_1 and DP_2. In such a case a strict enforcement mechanism (p_1, γ_1) associated with the land quality direct payment (DP_1) stimulates reduced input and land usage, while in the case of the land usage direct payment (DP_2) the

[208]Under the assumption that $F_{xb^f} < 0$ the results of comparative static analysis are summarized in:

	s	σ_1	σ_2	γ	b^R	$\bar{Q}_i$	p
$x_{ij}^{\#}$	+	?	− (?)	− (?)	−	−	− (?)
$b_{\#}^{F}$	−	?	+ (?)	+ (?)	+	+	+ (?)

where the impact of (σ_2, γ, p) on production choices is clearly assessed if $\left(\overline{L} - L_{\#}^{c}\right) \geq \left(\left(\overline{L} - \widetilde{L}^{c}\right)\right)/2\right)$, while if $\left(\overline{L} - L_{\#}^{c}\right) < \left(\left(\overline{L} - \widetilde{L}^{c}\right)\right)/2\right)$ then their impact is uncertain as indicated by the question marks (?) in the parentheses.

relative impact of (p_2, γ_2) remains dependent on the relative magnitude of the voluntarily and mandatorily set-aside land.

3. Assessment of CAP Regimes associated with CMOs and Behavioural Strategies

Consider two CAP regimes, given as g and h, that involve different types of payments. To compare the equilibrium production choices $(\mathbf{x}_{ig}, b_{ig}^f)$ of regime g with the profit maximizing choices $(\mathbf{x}_{ih}, b_{ih}^f)$ of regime h, the optimality conditions π_x^g and $\pi_{b^f}^g$ of the initial regime are evaluated at the equilibrium choices of the latter. The expressions are:[209]

$$\pi_x^g(\mathbf{x}_{ih}, b_{ih}^f) \text{ and } \pi_{b^f}^g(\mathbf{x}_{ih}, b_{ih}^f)$$

If both expressions are zero then the compared CAP regimes involve the same production choices and thus are identical in environmental terms, while if the expressions are nonzero then deviation in the equilibrium production choices, and thus in the environmental performance, of the regulated population occurs. The performance of the population of farmers under regime g is environmentally inferior to that of regime h, in the sense of higher input usage $(\mathbf{x}_{ig} > \mathbf{x}_{ih})$ and less land-set-aside $(b_{ig}^f < b_{ih}^f)$, if:

$$\pi_x^g(\mathbf{x}_{ih}, b_{ih}^f) > 0 \text{ and } \pi_{b^f}^g(\mathbf{x}_{ih}, b_{ih}^f) < 0$$

while in the opposite case its performance is environmentally superior. mechanism operates in the following way. Assume that under each CAP regime the optimality conditions yield a unique solution that is defined as:[210]

$$\left(\tilde{\mathbf{x}}_i, \tilde{b}_i^f\right): \quad \pi_x(\tilde{\mathbf{x}}_i, \tilde{b}_i^f) = 0 \text{ and } \pi_{b^f}(\tilde{\mathbf{x}}_i, \tilde{b}_i^f) = 0$$

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[209]It holds $\pi_x^h(\mathbf{x}_{ih}, b_{ih}^f), \pi_{b^f}^h(\mathbf{x}_{ih}, b_{ih}^f) = 0$ due to first-order conditions.

[210]This involves that both optimality conditions have a global maximum at $\tilde{\mathbf{x}}_i$ and $\tilde{b}_i^f$ respectively, and they can be both illustrated by an inverse "U" curve.

implying that the farmer i uses both $\mathbf{x}_i$ and L_i^c up to the point that marginal costs are equated with marginal revenues $\left(i.e.\ MC(\tilde{\mathbf{x}}_i, \tilde{b}_i^f) = MR(\tilde{\mathbf{x}}_i, \tilde{b}_i^f) \right)$.

When optimality conditions are evaluated at another pair of production choices, in the sense that $\left(\mathbf{x}_i, b_i^f\right) \neq \left(\tilde{\mathbf{x}}_i, \tilde{b}_i^f\right)$, then there is a divergence between marginal costs and revenues, a fact that involves nonattainment of maximum payoffs. Therefore, if the optimality condition with respect to input usage of regime g is evaluated at the production choices of regime h and yields $\pi_x^g(\mathbf{x}_{ih}, b_{ih}^f) > 0$, this implies that the profits are increasing at the production choices of regime h and therefore these values do not yield the maximum profits. Marginal revenues exceed marginal costs $\left(i.e.\ MC_i^g\left(\mathbf{x}_{ih}, b_{ih}^f\right) < MR_i^g\left(\mathbf{x}_{ih}, b_{ih}^f\right) \right)$, indicating that there is room for a further increase of input usage. The given production choice under regime h falls behind the profit maximizing production choice, in the sense that $\mathbf{x}_{ih} < \tilde{\mathbf{x}}_{ig}$. Hence, regime g is considered to be environmentally inferior for the given production choice. On the other hand, if $\pi_x^g(\mathbf{x}_{ih}, b_{ih}^f) < 0$ then profits are decreasing at the production choices of regime h and therefore this regime is characterized by excess input use.

Findings are summarized in the following table.[211]

$\Delta x_h^g = (x_g - x_h)$					
$g \setminus h$	2	3_a	3_b	4_a	4_b
1	−	−	?	0	+
2		0	+	+	+
3_a			+	+	+
3_b				?	+
4_a					+

$\Delta(b^f)_h^g = \left(b_g^f - b_h^f\right)$				
2	3_a	3_b	4_a	4_b
+	?	?	?	?
	?	?	?	?
		− (?)	−	−
			?	−
				− (?)

(1) unregulated competitive regime (UN), (2) full coupling regime (FC), (3) partial decoupled regime (PD) under the absence (3a) and presence (3b) of land quality and

[211] Analysis is carried out both under the compliant and deviating strategy, providing the same results regarding input usage $\left(\Delta x_j^i\right)$. Only in two cases in the $\left(\Delta\left(b^f\right)_j^i\right)$ table is the indication modified under the deviating strategy denoted in parentheses.

usage constraints, (4) full decoupled regime (FD) under the (4a) absence and (4b) existence of environmental considerations.[212]

Nonintervention (UN) is preferable on environmental grounds to intervention via coupled payments (FC), since it can be verified that the population of farmers is induced to employ both less inputs and land:[213]

$$\pi_x^1(\mathbf{x}_2^*, b_2^{*f}) = \left\{ P(1+s)\frac{\partial f(\mathbf{x}_2^*, L_2^{*c})}{\partial x} - w \right\} - Ps\frac{\partial f(\cdot)}{\partial x} = -Ps\frac{\partial f_2^*}{\partial x} < 0$$

$$\pi_{b^f}^1(\mathbf{x}_2^*, b_2^{*f}) = \left\{ -P(1+s)\frac{\partial f(\mathbf{x}_2^*, L_2^{*c})}{\partial L_i^c} \right\} + Ps\frac{\partial f(\mathbf{x}_2^*, L_2^{*c})}{\partial L_i^c} = Ps\frac{\partial f_2^*}{\partial L_i^c} > 0$$

Even though the FC regime is clearly environmentally inferior compared to the rest of the CAP regimes in terms of input usage, the relative performance of the population of both compliant and deviating farmers in set-aside terms is ambiguous. Hence:

Conclusion 1: *There is no clear evidence that the transition from the FC regime to the regime of partially or fully decoupled payments (i.e. Agenda 2000 regimes) can induce the population of regulated farmers to enhance their environmental performance compared to the old regime with respect to the land set-aside decision, whilst there is evidence that the transition has led to an environmentally superior performance of farmers with respect to the input usage.*

In the same context:

Conclusion 2: *Intervention via decoupled payments (FD) is environmentally preferable in terms of both inputs and set-aside to intervention via a combination of coupled and decoupled payments (PD), under both the absence and presence of farming standards, indicating the distorting role of production subsidies on farmers' production choices.*

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[212] Indication (-) in the Δx_h^g table implies that regime h involves higher input usage, while the same indication in the $\Delta\left(b^f\right)_h^g$ table denotes that regime h sets aside more land. Indication (0) denotes that the examined regimes involve the same level of the given production choice, while (?) that their relative performance is uncertain.

[213] Where $\pi_x^2(\mathbf{x}_2^*, L_2^{*c}) = P(1+s)f_x^*\left(x_2^*, L_2^{*c}\right) - w = 0$ and $\pi_x^2(\mathbf{x}_2^*, L_2^{*c}) = -P(1+s)f_{L^c}^* = 0$.

The incorporation of such standards within the direct payment regime has enhanced the environmental performance of the population of compliant farmers under both the PD and FD regimes, while there is uncertainty about their exact impact on the production choices of the population of deviating farmers. Undoubtedly the provision of DPs, as well as the introduction of farming constraints, restrain input usage compared to the UN and FC regimes, however their final impact on the set-aside decision is ambiguous given that DPs are associated with conflicting land usages.

The given procedure is further employed to compare the compliant and deviating strategy by evaluating the optimality conditions of the representative deviating farmer at the equilibrium values of the compliant strategy:

$$\pi_x^{\#}(\mathbf{x}_{ij}^*, b_{i*}^f) = \{\sigma_1 L_{i*}^c p\gamma - \lambda_1\}\frac{\partial Q_i}{\partial e_i}\frac{\partial e_i(\mathbf{x}_{ij}^*, L_{i*}^c)}{\partial x_j} \tag{11}$$

$$\begin{aligned}\pi_{b^F}^{\#}(\mathbf{x}_{ij}^*, b_{i*}^f) = \sigma_1 p\gamma\left[\left(\overline{Q}_i - Q_i^*\right) - \frac{\partial Q_i}{\partial e_i}\frac{\partial e_i^*}{\partial L_i^c}L_{i*}^c\right] + \lambda_1\frac{\partial Q_i}{\partial e_i}\frac{\partial e_i^*}{\partial L_i^c} \\ - \lambda_2 - \sigma_2 p\gamma\left[\left(\overline{L}_i - L_{i*}^c\right) - 2\left(\overline{L}_i - \widetilde{L}^c\right)\right]\end{aligned} \tag{12}$$

As it can be seen by conditions (11) and (12), if the partial or full decoupling CAP regime is characterized by non-enforcement of constraints, in the sense that either no inspection is realized to verify compliance $(i.e.\ p = 0)$ or no detected deviating farmer is penalized $(i.e.\ \gamma = 0)$, then the deviating strategy is environmentally inferior. In particular, if p or $\gamma = 0$ it holds:

$$(11){:}\ \pi_x^{\#}(\mathbf{x}_{ij}^*, b_{i*}^f) = \left\{-\lambda_1\frac{\partial Q_i}{\partial e_i}\frac{\partial e_i(\mathbf{x}_{ij}^*, L_{i*}^c)}{\partial x_j}\right\} > 0 \quad \rightarrow\ \mathbf{x}_{ij}^* < \mathbf{x}_{ij}^{\#}$$

$$(12){:}\ \pi_{b^F}^{\#}(\mathbf{x}_{ij}^*, b_{i*}^f) = \left\{\lambda_1\frac{\partial Q_i}{\partial e_i}\frac{\partial e_i^*}{\partial L_i^c} - \lambda_2\right\} < 0 \qquad \rightarrow\ b_{i*}^f > b_{i\#}^f$$

indicating that the deviating strategy involves higher usage of both inputs $\mathbf{x}_i$ and land L_i^c. Such an environmentally inferior behaviour may also be observed even under the existence of a compliance enforcement mechanism, indicating that the introduction of such an enforcement mechanism by Agenda 2000 may not sufficient to induce the adoption by the regulated population of a behaviour tending to the compliant rule. In particular, if p,γ are sufficiently small, in the sense that $p,\gamma \gg 0$, then the deviating strategy involves higher input and land usage if it simultaneously holds:

$$\pi_x^{\#}(\mathbf{x}_{ij}^*, b_{i*}^f) > 0 \quad \rightarrow \ \mathbf{x}_{ij}^* < \mathbf{x}_{ij}^{\#} \quad \text{if } \left\{\sigma_1 L_{i*}^c p\gamma - \lambda_1\right\} < 0$$

and,

$$\pi_{b^F}^{\#}(\mathbf{x}_{ij}^*, b_{i*}^f) < 0 \quad \rightarrow \ b_{i*}^f > b_{i\#}^f \quad \text{if:}$$

$$\text{i) } \left\{\lambda_1 Q_{L^c}^* - \lambda_2\right\} > p\gamma\left\{\sigma_1\left[\left(\bar{Q}_i - Q_i^*\right) - Q_{L^c}^* L_{i*}^c\right] - \sigma_2\left[\left(\bar{L}_i - L_{i*}^c\right) - 2\left(\bar{L}_i - \tilde{L}^c\right)\right]\right\}$$
$$\text{and } \left(\bar{L}_i - L_{i*}^c\right) < 2\left(\bar{L}_i - \tilde{L}^c\right), \text{ or}$$
$$\text{ii) } \left\{\lambda_1 Q_{L^c}^* - \lambda_2 - \sigma_2 p\gamma\left[\left(\bar{L}_i - L_{i*}^c\right) - 2\left(\bar{L}_i - \tilde{L}^c\right)\right]\right\} > \sigma_1 p\gamma\left[\left(\bar{Q}_i - Q_i^*\right) - Q_{L^c}^* L_{i*}^c\right]$$
$$\text{and } \left(\bar{L}_i - L_{i*}^c\right) \geq 2\left(\bar{L}_i - \tilde{L}^c\right).$$

where $Q_{L^c}^* = \left(\partial Q_i / \partial e_i\right)\left(\partial e_i^* / \partial L_i^c\right)$.

Hence, it can be concluded that:

Conclusion 3: *In the absence of the cross-compliance mechanism or even under the existence of a lax enforcement mechanism, the relationship between the production choices of the compliant and deviation farmer are characterized by:*

$$\pi_x^{\#}(\mathbf{x}_{ij}^*, b_{i*}^f) > 0 \ \text{ with } \mathbf{x}_{ij}^* < \mathbf{x}_{ij}^{\#} \text{ and}$$
$$\pi_{b^f}^{\#}(\mathbf{x}_{ij}^*, b_{i*}^f) < 0 \ \text{ with } b_{i*}^f > b_{i\#}^f \ \text{ if } p \text{ or } \gamma \geq 0$$

where p,γ are sufficiently small if considered to be nonzero.[214]

Under the generalized CAP regime the signs of (11) and (12) are uncertain, implying that in equilibrium the deviating strategy may involve less input and land usage to the compliant rule. In particular, the deviating farmer applies less inputs compared to a compliant farmer either if the land quality constraint (3) is nonbinding involving $\lambda_1 = 0$, or if the marginal costs resulting from a marginal increase of input usage defined in terms of forgone direct payment on land usage are higher than the

[214] Moreover, the same inequalities are expected to occur either under the absence of a regime of direct payment or under the existence of a lax regime of direct payments.

associated marginal benefits resulting from the nonattainment of the land quality constraint $\left(i.e.\ \sigma_1 L^c_{i*} p\gamma \frac{\partial Q_i}{\partial e_i}\frac{\partial e^*_i}{\partial x_j} > -\lambda_1 \frac{\partial Q_i}{\partial e_i}\frac{\partial e^*_i}{\partial x_j} \right)$. Similarly the deviating strategy involves higher set-aside fraction if the associated cost-benefit analysis indicates that a marginal decrease in the size of cultivated land stimulates higher marginal benefits than costs. Nevertheless, analysis considers that $x^* < x^\#$ and $L^c_* < L^c_\#$.

4. The Farm Model under the CAP Regime associated with Rural Development

The function of crop yields (1) and emission flows (2) is redefined as:

$$y_i = f(\mathbf{x}_{ij}, L^c_i, \ell_i) \text{ and } e_i = e_i(\mathbf{x}_{ij}, L^c_i, \overline{L} - L^c_i, \ell_i)$$

where ℓ represents either hired or family labour.

Given the environmental requirements incorporated in DP_1, the population of farmers complies with the land quality constraint $\overline{Q}_i$ by either restricting main production choices $(\mathbf{x}_{ij}, L^c_i, \ell_i)$ or by treating them in an environmentally benign way via secondary production choices that are disassociated by production but directly related with emission flows abatement. Let $\mathbf{t}_i = (\mathbf{t}^x_{ij}, t^{nc}_i, t^c_i, t^\ell)$ be the vector of the secondary production choices established by farmer i, which are distinguished into:

- *Treatments of inputs* (i.e. advanced irrigation) reduce the impact of inputs on emission flows *as if* the farmer has employed fewer inputs in production. Given that $\frac{\partial e_i}{\partial x_{ij}} > 0$, the vector of effective input usage in emission generation is:

  $$\mathbf{x}^e_{ij} = (1 - \mathbf{t}^x_{ij})\mathbf{x}_{ij} \text{ with } \frac{\partial e_i}{\partial x^e_{ij}} > 0$$

  where $\mathbf{t}^x_{ij} = (t^x_{i1}, t^x_{i2}, ..., t^x_{im})$ is the vector of undertaken treatments per unit of input used.

- *Treatments of cultivated land* (i.e. contour farming, conservation tillage, terracing) reduce emission flows *as if* the farmer had set less land into production. Given that $\frac{\partial e_i}{\partial L^C} > 0$, the effective land usage in emission generation is:

$$L_c^e = \left(1 - t_i^c\right) L_i^c \ \text{ with } \frac{\partial e_i}{\partial L_c^e} > 0$$

- *Treatments of land set-aside* (i.e. non-fertilised grass strips, hedges, trees, watercourses, ditches) make set-aside land more effective in emission abatement *as if* the farmer has set aside more land. Given that $\frac{\partial e_i}{\partial L^{nc}} < 0$, the effective set-aside land in emission generation is:

$$L_{nc}^e = \left(1 + t_i^{nc}\right)\left(\overline{L} - L_i^c\right) \ \text{ with } \frac{\partial e_i}{\partial L_{nc}^e} < 0$$

- *Treatments of labour* (i.e. vocational training, advisory services) affect the impact of labour (ℓ) on both crop yields and emission flows. Let ℓ_y^e be the effective labour in crop yields generation and ℓ_e^e the effective labour in emission generation, involving:

$$\ell_y^e = (1 + t^\ell)\ell \ \text{ with } \frac{\partial y_i}{\partial \ell_y^e} > 0 \ \text{ and } \ \ell_e^e = (1 - t^\ell)\ell \ \text{ with } \frac{\partial e_i}{\partial \ell_e^e} > 0$$

  Even though t^ℓ is classified with secondary choices, it is a mixed production choice affecting both crop yields and emission flows.

The production and emission functions are modified into:

$$y_i = f(\mathbf{x}_{ij}, L_i^c, \ell_y^e) \ \text{ and } \ e_i = e\left(\mathbf{x}_{ij}^e, L_c^e, L_{NC}^e, \ell_e^e\right)$$

Treatments involve costs that can either be self-financed fully $\left(TC_i^o\right)$ or partially $\left(TC_i^{RD}\right)$ through a rural development (RD_i) program – in the form of a public VA - involving the granting of subsidies per unit of undertaken treatment. The associated costs are respectively given:

$$TC_i^o = \mathbf{r}_j \mathbf{t}_{ij}^x + \kappa t_i^{nc} + c t_i^c + d t^\ell$$
$$TC_i^{RD} = TC^o - RD_i = \mathbf{r}_j \left(1 - s^x\right) \mathbf{t}_{ij}^x + \kappa\left(1 - s^{nc}\right) t_i^{nc} + c\left(1 - s^c\right) t_i^c + d\left(1 - s^\ell\right) t^\ell$$

where $\mathbf{r}_j$ is the vector of the per unit cost of the m input usage treatments and s^x the associated per unit subsidy characterized by $1 > s^x > 0$,[215] κ and s^{nc} are the per unit cost and subsidy of t_i^{nc}, c and s^c the per unit cost and subsidy of t_i^c, while d and s^ℓ the per unit cost and subsidy of t^ℓ in the competitive market. Finally, $RD_i = \mathbf{r}_j s^x \mathbf{t}_{ij}^x + \kappa s^{nc} t_i^{nc} + c s^c t_i^c + d s^\ell t^\ell$ represents the amount of payments provided by Pillar II to the representative farmer i.

RD payments are subject to both performance standards and the cross-compliance principle, involving a probabilistic reduction (or even cancellation) of provided rural development payments by the amount:

$$\widetilde{R}Dp\gamma\left(\overline{Q}_i - Q_i\right)$$

where $\widetilde{R}D = \mathbf{r}_j s^x \mathbf{t}_{ij}^x + \kappa s^{nc} t_i^{nc} + c s^c t_i^c = RD - d s^\ell t^\ell$ given that the aid for vocational training is not conditional to the land quality constraint.

Under a RD program the alternative maximization problems are:[216]

- **Compliant Strategy.**

$$\begin{aligned} \max \pi_i^C &= P(1+s) f(x_i, L_i^c, (1+t^\ell)\ell) - wx - v\ell + \sigma_1 L^c \\ &+\sigma_2\left(\overline{L} - L^c\right) - \left(TC^o - RD\right) \\ &\text{subject to} \\ &L^c \le \widetilde{L}^c \\ &Q_i(e_1, e_2, ..., e_n) \ge \overline{Q}_i \end{aligned}$$

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[215]The provided s^x is uniform for each t_{ij}^x treatment.

[216]In the absence of farming standards in the provision of DPs and RD payments the maximization problems reduce to:

$$\pi_i = P(1+s) f(x_i, L_i^c, (1+t^\ell)\ell) - \mathbf{w}_j \mathbf{x}_{ij} - v\ell + DP_1 + DP_2 - \left(TC^o - RD\right)$$

Given that the amount of undertaken vocational training is predetermined by the Commission, training cannot be a choice variable. Thus t^{ℓ} represents advice and $s^{\ell}=0$.

- **Deviating Strategy.**

$$\max \pi_i^{NC} = P(1+s)f(x_i, L_i^c, (1+t^{\ell})\ell) - wx - v\ell - TC^o + ds^{\ell}t^{\ell}$$
$$+\left[\sigma_1 L^c + \widetilde{R}D\right]\left\{1 - p\gamma\left(\overline{Q}_i - Q_i\right)\right\} + \sigma_2\left(\overline{L} - L^c\right)\left\{1 - p\gamma(\widetilde{L}^c - L^c)\right\}$$

Optimality conditions indicate that nonzero secondary production choices allow both for increased usage of $\left(\mathbf{x}_{ij}, L_i^c, \ell_i\right)$ along with attainment of the land quality constraint.

Comparisons between the environmental performance of the regulated population under the various CAP regimes in terms of main and secondary production choices are conducted, where the set of examined regimes is enriched by: (i) *extended full coupling regime*, involving the granting of both coupled and Pillar II payments, (ii) *extended partial decoupling regime* characterised by coupled, decoupled and RD payments, (iii) *extended full decoupling regime* that provides decoupled and RD payments, and (v) *rural development regime* involving only rural development subsidies.[217]

In the extended case regime g is environmentally inferior to regime h, in the sense that it involves both higher usage of the main production choices $\left(i.e.\ \left(\mathbf{x}_{ij}^g, L_{ig}^c, \ell_i^g\right) > \left(\mathbf{x}_{ij}^h, L_{ih}^c, \ell_i^h\right)\right)$ and less usage of secondary production choices $\left(i.e.\ \left(\mathbf{t}_{ij}^{xg}, t_{ig}^{nc}, t_{ig}^{c}, t_{ig}^{\ell}\right) < \left(\mathbf{t}_{ij}^{xh}, t_{ih}^{nc}, t_{ih}^{c}, t_{ih}^{\ell}\right)\right)$, if the following inequalities are simultaneously satisfied:

$$\pi_x^g(\mathbf{q}_{ih}, \mathbf{t}_{ih}), \pi_{\ell}^g(\mathbf{q}_{ih}, \mathbf{t}_{ih}) > 0 \text{ and } \pi_{b^f}^g(\mathbf{q}_{ih}, \mathbf{t}_{ih}) < 0$$

$$\pi_{t^x}^g(\mathbf{q}_{ih}, \mathbf{t}_{ih}), \pi_{t^c}^g(\mathbf{q}_{ih}, \mathbf{t}_{ih}), \pi_{t^{nc}}^g(\mathbf{q}_{ih}, \mathbf{t}_{ih}), \pi_{t^{\ell}}^g(\mathbf{q}_{ih}, \mathbf{t}_{ih}) < 0\,.$$

[217] Findings are summarized in tables (1) - (4) available in Appendix II.

where for simplicity let $\mathbf{q}_{ih} = \left(\mathbf{x}_{ij}^{h}, L_{ih}^{c}, \ell_{i}^{h}\right)$ be the vector of main production choices under the regime h, while $\mathbf{t}_{ih} = \left(\mathbf{t}_{ij}^{xh}, t_{ih}^{nc}, t_{ih}^{c}, t_{ih}^{\ell}\right)$ is the vector of the associated secondary production choices.

Analysis indicated that if CAP regimes associated with CMOs are extended with RD payments, the environmental performance of the population of farmers is enhanced relative to the case where no RD payments are provided. On the other hand, regimes involving production subsidies involve higher labour usage treatment to regimes providing either decoupled and / or Pillar II payments, since higher t^{ℓ} allows farmers both to attain the land quality standard and increase the received amount of coupled payments.

Despite the environmental benefits arising from the second pillar of CAP, there is no clear evidence that the transition from the FC regime to the regime of partially or fully decoupled payments (i.e. Agenda 2000 regimes), and ultimately to the rural development CAP regime (i.e. 2003 CAP reform), enhances the environmental performance of farmers' population. In particular, when evaluating the optimality conditions of the initial CAP regime (i.e. full coupling) at the equilibrium production choices of the rural development regime, there is clear evidence that it involves higher usage of the main production choices, in the sense that $\mathbf{q}_{2}^{i*} > \mathbf{q}_{8b}^{i*}$, since it simultaneously holds:

$$\pi_{x}^{2}(\mathbf{q}_{8b}^{i*}, \mathbf{t}_{8b}^{i*}) = \left\{ Ps \frac{\partial f_{i}^{*}}{\partial x} - \lambda_{1} \frac{\partial Q_{i}}{\partial e_{i}} \frac{\partial e_{i}^{*}}{\partial x} \left(1 - t_{8b}^{ix}\right) \right\} > 0$$

$$\pi_{b^f}^{2}(\mathbf{q}_{8b}^{i*}, \mathbf{t}_{8b}^{i*}) = \left\{ -Ps \frac{\partial f_{i}^{*}}{\partial L_{i}^{c}} + \lambda_{1} \frac{\partial Q_{i}}{\partial e_{i}} \left[\frac{\partial e_{i}^{*}}{\partial L_{c}^{e}} \left(1 - t_{8b}^{c}\right) - \frac{\partial e_{i}^{*}}{\partial L_{nc}^{e}} \left(1 + t_{8b}^{c}\right) \right] \right\} < 0$$

$$\pi_{\ell}^{2}(\mathbf{q}_{8b}^{i*}, \mathbf{t}_{8b}^{i*}) = \left\{ -\lambda_{1} \frac{\partial Q_{i}}{\partial e_{i}} \frac{\partial e_{i}^{*}}{\partial \ell} \left(1 - t_{8b}^{\ell}\right) \right\} > 0$$

On the other hand, their relative environmental performance in terms of secondary production choices is ambiguous. Even though the RD regime involves higher usage of the secondary production choices $\left(\mathbf{t}_{ij}^{xh}, t_{ih}^{nc}, t_{ih}^{c}\right)$, its relative performance in terms of t_{ih}^{ℓ} is uncertain. It can be easily verified:

$$\pi_{t^x}^2(\mathbf{q}_{8b}^{i*}, \mathbf{t}_{8b}^{i*}) = \left\{-rs^x + \lambda_1 \frac{\partial Q_i}{\partial e_i} \frac{\partial e_i^*}{\partial x_i^e} x\right\} < 0$$

$$\pi_{t^c}^2(\mathbf{q}_{8b}^{i*}, \mathbf{t}_{8b}^{i*}) = \left\{cs^c - \lambda_1 \frac{\partial Q_i}{\partial e_i} \frac{\partial e_i^*}{\partial L_c^e} L^c\right\} < 0$$

$$\pi_{t^{nc}}^2(\mathbf{q}_{8b}^{i*}, \mathbf{t}_{8b}^{i*}) = \left\{\kappa s^{nc} - \lambda_1 \frac{\partial Q_i}{\partial e_i} \frac{\partial e_i^*}{\partial L_{nc}^e}\left(\overline{L} - L^c\right)\right\} < 0$$

$$\pi_{t^\ell}^2(\mathbf{q}_{8b}^{i*}, \mathbf{t}_{8b}^{i*}) = \left\{Ps \frac{\partial f_i}{\partial \ell_y^e} \ell + \lambda_1 \frac{\partial Q_i}{\partial e_i} \frac{\partial e_i^*}{\partial \ell_e^e} \ell\right\} < 0 \quad \text{if } Ps \frac{\partial f_i}{\partial \ell_y^e} \ell < \lambda_1 \frac{\partial Q_i}{\partial e_i} \frac{\partial e_i^*}{\partial \ell_e^e} \ell$$

Hence, on the whole the environmental performance under the RD regime cannot be clearly inferred as superior to the relative environmental performance under the FC regime. In a similar way is assessed the relative environmental performance of the full coupling regime compared to the partially and fully decoupled CAP regime, providing identical results. Finally, even in the absence of an enforcement mechanism or the presence of a lax mechanism, the environmental performance of the deviating to the compliant strategy is uncertain.[218]

II.2 Design of Optimal Policies

After assessing the relative environmental effectiveness of the various CAP subregimes, the design of optimal regulatory policies is discussed in this section. In the analysis we use the alternative analytical framework of unbounded and bounded rationality by considering the mechanism that provides the type of the optimal CAP instruments that ensure the collective attainment of a social environmental target, along with the type of interdependence characterizing them.

1. Assessment of Optimal Static CAP Measures

[218] The deviating rule involves less t^{ℓ}, higher usage $\left(\mathbf{x}_{ij}, L_i^c, \ell_i\right)$, while its performance in $\left(\mathbf{t}_{ij}^{x}, t_i^{C}, t_i^{nc}\right)$ terms is uncertain.

associated with Common Markets Organizations

Individual emission flows affect aggregate land quality $\left(Q^T\right)$ defined as:

$$Q^T = H(Q_1, Q_2, ..., Q_n)$$

where deviations from an aggregate land quality reference level $\overline{Q}^T$ impose external costs on the society:

$$D(\overline{Q}^T - Q^T)$$

The social planner or a regulator wishes to define the vectors of production choices $\left(\overline{\mathbf{x}}^{SP}, \mathbf{b}^f_{SP}\right)$ that maximize the net social benefit (*NSB*) from farming activity:[219]

$$\max_{x,b} NSB = \max_{x,b^f} \int_0^{\sum y} F(u)du - \mathbf{w}_{\mathbf{j}}\overline{\mathbf{x}} - D(Z) \qquad (13)$$

where $y = \sum_{i=1}^{n} f(\mathbf{x}_{ij}, L_i^c)$ is aggregate crop yields, $F(u)$ aggregate demand, while $\mathbf{w}_j\mathbf{x}$ is the aggregate purchase costs of the m inputs $\left(i.e. \sum_{\mathrm{i}=1}^{\mathrm{n}} \sum_{j=1}^{m} \mathbf{w}_{ij}\mathbf{x}_{ij}\right)$. For simplicity let $Z = \left(\overline{Q}^T - Q^T\right)$.[220]

The associated Kuhn-Tucker conditions are:[221]

$$FOC_{x_j}^{SP} : P\frac{\partial f(\mathbf{x}_{ij}, L_i^c)}{\partial x_i} - w + \frac{\partial D}{\partial Z}\frac{\partial Q^T}{\partial Q_i}\frac{\partial Q_i}{\partial e_i}\frac{\partial e_i(\mathbf{x}_{ij}, L_i^c)}{\partial x_i} = 0 \text{ if } x_i^{SP} > 0 \qquad (14)$$

$$\text{or } \frac{\partial NSB}{\partial x_i} < 0 \quad \text{if } x_i^{SP} = 0$$

$$FOC_{b^F}^{SP} : -P\frac{\partial f(\mathbf{x}_{ij}, L_i^c)}{\partial L_i^c} - \frac{\partial D}{\partial Z}\frac{\partial Q^T}{\partial Q_i}\frac{\partial Q_i}{\partial e_i}\frac{\partial e_i(\mathbf{x}_{ij}, L_i^c)}{\partial L_i^c} = 0 \text{ if } b_{iSP}^f > 0 \qquad (15)$$

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[219] Let $\overline{\mathbf{x}}^{SP} = \left(\mathbf{x}_1^{SP}, \mathbf{x}_2^{SP}, ..., \mathbf{x}_n^{SP}\right)$ and $\overline{\mathbf{b}}^f_{SP} = \left(b_{SP}^{f1}, b_{SP}^{f2}, ..., b_{SP}^{fn}\right)$ be the vectors of the socially optimal input and set-aside choices respectively of each $i = 1, 2, ..., n$ farmer.

[220] It holds $D_Z, D_{ZZ} > 0$, or equivalently $D_{Q^T} < 0$ and $D_{Q^TQ^T} > 0$.

[221] It is assumed that the second-order-conditions are satisfied.

$$\text{or } \frac{\partial NSB}{\partial b_i^f} < 0 \quad \text{if } b_{iSP}^f = 0$$

defining the socially optimal production choices for the representative farmer i, which when adopted by the entire population of farmers would result into the first-best aggregate land quality Q_{SP}^T. Condition (15) is assumed to have an interior solution for the socially optimum set-aside decision $\left(i.e.\ b_{SP}^f > 0\right)$. If the marginal productivity of land is too high or if its marginal social damage is too low, the socially optimum b_{SP}^f is on the boundaries $\left(i.e.\ \frac{\partial \mathrm{SW}}{\partial \mathrm{Q}^{\mathrm{T}}} < 0 \text{ and } b_{SP}^f = 0\right)$ and any increase in set-aside land reduces social welfare given the land usage constraint involved by Agenda 2000. To avoid, however, complexities it is assumed that b_{SP}^f is nonzero, as well as that compliant farmers' production choices match with socially optimum choices.[222]

1.1 Optimal Static CAP Measures associated with CMOs

Under unbounded rationality for the farmers the optimality conditions of the social planner and the representative deviating farmer define a system that provides both the type of CAP measures, as well as the type of correlation between Agenda 2000 measures, which induce the population of deviating farmers to adopt the socially optimal choices $\left(\mathbf{x}_i^{SP}, b_{SP}^f\right)$.The system is given as:[223]

$$P(1+s)\alpha_1^{\#} + \sigma_1 L_{\#}^c p\gamma\beta_1^{\#} = P\alpha_1^{SP} + \delta_1 \tag{16}$$

$$\alpha_2^{SP}\left[\sigma_2\{1 - p\gamma B\} - \sigma_1\{1 - p\gamma A\}\right] = -(1+s)\alpha_2^{\#}\delta_2 \tag{17}$$

[222]It is assumed that $\pi_x^C(\mathbf{x}_i^{SP}, b_{SP}^f), \pi_{b^f}^c(\mathbf{x}_i^{SP}, b_{SP}^f) = 0.$

[223]Let $\alpha_1^{SP}, \alpha_2^{SP}, \beta_1^{SP}, \beta_2^{SP}$ and $\alpha_1^{\#}, \alpha_2^{\#}, \beta_1^{\#}, \beta_2^{\#}$ represent the impact of the social and individual optimum production choices on crop yields and individual land quality respectively, while δ_1, δ_2 denote the impact of social optimum choices on social damage. We define: $\alpha_1^{SP} = f_x^{SP}$, $\alpha_2^{SP} = f_{L^c}^{SP}$ and $\beta_1^{SP} = Q_x^{SP}$, $\beta_2^{SP} = Q_{L^C}^{SP}$, $\alpha_1^{\#} = f_x^{\#}$, $\alpha_2^{\#} = f_{L^c}^{\#}$ and $\beta_1^{\#} = Q_x^{\#}$, $\beta_2^{\#} = Q_{L^c}^{\#}$, as well as $\delta_1 = D_x^{SP}$ and $\delta_2 = D_{L^c}^{SP}$, which at the equilibrium are known and thus treated as parameters. Also, $A = \left[\left(\overline{Q}_i - Q_i^{\#}\right) - \beta_2 L_{i\#}^c\right]$ and $B = \left\{1 - p\gamma\left(2(\overline{L}_i - L_{i\#}^c) - \left(\overline{L}_i - \widetilde{L}^c\right)\right)\right\}$.

where condition (16) is defined by setting equal the optimality condition (9) of the unbounded rational deviating farmer and regulator's optimality condition (14),[224] while condition (17) resulted from the equalization of the conditions (15) and (10).[225]

To simplify the analysis production choices are restricted into a single input (x) and the set-aside decision. There is however an indeterminacy in the definition of optimal CAP measures. A unique determination of CAP instruments requires an equal number of production choices and measures. In this case CAP measures are more than externalities. For instance the optimum coupled payments and land usage premium are defined for fixed values of the rest of the CAP measures as:[226]

$$\bar{s} = \frac{1}{P\alpha_1^{\#}}\left[P\left(\alpha_1^{SP} - \alpha_1^{\#}\right) + \delta_1 - \bar{\sigma}_1 L_{\#}^c p\gamma\beta_1^{\#}\right] \tag{18}$$

$$\bar{\sigma}_1 = \frac{\left\{\alpha_2^{SP}\sigma_2\{1 - p\gamma B\} + \alpha_2^{\#}\delta_2\left(1 + \frac{\delta_1}{P\alpha_1^{\#}} + \frac{\alpha_1^{SP} - \alpha_1^{\#}}{\alpha_1^{\#}}\right)\right\}}{\left\{\alpha_2^{SP}\{1 - p\gamma A\} + \frac{\alpha_2^{\#}}{P\alpha_1^{\#}}\delta_2 L_{\#}^c p\gamma\beta_1^{\#}\right\}} \tag{19}$$

The sign of both expressions is uncertain,[227] implying that the simultaneous cancellation of coupled payments and DP_1 payment, which means $\bar{s} = \bar{\sigma}_1 = 0$, is socially optimal if both nominators are equal to zero. In particular:

Proposition 3: *The optimum CAP regime involves gradual cancellation of coupled payments:*

i) *If under* $\left(\alpha_1^{SP} \geq \alpha_1^{\#}\right)$ *the marginal revenues* $\left(P\left(\alpha_1^{SP} - \alpha_1^{\#}\right) - \bar{\sigma}_1 L_{\#}^c p\gamma\beta_1^{\#}\right)$ *from the adoption of the social optimum input usage value defined in terms of additional*

[224] To do so, both conditions are restructured as, (9): $w = P(1+s)\alpha_1^{\#} + \sigma_1 L_{\#}^c p\gamma\beta_1^{\#}$ and (14): $w = P\alpha_1^{SP} + \delta_1$.

[225] To do so, both conditions are rewritten as, (10): $P = \left[\sigma_2\{1 - p\gamma B\} - \sigma_1\{1 - p\gamma A\}\right] / \left\{(1+s)\alpha_2^{\#}\right\}$ and (15): $P = (-\delta_2)/\alpha_2^{SP}$ respectively.

[226] Let $\alpha_1^{SP} = f_x\left(\mathbf{x}_{ij}^{SP}, L_{SP}^c\right)$ and $\alpha_1^{\#} = f_x\left(\mathbf{x}_{ij}^{\#}, L_{\#}^c\right)$ represent the impact of the social and individual optimum production choices on crop yields.

[227] In both expressions the denominators are positive, while the sign of the nominators is uncertain.

market revenues and retained land usage direct payments equal the marginal costs of incurred social damage (δ_1), *or*

ii) *If under* $\left(\alpha_1^{SP} < \alpha_1^{\#}\right)$ *the marginal revenues* $\left(-\overline{\sigma}_1 L_{\#}^{c} p\gamma\beta_1^{\#}\right)$ *in terms of the retained land usage direct payment equal the marginal cost* $\left(P\left(\alpha_1^{SP} - \alpha_1^{\#}\right) + \delta_1\right)$ *in terms of foregone market revenues and incurred social damage.*

Hence, if both (18) and (19) are zero, the optimum CAP regime is characterised by nonintervention if no set-aside premium is provided $(\sigma_2 = 0)$, while if $\sigma_2 \neq 0$ it involves only set-aside premiums. On the other hand, if both (18) and (19) are nonzero, then depending on the sign of the nominators:

Proposition 4: *The optimum CAP regime involves intervention via partially decoupled measures of the form either of:*

i) *Premiums* $(\overline{s}, \overline{\sigma}_1 > 0)$ *both on crop yields and land usage if both nominators are positive, or*

ii) *Charges* $(\overline{s}, \overline{\sigma}_1 < 0)$ *both on crop yields and land usage if both nominators are nonpositive.*

In the latter case such kinds of penalties are not included in the current structure of CAP, which implies the possibility of suboptimalities in the policy design relative to the social optimum aggregate land quality target $\overline{Q}^{T}$.

Farmers' production choices are affected by a marginal change of a given CAP instrument, requiring optimal CAP instruments $(\overline{s}, \overline{\sigma}_1)$ to be analogously modified. The type of interdependencies between the optimal CAP pair $(\overline{s}, \overline{\sigma}_1)$ and the rest of the instruments of the 1999 reform is assessed, by estimating the total derivatives of (18) and (19) with respect to the remaining instruments:[228]

[228] Where $G = \left(\alpha_2^{SP}\{1 - p\gamma A\} + \dfrac{\alpha_2^{*}}{P\alpha_1^{*}}\delta_2 L_{\#}^{c} p\gamma\beta_1^{\#}\right) > 0$, $H = \alpha_2^{SP}\sigma_2 BG + \left(\alpha_2^{SP} A - \dfrac{\alpha_2^{*}}{\alpha_1^{*}}\delta_2 L_{\#}^{c}\beta_1^{\#}\right) R$, $R = \alpha_2^{SP}\sigma_2\{1 - p\gamma B\} + \alpha_2^{\#}(1 + \frac{\delta_1}{P\alpha_1^{\#}})\delta_2 + \delta_2\left(\alpha_1^{SP} - \alpha_1^{\#}\right)\left(\alpha_2^{*}/\alpha_1^{*}\right)$

$$\frac{d\overline{\sigma}_1}{d\sigma_2} = \frac{\alpha_2^{SP}\sigma_1(1-p\gamma B)}{G} \text{ and } \frac{d\overline{s}}{d\sigma_2} = \frac{1}{P\alpha_1^{\#}}\left[-p\gamma\beta_1^{\#}\frac{d\overline{\sigma}_1}{d\sigma_2}\right]$$

$$\frac{d\overline{\sigma}_1}{dp} = \frac{-\gamma H}{G^2} \text{ and } \frac{d\overline{s}}{dp} = \frac{1}{P\alpha_1^{\#}}\left[P\left(\alpha_1^{SP}-\alpha_1^{\#}\right)+\delta_1-\gamma\beta_1^{\#}\left(\overline{\sigma}_1-\frac{d\overline{\sigma}_1}{dp}\right)\right]$$

$$\frac{d\overline{\sigma}_1}{db^R} = \frac{-\alpha_2^{SP}p\gamma\overline{L}_i}{G} \text{ and } \frac{d\overline{s}}{db^R} = \frac{1}{P\alpha_1^{\#}}\left[P\left(\alpha_1^{SP}-\alpha_1^{\#}\right)+\delta_1-p\gamma\beta_1^{\#}\frac{d\overline{\sigma}_1}{db^R}\right]$$

$$\frac{d\overline{\sigma}_1}{d\overline{Q}_i^{'}} = \frac{-\alpha_2^{SP}p\gamma R}{G^2} \text{ and } \frac{d\overline{s}}{d\overline{Q}_i^{'}} = \frac{1}{P\alpha_1^{\#}}\left[P\left(\alpha_1^{SP}-\alpha_1^{\#}\right)+\delta_1-p\gamma\beta_1^{\#}\frac{d\overline{\sigma}_1}{d\overline{Q}_i^{'}}\right]$$

There is interdependence between the optimal coupled payment and land usage premium, since the impact of a given CAP measure on $\overline{s}$ is affected by its prior impact on $\overline{\sigma}_1$. Optimal σ_1 is negatively correlated to the land usage constraint constant, while there is complementarity between the optimal pair $(\overline{\sigma}_1, \overline{s})$ and the set-aside premium if $\left(\overline{L}_i - L_i^c\right) \geq \left(\left(\overline{L}_i - \widetilde{L}^c\right)2\right)$.[229] However, the type of interdependence between the optimal pair of CAP instruments and the remaining CAP measures cannot be clearly inferred. This implies that the optimal CAP pair $(\overline{\sigma}_1, \overline{s})$ may not always be modified properly following changes of CAP measures such as the enforcement mechanism (p, γ), leading to production choices that deviate from the socially optimal choices $\left(\mathbf{x}_i^{SP}, b_{SP}^f\right)$.

Hence, to avoid having the regulated population of farmers adopt a suboptimal environmental performance diverging from the aggregate land quality target $\overline{Q}^T$, the social planner needs to:

Proposition 5: *Precommit to the chosen structure of regulatory policy and offer assurances to regulated agents that he will not change both the optimal CAP pair* $(\overline{s}, \overline{\sigma}_1)$ *and the rest of the CAP elements for a given time period as long as there is no technological change.*

[229] The impact of b^R on $\overline{s}$ is ambiguous. If $\left(\overline{L} - L^c\right) < \left(\left(\overline{L} - \widetilde{L}^c\right)/2\right)$ the correlation between the optimal pair and σ_2 is uncertain. Such an uncertain context is also observed regarding the exact impact of σ_2, $\overline{Q}_i^{'}$ and p (or γ) on both $(\overline{\sigma}_1, \overline{s})$.

Such a CAP regime is characterised by "non-surprise" features in the sense that none of the CAP measures is modified for a given time period.

The socially optimal $(\bar{s}, \bar{\sigma}_2)$ and $(\bar{s}, \bar{\gamma})$ CAP pairs are respectively determined for given values of the remaining CAP measures. In particular, the optimum land set-aside premium $\bar{\sigma}_2$ is given by:

$$\bar{\sigma}_2 = \left\{\alpha_2^{SP}\sigma_1\left\{1 - p\gamma A\right\} + \alpha_2^{\#}\delta_2\left(1+\bar{s}\right)\right\} \Big/ \left\{\alpha_2^{SP}\left(1 - p\gamma B\right)\right\}$$

The sign of the expression $\bar{\sigma}_2$ is uncertain,[230] implying that the provision of a set-aside premium may not always be the socially optimal type of intervention. In particular:

Proposition 6: *The optimum CAP regime involves intervention on the basis of set-asided land of the form of:*

i) *A premium* $(\bar{\sigma}_2 > 0)$ *either if the denominator is positive or if the enforcement mechanism of performance standards is insufficient or nonexistent* $(p,\gamma \gg 0 \text{ or } p,\gamma = 0)$.

ii) *A charge* $(\bar{\sigma}_2 < 0)$ *if the denominator is nonpositive.*

On the other hand, the optimal cross-compliance rate $\bar{\gamma}$ resulting from the optimal CAP pair $(\bar{s}, \bar{\gamma})$ is defined as:[231]

$$\bar{\gamma} = \left\{\alpha_2^{SP}\left(\sigma_1 - \sigma_2\right) + \frac{\alpha_2^{\#}}{\alpha_1^{\#}}\left[\delta_2\left(\alpha_1^{SP} - \alpha_1^{\#}\right) + \frac{1}{P}\delta_1\delta_2\right] + \alpha_2^{\#}\delta_2\right\} \Big/$$
$$\left\{p\left[\alpha_2^{SP}\left(\sigma_2 B - \sigma_1 A\right) + \sigma_1 L_{\#}^{c}\beta_1^{\#}\delta_2\frac{\alpha_2^{\#}}{P\alpha_1^{\#}}\right]\right\}$$

where the sign of the expression $\bar{\gamma}$ is uncertain.[232] This implies that in the event of detected non-compliance a proportional reduction of provided *DPs* $(i.e.\ \bar{\gamma} > 0)$ may

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[230] The nominator is positive, while the sign of the denominator is ambiguous.

[231] The socially optimal inspection probability $\bar{p}$ can be equivalently assessed by replacing γ by the term p.

not always be the socially optimal type of intervention. In particular, if the nominator is equal to zero then no action should be undertaken to enforce the performance standards since it is socially optimal to proceed in no reduction of provided direct payments $\left(i.e.\ \bar{\gamma}=0\right)$, while if both the nominator and denominator are nonzero then:

Proposition 7: *The optimum CAP regime involves intervention in the event of detected non-compliance of the form of:*

i) *A proportional reduction of provided direct payments* $\left(\bar{\gamma}>0\right)$ *if both the nominator and denominator are positive (or negative).*

ii) *A proportional increase of provided direct payments* $\left(\bar{\gamma}<0\right)$ *if the nominator and denominator have reverse signs.*

Given, however, that measures like a charge on land set-aside $\left(i.e.\ \bar{\sigma}_2<0\right)$ and a nonpositive cross-compliance rate $\left(i.e.\ \bar{\gamma}<0\right)$, are not foreseen by Agenda 2000, the current structure of CAP may not be able to induce the population of deviating farmers to adopt the socially optimal choices $\left(\mathbf{x}_i^{SP}, b_{SP}^f\right)$ and thus the attainment of the social optimum aggregate land quality target is infeasible.

2. Assessment of CAP Regimes in a Dynamic Context

In a dynamic context the distinction between unbounded and bounded rationality is more evident in the employed analytical framework. Under unbounded rationality the dynamic problem of the social planner is considered to define the mechanism for the design of the dynamic socially optimal CAP instruments, while under the assumption of bounded rational farmers an evolutionary context is employed to assess the policy effectiveness of Agenda 2000 by defining the type and range of values of CAP measures inducing the majority or even all farmers to adopt the compliant strategy.

2.1 Optimal Dynamic CAP Measures associated with CMOs

[232]The sign of both the nominator and denominator is uncertain.

Consider a social planner seeking to define the optimal path of $\left(\mathbf{x}^{SP},\mathbf{b}^{f}_{SP}\right)$ production choices that maximize the current value of net social benefit from farming activity subject to a transition equation describing the evolution of aggregate land quality. The maximization problem is:

$$\max_{x,b^f}\int_0^\infty e^{-rt}\left[\int_0^{\Sigma y}F(u)du-\mathbf{wx}-D(Z)\right]dt$$
$$st.\ \dot{Q}^T=g(\mathbf{x},\mathbf{L}^C)+h\left(Q^T\right)$$

where $g(\mathbf{x},\mathbf{L}^C)$ are the collective emissions generated each period t and $h\left(Q^T\right)$ is a concave "growth" function indicating nature's ability to enhance land quality that attains an interior maximum.[233] Note that $Z=\left(\overline{Q}^T-Q^T\right)$.

The current value Hamiltonian function is defined as:

$$H=\int_0^{\Sigma y}F(u)du-\mathbf{wx}-D(Z)+\mu\left[g(\mathbf{x},\mathbf{L}^C)+h\left(Q^T\right)\right]$$

where $\mu(t)$ is the dynamic shadow value of the aggregate land quality Q^T that is nonnegative ($i.e.$ $\mu>0$).

The Pontryagin necessary conditions for optimality are:

$$FOC_x^{SP}:P\frac{\partial f(x_i,L_i^c)}{\partial x}-w+\frac{\partial D}{\partial Z}\frac{\partial Q^T}{\partial Q_i}\frac{\partial Q_i}{\partial e_i}\frac{\partial e_i}{\partial x_i}+\mu\frac{\partial g}{\partial e_i}\frac{\partial e_i}{\partial x_i}=0\ \text{if}\ x_i^{SP}>0$$
$$\text{or}\ \frac{\partial H}{\partial x}<0\quad \text{if}\ x_i^{SP}=0$$

$$FOC_{\mathbf{b}^F}^{SP}:-P\frac{\partial f(x_i,L_i^c)}{\partial L_i^c}-\frac{\partial D}{\partial Z}\frac{\partial Q^T}{\partial Q_i}\frac{\partial Q_i}{\partial e_i}\frac{\partial e_i}{\partial L_i^c}-\mu\frac{\partial g}{\partial e_i}\frac{\partial e_i}{\partial L_i^c}=0\ \text{if}\ b_{SP}^f>0$$
$$\text{or}\ \frac{\partial H}{\partial b^f}<0\quad \text{if}\ b_{SP}^f=0$$

$$\dot{\mu}=\mu(r-\frac{\partial h}{\partial Q^T})-\frac{\partial D}{\partial Z}$$
$$\dot{Q}^T=g(\mathbf{x},\mathbf{L}^C)+h\left(Q^T\right)$$

[233] Where $\mathbf{L}^C=(L_1^c,L_2^c,...,L_n^c)$ is the vector of individual choices regarding land usage. Aggregate emissions flows can also be given as $g(\mathbf{x},\mathbf{L}^C)=\sum_{i=1}^n e_i(x_i,L_i^c)$.

and the Arrow type transversality condition at infinity is:

$$\lim_{t\to\infty} \exp(-rt)\mu(t)Q^T(t) = 0$$

Under the assumption that farmers systematically ignore the evolution of Q^T (i.e. myopic informational structure)[234] the system defining the dynamic social optimum CAP measures is:[235]

$$P(1+s)\alpha_1^{\#} + \sigma_1 L_{\#}^c p\gamma\beta_1^{\#} = P\alpha_{1d}^{SP} + \delta_{1d} - \mu\varphi_{1d} \qquad (20)$$

$$\alpha_{2d}^{SP}\left[\sigma_2\{1-p\gamma B\} - \sigma_1\{1-p\gamma A\}\right] = -(1+s)\alpha_2^{\#}\{\mu\varphi_{2d} + \delta_{2d}\} \qquad (21)$$

which is similar to the static system (16) and (17). It is evident that the expressions of the dynamic and static optimum CAP measures that induce the population of unboundedly rational farmers to adopt the socially desired production choices and thus deliver the desired aggregate land quality level are identical. The only modification is the term containing the Hamiltonian multiplier (μ) that is zero in the static context.

2.2 Farmers' Compliance and Dynamic CAP Measures associated with CMOs

Assume that farmers are subject to dynamic socially optimum CAP measures. Under bounded rationality farmers have imperfect knowledge about the true structure of payoffs; they choose between the two predetermined strategies (i.e. compliant and non-compliant strategy) based on individual perceptions and information revealed via their interaction over time.

Thus, if individual farmers take CAP measures as given, then the socially optimum production choices $\left(x_i^{SP}, L_{iSP}^c\right)$ are adopted and these farmers comply with the land-quality and land-usage constraints. However, if it is perceived that the announced

[234] Farmers face a static problem, either (5) or (6), according to the behavioural rule.

[235] Let $\alpha_{1d}^{SP}, \alpha_{2d}^{SP}, \delta_{1d}, \delta_{2d}, \phi_{1d}, \phi_{2d}$ represent the impact of the dynamic social optimum production choices on crop yields, social damage and aggregate emission flows. In particular, it holds: $\alpha_{1d}^{SP} = f_x^{SP}$, $\alpha_{2d}^{SP} = f_{L^c}^{SP}$, $\delta_{1d} = D_x^{SP}$, $\delta_{2d} = D_{L^c}^{SP}$ and $\phi_{1d} = g_x^{SP}$, $\phi_{2d} = g_{L^c}^{SP}$.

enforcement mechanism (p,γ) is not effective and that the anticipated inspection probability (p^a) and reduction rate (γ^a) are either sufficiently small or even equal to zero, then a suboptimal pair of production choices $(x^\#, L^c_\#)$ is adopted, stimulating deviation from farming standards. It implies that:

$$\text{if } (\bar{p},\bar{\gamma}) > (p^a,\gamma^a) \geq 0 \text{ then } (x^*_i, L^c_{i*}) < (x^\#_i, L^c_{i\#})$$

and the population of farmers is divided into two subgroups, where z is the proportion of farmers adopting the compliant strategy, while $(1-z)$ is the deviating proportion. Given that farmers learn the true structure of payoffs via their interactions, the proportion of farmers adopting the complying strategy evolves in time according to the rule of replicator dynamics. Hence, under the generalized CAP regime the evolution of the compliant strategy is given by:

$$\dot{z} = z(1-z)\left(\pi_i^C - \pi_i^{NC}\right) \tag{22}$$

with

$$\begin{aligned}\pi_i^C - \pi_i^{NC} &= P(1+s)\Delta^*_\#(f(x,L^c_i)) - w\Delta^*_\#(x) + (\sigma_1-\sigma_2)\Delta^*_\#(L^c_i) \\ &\quad + p\gamma\left[\sigma_1 L^c_\#\left(\overline{Q}_i - Q_i(x,L^c_\#)\right) + \sigma_2\left(\overline{L}_i - L^c_\#\right)\left(L^c_\# - \widetilde{L}^c\right)\right]\end{aligned}$$

where $(\pi_i^C - \pi_i^{NC})$ is the payoff divergence of the compliant and deviating strategy.[236]

The critical points of (22) provide evolutionary stable fractions of compliant farmers $(\hat{z})$. It involves a monomorphic steady state characterized either by full compliance $(\hat{z}_1 = 1)$ or full deviation $(\hat{z}_2 = 0)$. A polymorphic steady state characterized by partial compliance $(\hat{z} \in (0,1))$ may also exist if CAP measures are equal to the critical values that make zero the profit divergence $\Omega = \left(\pi_i^C - \pi_i^{NC}\right)$.

The type of the prevailing steady state depends on the profit divergence $(\pi_i^C - \pi_i^{NC})$ as can be seen by the stability condition:

[236] Profit divergence consists of four elements: (i) the divergence of market revenues and coupled payments, (ii) the divergence of input purchase costs, (iii) the divergence of *DPs*, and (iv) the amount of *DPs* removed by farmers if found violating farming standards incorporated in direct payments regime.

$$\frac{d\dot{z}}{dz} = (1-2z)\Omega$$

Given that the social planner's ultimate target is to induce full compliance with farming standards, the stability requirement $\left.\frac{d\dot{z}}{dz}\right|_{\hat{z}_1=1} < 0$ is satisfied if the CAP instruments $(s,\sigma_1,\sigma_2,p,\gamma)$ are selected to turn the compliant strategy more profitable than the deviating, setting thus the profit divergence $\Omega(s,\sigma_1,\sigma_2,p,\gamma)$ positive. To define the type and the range of values of the various CAP instruments that make Ω nonnegative and stimulated full compliance of the population, the critical values $(\widetilde{s},\widetilde{\sigma}_1,\widetilde{\sigma}_2,\widetilde{p},\widetilde{\gamma})$ of CAP measures that set the divergence Ω equal to zero, along with their marginal impacts on the expression $\Omega(\widetilde{s},\widetilde{\sigma}_1,\widetilde{\sigma}_2,\widetilde{p},\widetilde{\gamma}) = 0$ are respectively assessed. Two cases are examined:

Case 1:

Consider that both compliant and deviating farmers are myopic and "hard wired" to their strategy in the sense that the impact of CAP measures on production choices is negligent. In such a case the type and range of values of the coupled payment $\widetilde{s}$ satisfying the requirement $\Omega = 0$ is given by:

$$\widetilde{s} = \frac{1}{P\Delta^*_\#(f(x,L^c_i))}\left[w\Delta^*_\#(x) - (\sigma_1-\sigma_2)\Delta^*_\#(L^c_i) - p\gamma\Xi\right] - 1 \qquad (23)$$

$$\frac{d\Omega(\widetilde{s})}{ds} = P\Delta^*_\#(f(x,L^c_i)) \qquad (24)$$

where $\Xi = \left[\sigma_1 L^c_\#\left(\bar{Q}_i - Q_i(x,L^c_\#)\right) + \sigma_2\left(\bar{L} - L^c_\#\right)\left(L^c_\# - \tilde{L}^c\right)\right]$.

Given that $x^* < x^\#$ and $L^c_* < L^c_\#$ the expression (24) is negative implying that compliance of the entire population of farmers is eventually attainable if $s \in [0,\widetilde{s})$. If s is set equal to the critical value $\widetilde{s}$ then partial compliance $(\hat{z}_3)$ may emerge in the long-run steady state. Then:

Proposition 8: Full compliance of the regulated population emerges if the dynamic CAP regime involves:

i) *A subsidy on crop yields if simultaneously* $\sigma_1 > \sigma_2$ *and* $0 < \left[w\Delta_{\#}^{*}(x) - (\sigma_1 - \sigma_2)\Delta_{\#}^{*}(L_i^c) - p\gamma\Xi\right] > P\Delta_{\#}^{*}\left(f\left(x, L^C\right)\right)$ hold.

ii) A *penalty on crop yields if* $\sigma_1 \leq \sigma_2$.

However, in the case where (23) involves a penalty on crop yields, such an instrument is not foreseen by the current CAP structure, and the attainment of the full compliance target is infeasible.

The type and range of values of direct payments $(\tilde{\sigma}_1, \tilde{\sigma}_2)$ and cross-compliance reduction rate $(\tilde{\gamma})$ inducing full compliance are also assessed involving similar findings.

Case 2:

Farmers' production choices are affected by changes in CAP measures, and optimal choices under both strategies are:

$$x_i^{*}(P, w, s, \sigma_1, \sigma_2) \text{ and } b_{i*}^{F}(P, w, s, \sigma_1, \sigma_2)$$
$$x_i^{\#}(P, w, s, \sigma_1, \sigma_2, \gamma, b^R, \overline{Q}_i, p) \text{ and } b_{i\#}^{F}(P, w, s, \sigma_1, \sigma_2, \gamma, b^R, \overline{Q}_i, p)$$

and the replicator dynamic equation (22) is modified into:

$$\dot{z} = z(1-z)\left(\pi_i^{C}(P, w, s, \sigma_1, \sigma_2, \gamma, b^R, \overline{Q}_i, p) - \pi_i^{NC}(P, w, s, \sigma_1, \sigma_2, \gamma, b^R, \overline{Q}_i, p)\right)$$

let

$$\Delta_{\#}^{*}(x) = x^{*}(P, w, s, \sigma_1, \sigma_2) - x^{\#}(P, w, s, \sigma_1, \sigma_2, \gamma, b^R, \overline{Q}_i, p)$$
$$\Delta_{\#}^{*}\left(L_i^c\right) = L_{*}^{c}(P, w, s, \sigma_1, \sigma_2) - L_{\#}^{c}(P, w, s, \sigma_1, \sigma_2, \gamma, b^R, \overline{Q}_i, p)$$
$$\Delta_{\#}^{*}(f(x, L_i^c)) = f(x^{*}(\cdot), L_{*}^{c}(\cdot)) - f(x^{\#}(\cdot), L_{\#}^{c}(\cdot))$$

The type and range of values of given CAP measures satisfying the full compliance requirement $\Omega(P, w, s, \sigma_1, \sigma_2, \gamma, b^R, \overline{Q}_i, p) > 0$ provide identical expressions to case 1 for the critical values. The expressions describing the marginal impact of CAP measures on profit divergence Ω are altered and depend, among other things, on the impact of the examined measure on farmers' production choices under the alternative strategies. In particular, the impact of the critical coupled payment $\widetilde{s}$ on $\Omega = 0$ is given by:

$$\frac{d\Omega(\widetilde{s})}{ds} = P(1+s)\Delta^*_{\#}\left(\frac{\partial f}{\partial x}\frac{\partial x}{\partial s} - \frac{\partial f}{\partial b^f}\frac{\partial b^f}{\partial s}\overline{L}_i\right) - w\Delta^*_{\#}\left(\frac{\partial x}{\partial s}\right) \tag{25}$$

$$-p\gamma\sigma_1\left\{L^c_{\#}\left(\frac{\partial Q^{\#}_i}{\partial x}\frac{\partial x^{\#}}{\partial s} - \frac{\partial Q^{\#}_i}{\partial b^f}\frac{\partial b^f_{\#}}{\partial s}\right) + \frac{\partial b^f_{\#}}{\partial s}\overline{L}_i\left(\overline{Q}_i - Q^{\#}_i\right)\right\}$$

$$+\sigma_2\frac{\partial b^f_{\#}}{\partial s}\overline{L}_i\left[(\overline{L}_i - \widetilde{L}^c) - 2(\overline{L}_i - L^c_{\#})\right] - (\sigma_1 - \sigma_2)\Delta^*_{\#}\left(\frac{\partial b^f}{\partial s}\overline{L}_i\right)$$

which depends on the marginal impact of s on input and land usage $\left(i.e. \frac{\partial \mathrm{x}}{\partial \mathrm{s}} \text{ and } \frac{\partial \mathrm{b}^{\mathrm{F}}}{\partial \mathrm{s}}\right)$ under both strategies, turning the assessment of the sign of (25) infeasible given the informational requirements. Furthermore, it is evident that the attainment of full compliance from a given population of farmers with environmental considerations requires continuous change of the dynamic socially optimal CAP instruments. However, in practice dynamic CAP measures are neither time invariant nor allow for discrete changes over time, leading to suboptimal solutions.

3. Optimal Policy Design under the CAP Regime associated with Rural Development

Static and dynamic optimality analysis under the assumption of unbounded rationality, along with evolutionary dynamics analysis under the assumption of bounded rationality, indicated also that charges on secondary production choices instead of subsidies may be socially optimal, turning the CAP regime involved by Mid-term Review (i.e. rural development regime) socially suboptimal. In each case the type of the social optimal Pillar II CAP instruments, as well as the type of correlation between the various CAP instruments, is assessed though the following mechanisms:

3.1 Assessment of Optimal Static CAP Measures associated with RD

In a static context the social planner seeks to define the socially optimal equilibrium values for both the main and secondary production choices, given as $\left(\widetilde{\mathbf{x}}_i^{SP}, \widetilde{b}_{SP}^{f}, \widetilde{\ell}_{SP}\right)$ and $\left(\widetilde{\mathbf{t}}_{SP}^{x}, \widetilde{t}_{SP}^{c}, \widetilde{t}_{SP}^{nc}, \widetilde{t}_{SP}^{\ell}\right)$, so that the net social benefit from agricultural activities is maximized and thus the first-best level of aggregate land quality Q_{SP}^{T} is attained. The maximization problem of the social planner is:

$$\max_{\mathbf{x}, b^F, \ell, t^x, t^c, t^{nc}, t^\ell} \int_0^{\Sigma y} F(u)du - \mathbf{w}_{\mathbf{j}}\mathbf{x} - \mathbf{v}\ell - \mathbf{TC} - D(Z)$$

where $\left(\mathbf{TC} = \sum_{i=1}^{n}\left(\sum_{j=1}^{m}\mathbf{r}_j\mathbf{t}_{ij}^{x} + \kappa t_i^{nc} + ct_i^{c} + dt_i^{\ell}\right)\right)$ are the aggregate costs associated with secondary production choices, whilst $\left(\mathbf{v}\ell = \sum_{i=1}^{n} v\ell_i\right)$ the aggregate labour costs.

The optimality conditions of the deviating farmer and the social planner define a system, the solution of which provides the type of the socially optimal CAP instruments, as well as the type of correlation between them, that induce the representative farmer to adopt the socially optimal production choices. To simplify analysis the set of production choices of farmer i is restricted to three choice variables, for instance a single input $\left(x_{ij}\right)$ and land usage $\left(b_i^f\right)$, along with the decision of the treatment $\left(t_{ij}^x\right)$ on the usage of the x_{ij} input, while the rest of the production choices are treated as fixed. Thus, the system is given by:[237]

$$P(1+s)\alpha_1 + \left[\sigma_1 L^c + \widetilde{R}D\right]p\gamma\beta_1\beta_i\left(1-t^x\right) = P\alpha_1^{SP} + \delta_1\beta_i\left(1-\widetilde{t}_{SP}^{x}\right) \quad (26)$$

$$\alpha_2^{SP}\left[\sigma_2\{1-p\gamma B\} - \sigma_1\{1-p\gamma A\} + \left[\sigma_1 L^c + \widetilde{R}D\right]p\gamma\beta_i\left(\beta_2\left(1-t^c\right) - \beta_3\left(1+t^{nc}\right)\right)\right]$$
$$= (1+s)\alpha_2\beta_i\left[\delta_3\left(1+\widetilde{t}_{SP}^{nc}\right) - \delta_2\left(1-\widetilde{t}_{SP}^{c}\right)\right] \quad (27)$$

$$\left[\sigma_1 L^c + \widetilde{R}D\right]p\gamma\beta_1\beta_i\widetilde{x}^{SP} + rs^x\{1-p\gamma A\} - rs^x = \delta_1\beta_i\widetilde{x}^{SP} \quad (28)$$

[237] Let $\alpha_1^{SP}, \alpha_2^{SP}$ and $\alpha_1, \alpha_2, \beta_1, \beta_2, \beta_3$ represent the impact of the social and individual optimum production choices on crop yields and individual land quality respectively, while $\delta_1, \delta_2, \delta_3$ denote the impact of socially optimum choices on social damage. The expressions $\beta_3 = Q_{L^c}$ and $\delta_3 = D_{L^c}$ are both positive and represent the impact of set-aside decision on individual land quality and social damage respectively.

the solution of which defines the type of RD CAP instruments that induce the adoption of the social optimally production choices $\left(\tilde{x}_i^{SP}, \tilde{b}_{SP}^{f}, \tilde{t}_{SP}^{x}\right)$. Our analysis indicated that the maximization of the social welfare criterion may require that charges are imposed on farmers instead of farmers being provided subsidies on given production choices (such as crop yields, land usage and established input usage treatments). However, given the fact that such charges are not involved in the Agenda 2000 structure, the attainment of the first-best aggregate land quality target is infeasible.

3.2 Assessment of Optimal Dynamics CAP Measures associated with RD

Under the assumption that individual farmers are unbounded rational but do not take into account the evolution of aggregate land quality Q^T, the social planner aims to define the optimal path of both main and secondary production choices so as to maximize the current value of the net social benefit from agricultural activities subject to the evolution of aggregate land quality. The associated maximization problem is given by:

$$\max_{\mathbf{x}_{ij}, L_i^c, \ell, \mathbf{t}_{ij}^x, t_i^c, t_i^{nc}, t_i^\ell} \int_0^\infty e^{-rt}\left[\int_0^{\Sigma y} F(u)du - \mathbf{w}_\mathbf{j}\mathbf{x} - \mathbf{v}\ell - \mathbf{TC} - D(Z)\right]dt$$
$$st.\ \dot{Q}^T = b\left(Q^T\right) - g(\mathbf{x}, \mathbf{L}^C)$$

After following the standard procedure a system similar to the static system (26) – (28) is obtained, the solution of which provides the type of the dynamic socially optimum CAP measures.

Under bounded rationality the type and range of values of the socially optimal rural development CAP measures are assessed by employing the evolutionary framework, where the associated replicator dynamic equation is:[238]

$$\dot{z} = z(1-z)\left(\pi_i^C - \pi_i^{NC}\right)$$
with
$$\begin{aligned}
&\pi_i^C - \pi_i^{NC} = \\
&P(1+s)\Delta_{NC}^C(f(x, L_i^c, (1+t^\ell)\ell)) - w\Delta_{NC}^C(x) - v\Delta_{NC}^C(\ell) \\
&-\Delta_{NC}^C\left(TC^o\right) + (\sigma_1 - \sigma_2)\Delta_{NC}^C\left(L_i^c\right) + \Delta_{NC}^C(RD) \\
&+p\gamma\left[\left(\sigma_1 L^c + \widetilde{R}D\right)\left(\overline{Q}_i - Q_i^{NC}\right) + \sigma_2\left(\overline{L}_i - L^c\right)\left(L^c - \widetilde{L}^c\right)\right]
\end{aligned}$$

which is similar to the expression (22) defined under the provision solely of CMOs payments. As expected our analysis indicated that the attainment of the target of full

[238] The profit divergence between the compliant and deviating strategy is decomposed into the following elements: (i) the divergence of market revenues and coupled payments, (ii) the divergence of purchase costs of input and land usage, as well as the establishment and maintenance costs of treatments, (iii) the divergence of direct payments and provided rural development subsidies, and (iv) the amount of decoupled payments and rural development subsidies removed if deviation from the environmental considerations incorporated in direct payments regime is detected.

compliance may not always be feasible since the assessed critical rural development payments $\left(i.e.\ s^x\right)$ may involve penalties on established treatments, instruments that however are not foreseen by the current CAP structure.

Conclusions

Common Agricultural Policy measures are classified among the factors responsible for the imbalance in the agricultural-environment relation. Following widespread criticism, CAP reformers introduced the Agenda 2000 CAP reform that is considered to be pioneering from an environmental aspect. Given that limited theoretical analysis regarding the environment impacts and the long term viability of this regime has been undertaken, a conceptual theoretical model of farming behaviour was developed to embody the basic reforms for the common market organizations and rural development. The generalized nature of the provided model allowed the assessment of the impacts of the various CAP regimes characterised either by CMOs payments (i.e. full coupling, partial and full decoupling regime), RD payments (i.e. rural development regime) or a combination of CMOs and RD payments (i.e. extended full coupling, partial and full decoupling regime), on the environmental performance of a representative farmer, and thus of a homogeneous population, in terms of primary and / or secondary production choices. The policy effectiveness of Agenda 2000 was evaluated by analysing the problem of optimal regulation of a population of unboundedly rational agents both in a static and dynamic context, allowing the assessment of the type of socially optimal Pillar I and Pillar II measures, along with type of interdependence characterizing them. Finally, the long-run viability of the 1999 CAP reform was assessed under the assumption of boundedly rational agents through the framework of replicator dynamics.

Intervention via decoupled payments under both the absence and presence of farming standards is environmentally preferable in terms of main production choices to intervention via a combination of coupled and decoupled payments. However, when the set of production choices is extended with secondary production choices, then the relative environmental performance of the population under the given CAP regimes of payments cannot be clearly inferred. There is no clear evidence that the transition initially from the full coupling regime to the intervention regime involving partial or full decoupling of Pillar I payments both in the absence and provision of rural development payments (i.e. Agenda 2000 regimes), and ultimately to the intervention regime involving solely the provision of second pillar payments (i.e. Mid-term review), induces the population of farmers to restrict main production choices and increase secondary choices. Nevertheless, it is evident that the incorporation of farming constraints and rural development measures enhances the environmental performance of the regulated population.

The definition of socially optimal CAP measures associated with CMOs and RD in both a static and dynamic context indicated that it may be socially desirable on environmental grounds not only to maintain coupled payments but also to impose on farmers a set of charges on the various aspects of farming activity: crop yields, land-usage, set-aside-land and / or secondary production choices related to emission flows abatement. Given that such measures are not foreseen in the current structure of CAP and that the attainment of first-best aggregate land quality requires time-flexible CAP measures associated with CMOs and RD, suboptimalities occur and both the effectiveness and long-run viability of Agenda 2000 and Mid-term review CAP reforms is doubtful and depends on existing conditions.

CHAPTER III: Design of Public Voluntary Environmental Programs for Nitrate Pollution in Agriculture: An Evolutionary Approach

The joint evolution of participation and compliance of farmers in a rural development program, in the form of a public voluntary agreement, along with the evolution of the pollution stock, is examined in this chapter. Replicator dynamics, modelling participation and compliance, are combined with pollution stock dynamics. Fast-slow selection dynamics are used to capture the fact that distinct decisions to participate in and comply with the second pillar program evolve in different time scales. Conditions for evolutionary equilibria and evolutionary stable strategies regarding participation and compliance are derived. Budget constraints associated with monitoring costs are also introduced into the analysis to assess their impact on participation and compliance decisions.

1. Agricultural Environment and Voluntary Approaches

Voluntary approaches (VAs) to environmental regulation have been regarded as an alternative instrument to pollution control. They are expected to increase economic and environmental effectiveness as well as social welfare, relative to traditional policy instruments,[239] since they allow farmers greater flexibility in their pollution control strategies and also have the potential to reduce transaction and compliance costs.[240] VAs can be classified into three basic categories, based mainly on the degree of public intervention.[241] *Negotiated agreements* imply a bargaining process between the

[239]Such as emission taxes, subsidies, or tradeable permit systems.

[240]The theoretical analysis of VAs to environmental regulation has been developed mainly in the past decade. See for example the work of Carraro and Siniscalco (1996), Segerson and Miceli (1998), Segerson and Dawson (2000), Brau et al. (2001), Lyon and Maxwell (2003).

[241]Examples of successful public VAs include the EPA's "33-50" program that seeks to encourage firms in the US Chemical industry to voluntarily reduce the discharges of 17 high-priority toxic chemicals under the background threat of legislation, the "US. Conservation Reserve Program" that used cost-sharing and other financial inducements to achieve reduction of agricultural pollution through voluntarily participation in soil conservation and other erosion control programs and its successor "Environmental Quality Incentives Program", the "Canadian Industry Program for Energy Conservation", the "US Green Lights", the "Motor Challenge" programs for industry, as well as the

regulatory body and a farmer or an industry group to jointly set the environmental goal and the means of achieving it. *Unilateral agreements* are environmental improvement programs prepared and voluntarily adopted by farmers themselves. *Public voluntary agreements* are environmental programs developed by a regulatory body and which farmers can only agree to adopt or not. In the latter category are classified the rural development programs offered under second pillar of the communal agricultural policy regime.

The potentially most serious drawback of VAs is that they leave room for free-riding. Particularly, in public VA where the attainment of an environmental target requires collective action, individual farmers may have incentives not to reduce their emissions but to rely upon other farmers to carry out the actions necessary to attain the target. Farmers can decide not to participate in the achievement of the established goal either ex-ante (non-participation), or ex-post after signing the agreement (non-compliance). It is possible that free-riding may impede the establishment of a public VA, or may result in the failure of the agreement because signatory farmers do not comply with the rules of the VA.[242] This suggests some limitations in the ability of VAs to attain desired targets. In fact there are some reservations, based on empirical observations, regarding the ability of public VAs to improve environmental quality as an independent policy tool. According to a report by Environment Canada, industrial sectors that relied solely on self monitoring or voluntary compliance had a sufficiently lower average compliance rating (60% vs. 94%) than those industries which were subject to federal regulations combined with a consistent inspection program.[243] Indeed without appropriate threats of sanctions or enforcement schemes, there may be a problem of compliance or uneven application. Both participation in and compliance with the agreement are important and thus a successful VA scheme may need to

"Golden Carrot" program for manufactures of highly energy-efficient refrigerators which has recently been consolidated with the "Motor Challenge" (OECD 1998). While "ProjectXL" and "Common Sense Initiative" involve negotiation, they also resemble public VAs.

[242]Despite the presence of apparent incentives to free-ride, it is possible to have an equilibrium in which the target is achieved and only a subset of firms in the industry comply with the agreement's provisions, while the remaining free-ride (Dawson and Segerson, 2002).

[243]Enforcement vs. Voluntary Compliance: An Examination of the Strategic Enforcement Initiatives Implemented by the Pacific and Yukon Regional Office of Environment Canada, Report No. DOEFRAP 19983.

include a mix of voluntary and mandatory features, to ensure that polluting agents will not only sign the public VA but also comply with its provisions and established goals.

The present chapter studies the long-run structure of a rural development program in the form of a public VA where the regulator makes an offer to a large number of homogeneous farmers to reduce nitrate emissions in order to voluntarily attain, by using flexible cost saving methods, a desired ambient pollution level.[244] The type of VA we study has many similarities with voluntary climate change programs or the various Energy Star programs.[245] If the offer attains full participation, a target ambient pollution stock is attained. If there is not full participation, then there is a deviation from the target and a positive probability of legislation through conventional instruments such as direct regulation. Thus limited participation may trigger regulation. Participating farmers are not directly observed by the regulator so there could be incentives not to comply. The regulator tries to deter non-compliance by random auditing and fines to those found not in compliance with the VA.

The general set up of compliance and auditing developed in this chapter can be used as a basis in order to gain some insights regarding nitrate pollution regulation. In particular, a similar type of regulatory framework can be used for the EU Nitrate Directive (91/676/EEC) that aims to reduce water pollution caused by nitrates generated from agricultural sources. The importance of the particular issue lies in the fact that only a minority of Member States has fully applied the directive and the Commission has opened a number of infringement proceedings against Member States for non-implementation. In this context the directive entails two regulatory frameworks (Article 4): (i) codes of good agricultural practice to be implemented on a voluntary basis, supplemented where necessary by the provision of training and information[246] and, (ii) a mandatory framework involving obligatory measures to be

[244]The flexible methods of reducing emissions through the VA program have a weak cost advantage relative to regulation like, for example, the XL Project or the EPA's 33-50.

[245]See, for example, OECD (1998).

[246]These codes contain provisions covering issues such as: (a) periods when application of fertilizers is inappropriate, (b) application of fertilizer to steeply sloping ground, (c) fertilizer application to water-saturated, flooded, frozen or snow-covered ground, (d) the conditions of application of fertilizer near water sources, (e) the capacity and construction of storage vessels for livestock manure and (f) procedures for fertilizer applications.

implemented in action programs for nitrate vulnerable zones[247]. Thus the developed general conceptual model of VA and nitrate pollution presented in this paper can be associated to some extent with the regulatory framework of the Nitrate Directive.

In modelling the process where farmers decide whether to participate in the agreement under a probabilistic regulation threat, we adopt an evolutionary framework. The basic characteristic of this framework is that, although farmers are profit maximizers in the output choice, when it comes to choosing a strategy regarding participating in the VA, or whether to comply or not, they adopt a more passive decision making and not an explicit optimizing behaviour.[248] This more passive decision making is modelled by an evolutionary process where decisions are taken by comparing the profits of a strategy to participate in and comply with the VA, with corresponding expected profits of a nonparticipating, non-complying farmer. Successful strategies are those attaining higher expected profits and are imitated by other farmers with a probability proportional to the difference between corresponding profits. Profit differentials exercise evolutionary pressures on the composition of population of farmers so that more successful strategies increase their share in the total population of farmers. A simple way to model the movements in the composition of population of farmers regarding participation in and compliance with the VA is the use of *replicator dynamics*.[249] We use replicator dynamics as selection dynamics to model in two stages the evolution of: (i) the decision to sign or not the agreement, and (ii) the decision to comply or not with the agreement's provisions after signing it.

The use of replicator dynamics allows us to determine evolutionary equilibria (EE), which can be related to evolutionary stable (ES) strategies regarding participation and

[247] Action programs consist of the following mandatory measures: (a) measures prescribed in the code(s) of good agricultural practice and (b) rules relating to periods of land application of certain types of fertilizers is prohibited, (c) measures concerning the minimum acceptable capacity of storage vessels, and (d) limitation in land application of fertilizers on particular grounds.

[248] This evolutionary approach might be encompassing ideas of bounded rationality since it can be associated with firms' bounded ability to fully perceive either advantages associated with flexibilities and cost superiority of the VA, or costs associated with probabilistic fines. For general presentations of these approaches, see for example Nelson (1995) and Conlisk (1996).

[249] For definitions, see, for example, Weibull (1995). For applications of this methodology to common property resources, see Sethi and Somanathan (1998).

compliance.[250] We further elaborate on the selection dynamics by considering the situation where decisions to participate or not evolve fast, since when the offer is made there is usually a legal time framework,[251] while decisions regarding compliance after participation are unconstrained and expected to evolve much more slowly. This suggests that the evolutionary equilibrium composition of farmers regarding participation is reached faster than the ES equilibrium composition regarding compliance, implying that selection dynamics operate in a *fast-slow dynamics* framework.

Our contribution lies in using, for the first time to our knowledge, an evolutionary approach with fast-slow selection dynamics to jointly determine the steady-state equilibrium fraction of signatory and complying farmers, as well as the corresponding steady-state equilibrium emission stock. Using this approach we are able to determine *"which strategies survive in the long-run"*, in the sense of evolutionary stability, define the structure that a long-term VA would have, in terms of participation and compliance, and identify policy rules that might produce desirable VAs.[252] Our analysis indicates that the value and characteristics of the legislation and auditing probability are of crucial importance for the resulting long-term equilibrium outcome. Under different assumptions about the legislation probability, the fast time dynamic system can alternatively converge to a polymorphic or monomorphic steady state, implying either partial or full (or non) participation in the public VA. Similarly by choosing the structure of the auditing probability, the regulator can achieve partial or full (or non) compliance. There is a possibility of unique or multiple EE with potential irreversibilities, while the convergence to these equilibria could be monotonic or oscillating. If full participation and full compliance are regarded as the desired outcome for the regulator, they can be attained if the regulator is pre-committed to certain legislation and inspection probabilities, or by appropriate choices of the legislation mandate and the non-compliance fine. Finally we show that under a limited budget for financing auditing inspections, which is partly financed exogenously and

[250] A strategy is ES if it can not be invaded by a mutant strategy. See for example Weibull (1995), page 36.

[251] EPA's National Environmental Performance Track accepts applications twice a year.

[252] For a similar approach regarding the regulation of a renewable resource, see Xepapadeas (2005).

partly through collected fines, a polymorphic compliance equilibrium is the most likely outcome.

2. A Model of Agricultural Nitrate Pollution and Regulation

Assume an industrial sector consisting of $i = 1, 2, ...n$ small and identical farmers, which operate under competitive conditions and emit into the ambient environment. Emissions accumulate in the environment and cause external damages, which exceed the socially-desirable levels without regulation. The regulator proposes formally a "take-it-or-leave-it" environmental protection scheme and gives each farmer in the industrial sector a chance to voluntarily meet an exogenously determined emission level e_v. This type of rural development program (i.e. public VA) offers full flexibility to choose the profit-maximizing and legislative means of achieving the target and could provide cost advantages over legislative regulation.

In particular the regulator proposes a long-term "preemptive" public VA[253] to which farmers can only agree or not. If all farmers follow the agreement then total emissions in the ambient environment will be $E_v = ne_v$, where we assume that the nitrate pollution stock S accumulates according to:

$$\dot{S}(t) = E(t) - \varphi(S(t)),\ E(t) = \sum_{i=1}^{n} e_i(t) \qquad (1)$$

where $E(t)$ denotes total nitrate emissions at time t due to agricultural activities, and $\varphi(S(t))$ denotes emissions outflows due to natural environmental self cleaning process and environmental feedbacks.

Let $\overline{S}(t)$ be the path of nitrate pollution stock under full participation and compliance to the agreement. If there is not full participation, a deviation at time t is expected between the observed and desired nitrate pollution stock, denoted by $\Delta S(t) = S(t) - \overline{S}(t)$. Participation in the VA does not imply that a farmer will also

[253]Such VAs indirectly reduce expected production costs because they reduce the probability of facing a (more costly) direct regulatory regime (Brau et al., 2001).

comply with its provisions. Thus although the regulator has full observability of participating farmers, we assume that simultaneous control of all signatory farmers is prohibitively costly. The mechanism usually applied to verify compliance and identify compliance problems is inspection of randomly chosen signatory farmers. Therefore a positive $\Delta S(t)$ might be the result of either partial participation and non-compliance by some of the participating farmers, or under full participation, the result of non-compliance by some signatory farmers. It would be intuitive to assume that from a farmer's point of view the subjective probability of having legislation introduced at time t depends on the deviation $\Delta S(t)$ and the proportion of participating farmers $x(t)$, or[254]

$$p(t) = p(\Delta S(t), x(t), \omega_v(t)), \text{ with } \frac{\partial p(\cdot)}{\partial \Delta S} > 0, \ \frac{\partial p}{\partial x} < 0 \ x \in [0,1] \qquad (2)$$

where $\omega_v(t)$ is a vector of other parameters affecting the probability of regulation.[255] The probability of regulation would increase due to either an increase in the deviation $\Delta S(t)$ or a decrease in the number of participating farmers.

We further specify the probability structure, by assuming that the probability of introducing legislation is common to all farmers and that: $p(0,1) = 0$;[256] $p(\Delta S, x | \Delta S > 0, x < 1) > 0$; $p(\Delta S, 1 | \Delta S > 0) = 0$ hold. That is, if everybody participates, then the deviation is due to non-compliance. We assume that $(\Delta S(t), x(t))$ are observable by the regulator and become public information, while there is uncertainty regarding the vector ω_v. Farmers can use announced $(\Delta S(t), x(t))$ to calculate subjective probabilities, but there is uncertainty regarding the probability law $p(\Delta S(t), x(t), \omega_v(t))$, thus farmers use model (2) as a benchmark for some fixed value of the vector ω_v.

[254]Segerson and Miceli (1998) assume a fixed legislation probability.

[255]It may include legislative procedures, transaction costs, etc.

[256] The possibility of $p(0, | x < 1) = 0$, which allows for overcompliance by some farmers so that the target is achieved even if some farmers are not participating, is not considered. The possibility of overcompliance implies the introduction of another strategy, $e_{OC} < e_v$.

If farmers believe that the only factor that affects the probability of legislation is the nitrate pollution deviation ΔS, then the probability can be simplified to[257]

$$p(t) = p\left(\Delta S(t), \omega_v(t)\right), \text{ with } \frac{\partial p(\cdot)}{\partial \Delta S} > 0 \qquad (3)$$

The decision to participate and then comply or not depends on the structure of profits. In our model, each farmer produces an output Q and emissions e. The cost function $C(Q,e)$ is a continuous function where $C_Q > 0$, $C_e < 0$, $C_{QQ} > 0$ and $C_{ee} > 0$. We assume that the VA offers only a cost advantage to participating and complying farmers since it deters the introduction of relatively more costly mandatory regulation and allows greater flexibility in the processes of emissions reduction.[258] The profit function is defined as $\Pi(e) = \max_Q \{PQ - C(Q,e)\}$.

At the unregulated equilibrium a farmer chooses emissions $e_o = \arg\max_e \Pi(e)$. Therefore when a farmer decides not to participate in the VA, and continues producing at the profit-maximizing emission level without facing a legislative mandate, then profits are defined as $\Pi_N(e_o)$. If a farmer decides to sign the VA and voluntarily cut emissions to the agreed level e_v, then profits are $\Pi_v(e_v) = \max_Q \{PQ - C_v(Q,e_v)\}$.

If a farmer decides not to participate in the VA and mandatory legislation is used to introduce either an emission tax τ, or an emission limit (performance standard) $\bar{e}$, then its profit function could be defined as:

$$\Pi_L(e,\tau) = \max_Q \{PQ - C_L(Q,e) - \tau_L e\} \qquad (4)$$

$$\Pi_L(e,\bar{e}) = \max_Q \{PQ - C_L(Q,e) :\ e \le \bar{e}\} \qquad (5)$$

In both cases $C_v(Q,e) < C_L(Q,e)$ under the cost advantage assumption of the VA. So under legislation, profits can be defined as $\Pi_L(e_L)$, where $e_L(\tau) = \arg\max_e \Pi_L(e,\tau)$

[257]It seems that ΔS shall always be part of the subjective probability in every case. If the subjective probability is a function of participation proportion x alone, then the incentive to participate is not linked with the achievement of the environmental target e_v.

[258]We assume that the VA does not improve a firm's public image and increase consumers' goodwill.

under taxation, or $e_L = \arg\max_e \Pi_L(e)$ subject to $e \le \bar{e}$, under a performance standard. Under standard assumptions $e_L = \bar{e}$.[259]

If a participating farmer decides not to comply with the VA and emits at the unregulated level e_o, then there is a possibility that the farmer will be caught after a random inspection. If the non-complying farmer is not inspected then profits are $\Pi_N(e_o)$. If caught the farmer is subjected to individual legislation and a non-compliance fine F. The profits of a non-complying farmer who is caught after a random inspection are $\Pi_C(e_L, F) = \Pi_L(e_L) - F$.

Since $e_o > e_L \ge e_v$ the structure of costs and profits implies:

$$\Pi_o(e_o) > \Pi_v(e_v) > \Pi_L(e_L) > \Pi_C(e_L, F)$$

In the case of non-participation in the agreement, the imposition of legislation is probabilistic, therefore the expected profits of non-participating farmers are:

$$E\Pi_N = p\Pi_L(e_L) + (1-p)\Pi_N(e_o)\,,\ p = p\left(\Delta S, x, \boldsymbol{\omega}_v\right) \qquad (6)$$

Thus the sufficient condition for participation in the VA is

$$\Pi_v(e_v) \ge p\Pi_L(e_L) + (1-p)\Pi_N(e_o) \qquad (7)$$

Let q be the subjective probability that a participating farmer will be inspected and let z be the proportion of participating farmers that comply with the terms of the VA. A farmer's subjective probability of being audited can generally be defined by $q(\boldsymbol{\omega}_c)$, where $\boldsymbol{\omega}_c$ is a vector of parameters. It is assumed that this function is common for all farmers and can be further specified in the following cases.

In the first case the regulator exercises fixed monitoring effort and makes a fixed number of inspections, say $\bar{n}$ per period. The regulator announces this policy and

[259] The target $\bar{e} = e_L$ can be achieved either through taxation, if the tax rate is chosen such that $e_L(\tau) = \bar{e}$ is a solution to $\max_e \Pi_L(e, \tau)$, or through a performance standard $\bar{e}$.

precommits to a certain auditing probability, which is known by the polluters. In this case the audit probability is fixed, or[260]

$$q(\omega_c) \equiv \overline{q} \qquad (8)$$

An alternative assumption would be that the regulator exercises variable monitoring effort, dependent on state variables of the problem observed by the regulator.[261] One such variable is the deviations from the desired nitrate pollution stock ΔS; and/ or the share of violators $1-u,\ u \in [0,1]$ detected during an audit. The regulator increases the monitoring effort if the stock or the share of violators is increasing. This policy can be regarded as a type of no full commitment - or partial commitment - auditing policy on the regulator's part. The regulator might, for example, not audit individual farmers if the deviation ΔS is sufficiently low, but start inspections if the deviation increases beyond a certain level.[262] The farmers are made aware of the results of the inspections, through public announcements and/or private communications, and perceive that if the deviation or the share of violators increases, more monitoring effort will be exercised and thus the subjective probability of being audited increases. In this case the probability q can be specified as stock dependent auditing probability:

$$q = q(\Delta S, \omega_c),\ q^{'}(\Delta S, \omega_c) > 0,\ q(0, \omega_c) = 0 \qquad (9)$$

where ω_c is a vector of parameters similar to ω_v.

If farmers use the observed u as an estimate for their perceived z, that is they set $u = z$, a compliance dependent auditing probability is defined as:

$$q = q(z, \omega_c),\ q^{'}(z, \omega_c) < 0,\ q(1, \omega_c) = 0, q(0\,\omega_c) > 0 \qquad (10)$$

[260]This is a common assumption in the enforcement literature in environmental economics (e.g. Malik, 1993; Garvie and Keeler, 1994; Segerson and Miceli, 1998; Stranlund and Dhana, 1999).

[261]In the enforcement literature, variable monitoring effort is usually related to firm specific variables (e.g. Malik, 1990; VanEgteren and Weber, 1996).

[262]Grieson and Singh (1990), Khalil (1997), and Franckx (2002) analyze no commitment frameworks. An environmental regulator chooses which firm to inspect without observing firms' actions but after observing ambient pollution.

It is expected that the value of $q(0)$ will be large but not unity since not every farmer is audited[263] even if nobody complies, while if everybody is complying the subjective probability is $q(1)=0$.

If (9) and (10) are taken together, a general formulation of the subjective audit probability with joint dependence on compliance and stocks would be:

$$q = q(z, \Delta S, \omega_c) \tag{11}$$

In this context the expected profits of a participating, non-complying farmer are:

$$E\Pi_N = q\Pi_C(e_L, F) + (1-q)\Pi_N(e_o) \tag{12}$$

and the sufficient condition for complying with the agreement's provisions is:

$$\Pi_v(e_v) \geq q\Pi_C(e_L, F) + (1-q)\Pi_N(e_o) \tag{13}$$

Given the above framework we explore how imitation and adaptation of behaviour, resulting in higher profits, determine which strategies (participate or not/comply or not) will survive in the long run. We model the selection dynamics that can be used to determine the ES strategies by replicator dynamics.

3. Replicator Dynamics as Selection Dynamics

Assume that at a given time t the sector consists of two groups of farmers, each group following a different strategy concerning participation in the public VA. Let $x(t)$ denote the proportion of farmers participating in the agreement, while $x_N(t)$ the remaining proportion of non-signatory agents at time t, with $x(t)+x_N(t)=1$.

Given the assumption of bounded rational farmers, the decision whether to comply or not depends on the information revealed by the interaction of farmers over time. The fraction of farmers complying with the provisions of the public VA evolves in time and is encountered more frequently in the population if farmers perceive that the compliant strategy involves higher profits than the noncompliant strategy. Based on the imitation behavioural rule described previously through the replicator dynamics

[263]This can be associated with a binding budget constraint for inspection costs.

framework, the equation describing the motion of the group of compliant agents x over time is modelled by:

$$\dot{x} = \alpha\beta x(1-x)[p\Delta\Pi_L^N - \Delta\Pi_v^N] \qquad (14)$$

where $\Delta\Pi_L^N = (\Pi_N(e_o) - \Pi_L(e_L))$ are the profit losses under the non-participating strategy when legislation is imposed and $\Delta\Pi_v^N = (\Pi_N(e_o) - \Pi_v(e_v))$ are the profit losses under the participating, complying strategy.

It has already been mentioned that participation in the VA does not imply that a farmer will also comply with its provisions. We assume that in choosing between compliance or not farmers imitate successful strategies, as in the choice of participation strategy, by collecting (incomplete) information regarding expected profits of non-complying farmers. Let $z(t)$ denote the proportion of farmers complying with the agreement, while $z_N(t)$ the remaining proportion of non-complying farmers at time t, with $z(t) + z_N(t) = 1$.

After following the same conceptional framework, the replicator dynamics equation for the compliance strategy is defined as:

$$\dot{z} = \gamma\delta z^t \left[\Pi_v(e_v) - \overline{\Pi}_{VN}(e)\right]$$

where γ and δ correspond to α and β above, and $\overline{\Pi}_{VN}(e)$ are the average profits for the whole population of signatory farmers.[264]

Then the replicator dynamics equation for the complying strategy is:

$$\dot{z} = \gamma\delta\, z(1-z)\left[q\Delta\Pi_C^N - \Delta\Pi_v^N\right] \qquad (15)$$

where $\Delta\Pi_C^N = (\Pi_N(e_o) - \Pi_C(e_L, F))$ are the profit losses under the non-complying, participating strategy when both legislation and fine are imposed.

Steady states (S-S) (or stationary points or rest points, or critical points) of the replicator dynamics equations (14) or (15) can be used to define evolutionary

[264]Where $\overline{\Pi}_{VN}(e) = z\Pi_v(e_v) + (1-z)[q\Pi_C(e_L, F) + (1-q)\Pi_N(e_o)]$.

equilibria. Following standard stability classification an (S-S) is *stable* (or *Lyapunov stable*) if no small perturbation from the (S-S) induces a movement away from (S-S), it is *asymptotically stable* (AS) if it is stable and small perturbations induce a movement back towards (S-S), or to put it differently if the solution of the replicator dynamic equation tends to the (S-S) from initial conditions in the neighbourhood of (S-S) as $t \to \infty$. We will define as *evolutionary equilibrium* (EE) an AS steady state under the replicator dynamics (Gintis (2000). The (S-S) is *globally asymptotically stable* (GAS) if it converges to the (S-S) independent of initial conditions for any initial state in the open interval $(0,1)$.[265] A stable (S-S) is a Nash equilibrium of the game defined in terms of two farmers following strategies of participation or non-participation, or compliance or non-compliance. Furthermore, if a strategy $\hat{x}$ is an evolutionary stable strategy then it corresponds to an EE under the replicator dynamics. Conversely, a strategy $\hat{x}$ is an ES strategy if it is a *strongly stable* equilibrium point of the replicator dynamics equation, where strong stability means that if $\hat{x}$ is contained in a *convex hull* of the strategy simplex, all strategies in the neighbourhood of $\hat{x}$ converge to $\hat{x}$ (see, for example, Hofbauer and Sigmund 2003).[266] Since GAS equilibria can be associated with the notion of strong stability, GAS steady states under the replicator dynamics can be regarded as reflecting ES strategies.

The evolution of the emission stock is affected by the decisions to participate in the agreement and further comply with its provisions and established goals. Therefore the nitrate pollution stock dynamic equation (1) can be further specified as:

$$\dot{S} = n\{x[ze_v + (1-z)Ee_L(q)] + (1-x)e_o\} - \varphi(S) \tag{16}$$

where $Ee_L(q) = qe_L + (1-q)e_o$ are the expected emissions of a non-complying but participating farmer. Finally, (16) can be further specified by assuming that the emissions outflows term is linear, implying that $\varphi(S) = bS$ with $b > 0$.

[265] We can not attain convergence from the boundaries 0 and 1 since they are invariant.

[266] A convex hull of a set A is the smallest convex set containing A. For example, the convex hull of three noncollinear points is the triangle with these points as vertices.

The combination of the replicator dynamics equations (14) or (15) with an emission dynamic equation (16) can be used to develop a unified dynamical system which characterizes participation, compliance and the associated movement of the nitrate pollution stock.

4. Fast - Slow Selection Dynamics in the Evolution of Public Voluntary Agreements

The purpose of introducing different time scales in the replicator dynamics framework is to capture the fact, observed in real situations, that when a VA of that type is offered, the composition regarding participation is finalized relatively fast. Since farmers have to decide whether to accept the offer within a relatively small time interval, determined by legal procedures, we expect evolutionary pressures to work relatively fast. On the other hand compliance behaviour is not constrained by a time framework so we expect evolutionary pressures to operate more slowly relative to the participation case. This implies that the rate of change of x with respect to time is large in absolute value, while the rate of change of z is relatively slower. That is, $\left|\frac{dx}{dt}\right| \equiv |\dot{x}| >> \left|\frac{dz}{dt}\right| \equiv |\dot{z}|$.

The above argument implies that in (14) and (15) we can set $\alpha\beta = 1$ and $\gamma\delta = \varepsilon$ where ε is a small positive parameter. Assuming that the natural system evolves in a time scale which is comparable to the slow compliance variable, then our dynamic system can be written in a fast time scale as:

$$\frac{dx}{d\tau} = f_1(x,S) \tag{17}$$

$$\frac{dz}{d\tau} = \varepsilon\, f_2(z,S) \tag{18}$$

$$\frac{dS}{d\tau} = \varepsilon\, f_3(x,z,S) \tag{19}$$

System (20) - (22) is the fast time system (FTS).[267] If fast time is scaled such that $\tau = t/\varepsilon$, so that $d\tau = dt/\varepsilon$, then the dynamics system characterizing participation, compliance and nitrate pollution accumulation in slow time can be written as:

$$\varepsilon\dot{x} = f_1(x,S) \tag{20}$$

$$\dot{z} = f_2(z,S) \tag{21}$$

$$\dot{S} = f_3(x,z,S) \tag{22}$$

The problem defined in the dynamical system (20) - (22) is a *singular perturbation* problem.[268] The general method for analyzing it, is to consider the systems at the limit $\varepsilon \to 0$. If the solutions satisfy certain regularity conditions for $\varepsilon = 0$, then solutions for small ε can be approximated by the solutions for $\varepsilon = 0$. By taking $\varepsilon = 0$ in system (20) - (22) we obtain the *reduced* system, otherwise known as slow-time system (STS), where the equation $0 = f_1(x,S)$ provides, if it can be solved for x, the equilibrium participation rate for fixed level of S, as:

$$x = h(S) \tag{23}$$

The solutions of (23) are equilibria of the FTS (17) - (19), defined for $\varepsilon \to 0$ and denoted by $h_j(S)$, $j = 1,...,J$.[269] For the stable equilibria from the set of equilibria of (x-reduced), the slow variables evolve as:

$$\dot{z} = f_2(z,S) \tag{24}$$

$$\dot{S} = f_3(h(S),z,S) \tag{25}$$

The analysis of the dynamic system (24) and (25) can be used to determine the long-run ES compliance and nitrate pollution stock (z^*,S^*). Then the long-run ES participation in the VA will be determined as $h(z^*,S^*)$.[270]

[267]Where f_i, $i = 1,2,3$ represent the right hand sides of (14), (15) and (16) respectively.

[268]For the analysis of problems in a fast-slow time framework see, for example, Wasow (1965, Chapter X) or Sastry (1999, Chapter 6).

[269]Where J is the number of these equilibria.

[270] In more technical terminology the dynamic system (24) and (25) is defined on the stable two-dimensional manifold (or union of) $M = \{(z,S,x) : g(x,z,S) = 0 : x_i^F(z,S) \text{ is stable in FTS}\}$. Solutions of the slow system (20)-(22) at least locally are attracted to this manifold.

5. Long-Run Structure for a Public VA

The conceptual framework developed above is used to determine the long-run structure regarding participation in and compliance with a public VA. Since the long-run structure is determined as a stable equilibrium of the replicator dynamics equation, it has the property of a stable EE. To illustrate the importance of the structure of legislation and auditing probabilities in determining the long-run structure for the public VA, we classify the following analysis according to the characteristics of these probabilities.

5.1 Participation Decision and Evolutionary Participation Equilibria

The decision regarding participation in a public VA is reached faster and is affected by the structure of the subjective probability of introducing legislation. The legislation probability can either depend solely on the nitrate pollution stock or jointly on the nitrate pollution stock and proportion of participating farmers.

5.1.1 Nitrate Pollution Stock Dependence of the Legislation Probability

Assume that the subjective probability of introducing legislation depends only on the nitrate pollution deviation ΔS. In the fast time participation system (FTPS) the observed emission stock S and the deviation ΔS are both regarded as fixed parameters. As a consequence the legislation probability is fixed, implying that $p = p(\overline{\Delta S})$.

Under this definition the slow time compliance nitrate pollution system (STCPS), is defined as:

$$0 = x(1-x)\left[p(\overline{\Delta S})\Delta\Pi_L^N - \Delta\Pi_v^N\right] \tag{26}$$

$$\dot{z} = z(1-z)\left[q\left(z,\Delta S,\omega_c\right)\Delta\Pi_C^N - \Delta\Pi_v^N\right] \tag{27}$$

$$\dot{S} = n\{x[ze_v + (1-z)Ee_L(q\left(z,\Delta S,\omega_c\right))] + (1-x)e_o\} - bS \tag{28}$$

The solution of the replicator dynamics equation (26) provides the S-S participation rates x^*, for fixed level of S, which correspond to an EE. Two S-S exist, $x_1^* = 1$ and $x_2^* = 0$, implying either full or non-participation in the public VA.

The derivative of (26) with respect to x defines the stability condition:

$$\frac{d\dot{x}}{dx} = (1-2x)\Omega \tag{29}$$

where $\Omega = [p(\overline{\Delta S})\Delta\Pi_L^N - \Delta\Pi_v^N]$. There is a critical probability value, defined as $\widehat{p}(\overline{\Delta S})$, that sets $\Omega = 0$ and behaves as a bifurcation parameter.[271] The sign of the expression Ω, and therefore the stability of the steady states, depend on the magnitude of the fixed legislative probability $p(\overline{\Delta S})$ relative to the critical value $\widehat{p}(\overline{\Delta S})$. Specifically, if the regulator announces and commits to a legislative probability higher than the critical value, then $\Omega > 0$. On the other hand, if $p(\overline{\Delta S}) < \widehat{p}(\overline{\Delta S})$, then $\Omega < 0$.

Under this definition it follows that:

$$\text{If } p(\overline{\Delta S}) > \widehat{p}(\overline{\Delta S}) \text{ then } \left.\frac{d\dot{x}}{dx}\right|_{x_1^*=1} < 0 \text{ and } \left.\frac{d\dot{x}}{dx}\right|_{x_2^*=0} > 0$$

$$\text{If } p(\overline{\Delta S}) < \widehat{p}(\overline{\Delta S}) \text{ then } \left.\frac{d\dot{x}}{dx}\right|_{x_1^*=1} > 0 \text{ and } \left.\frac{d\dot{x}}{dx}\right|_{x_2^*=0} < 0$$

In the first case, farmers perceive that the introduction of the legislation is highly likely. Therefore farmers prefer the profit loss $\Delta\Pi_v^N$ under the public VA to the higher profit losses $\Delta\Pi_L^N$, realized if legislation is imposed. Consequently, all farmers participate in the public VA and $x_1^* = 1$ is GAS. Furthermore the ambient nitrate pollution stock is equal to the industrial emission target E_v. In the second case, the legislation mandate appears less likely and farmers can maintain the unregulated

[271] Where $\widehat{p}(\overline{\Delta S}) = (\Pi_N - \Pi_V)/(\Pi_N - \Pi_L) < 1$, since $\Pi_N(e_o) - \Pi_v(e_v) < \Pi_N(e_o) - \Pi_L(e_L)$.

profits $\Pi_N(e_o)$. Therefore no farmer has the incentive to participate in the public VA and receive reduced profits by $\Delta\Pi_v^N$, so $x_2^* = 0$ is GAS.

These findings can be summarized in the following proposition:

Proposition 1: *Under an emission stock dependent legislative probability the FTPS converges to a monomorphic equilibrium. If* $p(\overline{\Delta S}) \in \left(\widehat{p}(\overline{\Delta S}),1\right]$, *then there is full participation in the public VA and* $x_1^* = 1$ *is the GAS evolutionary equilibrium. If* $p(\overline{\Delta S}) \in \left[0,\widehat{p}(\overline{\Delta S})\right)$, *then there is non-participation in the public VA and* $x_2^* = 0$ *is the GAS evolutionary equilibrium. By the strong stability property of the GAS steady states, participation or non participation are ES strategies for the appropriate value of the subjective legislation probability.*

From the total differential of $\Omega = 0$, we obtain

$$\frac{d\widehat{p}(\overline{\Delta S})}{de_L} = \frac{\widehat{p}(\Delta S)\Pi_L'(e_L)}{\Delta\Pi_L^N} < \mathbf{0} \tag{30}$$

Thus, the higher the legislative emission e_L [272] is set by the regulator, the lower is the critical probability value $\widehat{p}(\overline{\Delta S})$. There is a trade-off between the announced legislatively set emission level and the commitment to a given legislation probability value. Through stricter legislation, the range of legislation probability values that induce participation becomes wider, allowing the regulator to achieve the stable EE outcome by committing to a lower legislation probability.

5.1.2 Nitrate Pollution Stock and Participation Dependence of the Legislation Probability

Assume that the subjective probability of introducing legislation depends jointly on nitrate pollution deviation ΔS and the participation proportion x. Under $p = p(\Delta S, x)$ and (11) the STCPS is defined as:

[272] As noted above, a target e_L can be attained either through emissions taxes or emission limits. From our assumptions it follows that $\Pi_L'(e_L) < 0$.

$$0 = x(1-x)\left[p(\Delta S, x)\Delta\Pi_L^N - \Delta\Pi_v^N\right] \quad (31)$$

$$\dot{z} = z(1-z)\left[q(\cdot)\Delta\Pi_C^N - \Delta\Pi_v^N\right] \quad (32)$$

$$\dot{S} = n\{x(\Delta S)[ze_v + (1-z)Ee_L(q(\cdot))] + (1-x(\Delta S))e_o\} - bS \quad (33)$$

The fast time dynamic equation (31) defines two monomorphic S-S: $x_1^* = 1$ and $x_2^* = 0$, as well a polymorphic critical point $x_3^*(\Delta S) \in (0,1)$ that is defined by $\Omega = [p(\Delta S, x_3^*)\Delta\Pi_L^N - \Delta\Pi_v^N] = 0.$ The stability condition for these S-S is given by:

$$\frac{d\dot{x}}{dx} = (1-2x)\Omega + x(1-x)p^{'}(\Delta S, x)\Delta\Pi_L^N \quad (34)$$

There is a critical probability value $\widehat{p}(\Delta S, x_3^*)$ that sets Ω equal to zero and corresponds to the critical point $x_3^*(\Delta S)$. Furthermore if $x < x_3^*$ then $p(\Delta S, x) > \widehat{p}(\Delta S, x_3^*)$ and $\Omega > 0,$ while if $x > x_3^*$ then $p(\Delta S, x) < \widehat{p}(\Delta S, x_3^*)$ and $\Omega < 0.$ Then,

$$\left.\frac{d\dot{x}}{dx}\right|_{x_1^*=1}, \left.\frac{d\dot{x}}{dx}\right|_{x_2^*=0} > 0 \quad \text{and} \quad \left.\frac{d\dot{x}}{dx}\right|_{x_3^*} < 0$$

The FTPS converges to the polymorphic EE x_3^*, implying that only a sub-group of polluting farmers participate in the public VA in the long-run. This happens because, in the case of full participation, $p(\Delta S, 1 | \Delta S > 0) = 0$ holds, giving farmers an incentive not to participate in the VA when participation is already high. On the other hand, $p(\Delta S > 0, 0) \to 1$, giving farmers an incentive to participate in the agreement when participation is very low.

These findings can be summarized in the following proposition:

Proposition 2: *Under a legislative probability that depends jointly on the participation proportion and nitrate pollution stock, the participation system converges to a GAS polymorphic EE, implying partial participation in the public VA. Partial participation is an ES strategy.*

Furthermore,

$$\frac{dx}{de_L} = \frac{p(\Delta S, x)\Pi_L'(e_L)}{p'(\Delta S, x)(\Delta\Pi_L^N)} > 0 \qquad (35)$$

Under the threat of stricter legislative regulation, the participating proportion increases, shifting the polymorphic x_3^* steady state upwards, closer to the full participation critical point, $x_1^* = 1$. Therefore through proper design of the legislation mandate the regulator can induce the majority of farmers to participate in the VA.

5.2 Compliance Decisions and Evolutionary Compliance Equilibria

Assume that the regulator has set $p(\overline{\Delta S}) > \hat{p}(\overline{\Delta S})$ and thus the full participation S-S $x_1^* = 1$ is an EE and an ES strategy in the fast time.[273] We examine now the second level of decision, which is to comply or not with the VA. Substituting the GAS steady state, $x_1^* = 1,$ the slow-time system is defined in general terms as:

$$\dot{z} = z(1-z)\left[q(z, \Delta S, \omega_c)\Delta\Pi_C^N - \Delta\Pi_v^N\right] \qquad (36)$$

$$\dot{S} = n\{ze_v + (1-z)Ee_L(q\left(z, \Delta S, \omega_c\right))\} - bS \qquad (37)$$

The system has a hierarchical structure, if the audit probability q is independent of the nitrate pollution stock S, implying that the S-S and the stability properties of the replicator dynamics (36) can be determined first and then used to determine the nitrate pollution stock S-S of equation (37). In the following we examine how alternative assumptions about the structure of the auditing probability affect the compliance EE and nitrate pollution stock, given the full participation decisions.

5.2.1 Fixed Auditing Probability

[273] It makes no sense to examine the S-S when $x_2^* = 0$ is the ES strategy, since non-participating firms are not expected to do "self-regulation".

Assume that the regulator is committed to a fixed auditing probability. Participating farmers know exactly the probability $\overline{q}$ under which they may experience profit losses $\Delta\Pi_C^N$, if caught violating the agreement. Based on this knowledge they choose their evolutionary strategy of whether or not to comply.

Under this assumption there are two monomorphic S-S of the replicator dynamic satisfying the equilibrium condition $\dot{z}=0$ of (36), implying either full compliance $z_1^*=1$ or non-compliance $z_2^*=0$ with the agreement. The stability condition is determined by:

$$\frac{d\dot{z}}{dz}=(1-2z)\Phi \qquad (38)$$

where $\Phi=\left[\overline{q}\Delta\Pi_C^N-\Delta\Pi_v^N\right]$. There is a critical probability value $\overline{\overline{q}}$ that sets $\Phi=0$. In particular, if $\overline{q}>\overline{\overline{q}}$ then $\Phi>0$, and if $\overline{q}<\overline{\overline{q}}$ then $\Phi<0$. Thus the stability conditions of the replicator dynamic become:

$$\text{If } \overline{q}>\overline{\overline{q}} \text{ then } \left.\frac{d\dot{z}}{dz}\right|_{z_1^*=1}<0 \text{ and } \left.\frac{d\dot{z}}{dz}\right|_{z_2^*=0}>0$$
$$\text{If } \overline{q}<\overline{\overline{q}} \text{ then } \left.\frac{d\dot{z}}{dz}\right|_{z_1^*=1}>0 \text{ and } \left.\frac{d\dot{z}}{dz}\right|_{z_2^*=0}<0$$

The $\dot{S}=0$ isocline defines the corresponding nitrate pollution stock equilibrium. If $\overline{q}>\overline{\overline{q}}$ then full compliance, $z_1^*=1$, is the EE with $S_1^*=(ne_v/b)$, which is the desired nitrate pollution stock level. If $\overline{q}<\overline{\overline{q}}$ then non compliance, $z_2^*=0$, is EE with $S_2^*=(nEe_L(\overline{q})/b)>S_1^*$. In this case the nitrate pollution stock dynamic isocline $\dot{S}=0$ is a linear curve with negative slope defined as:

$$z(S)=\frac{bS}{n\{e_v-Ee_L(\overline{q})\}}-\frac{Ee_L(\overline{q})}{\{e_v-Ee_L(\overline{q})\}}=AS-B$$

where $A<0$ and $B<0$. The STCPS converges to a GAS monomorphic S-S.[274]

The above conclusions can be summarized in the following proposition:

[274]For details see the Appendix III.

Proposition 3: *Under a fixed auditing probability, the compliance-nitrate pollution system converges to a GAS monomorphic S-S. If* $\overline{q} \in (\overline{\overline{q}},1)$ *then there is full compliance with the public VA and the S-S* $z_1^* = 1$ *is the ES strategy. If* $\overline{q} \in \left[0, \overline{\overline{q}}\right)$ *then there is non-compliance with the public VA and the S-S* $z_2^* = 0$ *is the ES strategy.*

Furthermore,

$$\frac{d\overline{\overline{q}}}{dF} = \frac{\overline{\overline{q}}\Pi_C'(e_L, F)}{\Delta\Pi_C^N} < 0 \tag{39}$$

The higher the non-compliance fine is, the lower the critical probability value $\overline{\overline{q}}$ is.[275] Thus, by an appropriate choice of the fine, and provided that this choice is politically feasible, the regulator can lower the number of random inspections and achieve full compliance, as well as the desired goal E_v, with lower monitoring expenses.

5.2.2 Compliance Dependent Auditing Probability

Under an auditing probability which is dependent on the fraction of the complying farmers, defined as $q(z)$, $z_1^* = 1$ and $z_2^* = 0$ are EE for (36). Furthermore an additional EE $z_3^* \in (0,1)$ may exist, which also satisfies the equilibrium condition $\dot{z} = 0$. This S-S defines a critical probability value $\widehat{q}(z_3^*)$ such that $\Phi = [\widehat{q}(z_3^*)\Delta\Pi_C^N - \Delta\Pi_v^N] = 0$.

In this case the stability condition is defined as:

$$\frac{d\dot{z}}{dz} = (1-2z)\Phi + z(1-z)q'(z)(\Delta\Pi_C^N) \tag{40}$$

Due to (10), it holds that $\Phi > 0$ for $z < z_3^*$ since $q(z) > \widehat{q}(z_3^*)$, and $\Phi < 0$ for $z > z_3^*$ since $q(z) < \widehat{q}(z_3^*)$. It can be easily seen that the monomorphic EE of the replicator dynamic are not asymptotically stable since:

[275] This is the evolutionary analogue to Franckx's (2002) result, which indicates that the only role the fine plays is that when it increases, the equilibrium inspection probability is reduced.

$$\left.\frac{d\dot{z}}{dz}\right|_{z_1^*=1} = -\Phi > 0 \quad \text{and} \quad \left.\frac{d\dot{z}}{dz}\right|_{z_2^*=0} = \Phi > 0$$

Under full compliance the regulator may respond with a reduced or even zero number of random inspections, due to condition (10). This gives participating farmers an incentive to violate the agreement. On the other hand, under non compliance the value of $q(0)$ is sufficiently high, which gives participating farmers an incentive to comply with the agreement's provisions. In this case, since

$$\left.\frac{d\dot{z}}{dz}\right|_{z_3^*} = z_3^*(1-z_3^*)\, q'\left(z_3^*\right)\Delta\Pi_C^N < 0$$

the replicator dynamic converges to a polymorphic EE, implying that only a sub-group of participating farmers complies with the public VA.

For the $\dot{S}=0$ isocline we have that $S_1^* = \left(ne_v/b\right) < S_2^* = \left(nEe_L(q(0))/b\right)$, evaluated at $z_1^*=1$ and $z_2^*=0$ respectively, with

$$\frac{dz}{dS} = b/\left(n\{e_v - Ee_L(q(z)) + (1-z)\left(\partial q(z)/\partial z\right)(e_L - e_o)\}\right)$$

Thus in general the $\dot{S}=0$ isocline defines a non linear relationship on the (z,S) space, which could be monotonically decreasing, or have decreasing and increasing parts (see Figure 8).[276] As shown in the Appendix the S-S defined by the intersection of $z=z_3^*$ and the $\dot{S}=0$ isocline, with $S_3^* = n\left[z_3^* e_v + (1-z_3^*)Ee_L(q(z_3^*))\right]/b$, is unique and GAS in the interval $(0,1)$, with monotonic or oscillating approach dynamics. Therefore, in this case the following proposition holds:

Proposition 4: *Under a compliance dependent auditing probability, partial compliance to the public VA is the ES strategy.*

Furthermore,

[276] Moreover, it is clear that $dz/dS = b/n\left(e_v - e_o\right) < 0$ for $z_1^*=1$, while for $z_2^*=0$, $dz/dS = b/n\left(e_L - e_o + q'(z)(e_L - e_o)\right)$ is uncertain, which supports the potential existence of decreasing and increasing parts for the $\dot{S}=0$ isocline.

$$\frac{dz_3^*}{dF} = -\frac{q(z_3^*)}{q'(z_3^*)\Delta\Pi_C^N} > 0 \qquad (41)$$

Therefore increasing the fine increases the equilibrium compliance proportion and shifts the polymorphic steady state upwards, closer to the full compliance critical point. So under the appropriate adjustments of the fine, compliance in the left side neighbourhood of $z_1^* = 1$ is a GAS evolutionary equilibrium.

[Figure 8]

5.2.3 Emission Stock Dependent Auditing Probability

Assume that the auditing probability depends on the deviation from the established environmental goal. In the slow time scale the observed emission stock and thus the auditing probability $q(\Delta S)$ are no longer fixed. In this case the equilibrium condition $\dot{z} = 0$ for the replicator dynamic equation (36) defines the two monomorphic S-S $z_1^* = 1$ and $z_2^* = 0$, as well as a potential third one $z_3^* \in (0,1)$, determined by a critical emission stock level $\widehat{S}$, such that $\Phi = \left[q(\Delta\widehat{S})\Delta\Pi_C^N - \Delta\Pi_v^N\right] = 0$.

The type of the evolutionary equilibrium for the STCPS depends on the relationship between the critical emission stock level $\widehat{S}$, the full compliance emission stock level S_1^* and the non-compliance stock level S_2^*. In this case the nitrate pollution stock isocline $\dot{S} = 0$ is a non-linear, monotonic curve with negative slope,[277] while the critical emission stock level $\widehat{S}$ corresponding to $\dot{z} = 0$ is a vertical line in the (z, S) space. If $S_1^* > \widehat{S} > S_2^*$ then the intersection of $\widehat{S}$ with $\dot{z} = 0$ corresponds to $z_3^* \in (0,1)$ and the STCPS has three isolated S-S, while if $\widehat{S} < S_1^* < S_2^*$ or $\widehat{S} > S_2^* > S_1^*$ the STCPS has two isolated S-S (see Figure 9a). The properties of these EE are summarized in the following proposition:

[277] The slope of the pollution stock isocline $\dot{S} = 0$ is clearly negatively defined and equal to $dz/dS = \left(b - (1-z)q'(\Delta S)(e_L - e_o)\right)/n\left(e_v - Ee_L\left(q(\Delta S)\right)\right) < 0$.

Proposition 5: *Under an emission stock dependent auditing probability, the CPSTS could converge to either a polymorphic or monomorphic compliance evolutionary equilibrium. If* $\widehat{S} < S_1^* < S_2^*$ *then there is a GAS full compliance EE, and* $z_1^* = 1$ *is the ES strategy. If* $S_1^* > \widehat{S} > S_2^*$ *then there is a GAS partial compliance EE and* $z_3^* \in (0,1)$ *is the ES strategy with oscillating approach dynamics. If* $\widehat{S} > S_2^* > S_1^*$ *then there is a GAS no compliance EE and* $z_2^* = 0$ *is the ES strategy.*

For proof see Appendix III.

Furthermore since

$$\frac{d\widehat{S}}{dF} = -\frac{q(\Delta S)}{q'(\Delta S)(\Delta \Pi_C^N)} < 0 \tag{42}$$

the critical emission stock level declines with the level of the fine and the vertical isocline moves closer to the full compliance emission stock level in figure 9b. Moreover the polymorphic equilibrium point moves closer to the monomorphic steady state point A, implying that with the proper design of the non-compliance fine the regulator can induce a larger share of participating farmers to comply.

[Figure 9]

5.2.4 Joint Dependence of Auditing Probability on Compliance and Nitrate Pollution Stock

Assume that the auditing probability depends jointly on nitrate pollution stock and the proportion of complying farmers. Under $q = q(\Delta S, z)$ the condition $\dot{z} = 0$ for (36) defines two equilibria, $z_1^* = 1$ and $z_2^* = 0$, and a possible third one which is implicitly defined by an isocline $l(S)$ with the property:

$$z = l(S) \ : \ \Phi = \left[q(\Delta S, z)(\Delta \Pi_C^N) - (\Delta \Pi_v^N)\right] = 0$$

and slope $dz/dS = \left[-\vartheta q(\Delta S, z)/\vartheta S / \theta q(\Delta S, z)/\vartheta z\right] > 0$, which reflect the farmers' beliefs about the variability of the auditing probability value due to changes in the levels of the state variables S and z. If participating farmers perceive that changes in the nitrate pollution stock can not affect the auditing probability value, then $\partial q(\Delta S, z)/\partial S = 0$ and the auditing probability depends only on the compliance proportion and the isocline is parallel to the horizontal axis as in case 5.2.2. If participating farmers perceive that $\partial q(\Delta S, z)/\partial z = 0$, then the auditing probability depends only on the nitrate pollution stock and the isocline is vertical to the horizontal axis as in case 5.2.3. Thus the case of joint dependency of the auditing probability on S and z is a generalization of the two previous cases. It can be shown that the results are similar to the more specific cases above and can be summarized in the following proposition:

Proposition 6: *Under an auditing probability with joint dependence on compliance level and nitrate pollution stock, the evolutionary equilibrium of the CPSTS regarding compliance could be monomorphic, or polymorphic with possible multiple steady states. The type of the prevailing EE depends mainly on the slope and position of the* $z = l(S)$ *isocline. The flatter the isocline is, the more likely it is that the EE equilibrium implies partial compliance, which is the ES strategy in the case of a unique GAS evolutionary equilibrium. The more steeper the isocline is the more likely it is that EE equilibrium implies full compliance as the ES strategy*

For details see Appendix III and Figures 10 and 11.

The EE outcome can be further affected through the non-compliance fine, since it determines the position of the isocline $z(S)$. The higher the fine is, the more participating farmers tend to comply with the VA. Consequently the regulator can shift the isocline upwards, bringing the polymorphic equilibrium point closer to the monomorphic steady state, through the announcement of a sufficiently higher fine F.

[Figures 10 and 11]

5.2.5 Compliance Equilibria with a General Legislation Probability

Under a legislation probability jointly dependent on nitrate pollution deviation ΔS and participation proportion x, the EE steady state $x_3^*(\Delta S)$ in the fast time implies partial participation. To analyze the evolution of compliance and nitrate pollution stock we define the slow time system by substituting $x_3^*(\Delta S)$. Therefore under (11) the CPSTS is:

$$\dot{z} = z(1-z)\left[q(z,S)(\Delta\Pi_C^N) - (\Delta\Pi_v^N)\right] \qquad (43)$$

$$\dot{S} = n\{x_3^*(\Delta S)[ze_v + (1-z)Ee_L(q(z,S))] + (1-x_3^*(\Delta S))e_o\} - bS \qquad (44)$$

Under $p = p(\Delta S, x)$, the nitrate pollution stock isocline $z = k(S)$: $\dot{S} = 0$ could be a monotonic curve with a negative slope or have increasing and decreasing parts, depending on the type of the audit probability. In this case the $\dot{S} = 0$ isocline takes the following general form:

$$\psi(z,S) = z - \left(\frac{bS}{nx_3^*(\Delta S)\Delta e_L^v} - \frac{x_3^*(\Delta S)Ee_L(q(\cdot)) + (1-x_3^*(\Delta S))e_o}{x_3^*(\Delta S)\Delta e_L^v} \right) = 0$$
$$e_v - Ee_L(q(z,S)) = \Delta e_L^v$$

As previously the EE (z^*, S^*) of the CPSTS is highly dependent on the structure of the auditing probability q. Based on the conceptual framework developed in the previous section we conclude that:

Proposition 7: *Under a participation and nitrate pollution stock dependent legislation probability and a fixed or state variable dependent auditing probability, the EE equilibrium implies partial participation in the public VA and full, non or partial compliance of the participating subgroup of farmers.*

The CPSTS could be characterized either by a unique equilibrium or multiple equilibria and irreversibilities, with the final outcome crucially depending on initial conditions.[278]

6. The Impact of Auditing Costs and Budget Constraint on Evolutionary Equilibria

[278]Only in the case of a fixed audit probability is the $\dot{S} = 0$ isocline clearly a monotonic curve with negative slope and the CPSTS has a unique EE.

In this section we explicitly introduce a budget constraint that determines a maximum number of inspections. We assume that the available budget for auditing is exhausted in each period and that it consists of two components: an amount K exogenously determined by the regulator, and the sum of noncompliance fines F collected from participating farmers found in non-compliance after a random inspection.[279] Thus the budget is partially self financed and its level is determined endogenously. Particularly under (11) the flexible budget for period t can be defined as:

$$B_t = K_t + q(z, \Delta S, \omega_c)(1-z)F$$

The number of realized audits and therefore the auditing probability are dependent on the available budget of the regulatory body, implying that the auditing probability is endogenous to the budget. An increase in the budget allows a higher number of inspections and increases the auditing probability. Thus a more general formulation for the subjective audit probability (11) can be written as: [280]

$$q = q(z, \Delta S, B, \omega_c) \tag{45}$$

where $q_B > 0$ with $q_{BB} < 0$ and $0 < q_B < 1$. Moreover, we assume that $q = q(z, \Delta S, 0, \omega_c) = 0$, implying that no inspection can be conducted if there is not available budget.

Under this definition the available budget can take the general form:

$$B_t = K_t + q(z, \Delta S, B, \omega_c)(1-z)F \tag{46}$$

$$or\, B_t = B(K, S, z, F) \tag{47}$$

In this case even if the auditing probability is regarded as independent of z,[281] it is eventually dependent on the compliance proportion through the sum of collected fines, since it is defined as $\overline{q} = q(B)$ with $B_t = B(K, z, F)$.[282] After taking the total

[279] The noncompliance fine F is assumed to be fixed even though it could depend on compliance proportion and/or the pollution stock.

[280] No assumption is made about covering the monitoring costs in the following period.

[281] This corresponds to the case $\overline{q}$, as developed in the previous sections.

[282] The same holds under $q = q(\Delta S, B(K, S, z, F))$. In this case the CPSDS behaves as in the $q(z, \Delta S)$ case.

derivative of (46), the relationship between the budget and the variables K, S, z and F is determined. It holds that B_K, B_F and $B_S > 0$ while $B_z < 0$, denoting that the available budget increases either as K, F or ΔS increases and decreases as z increases.

Under the budget constraint and the general definition of the legislation and audit probability, (2) and (45), the CPSTS is defined as:

$$0 = x(1-x)\left[p(\Delta S, x)(\Delta S, x)\Delta\Pi_L^N - \Delta\Pi_v^N\right] \tag{48}$$

$$\dot{z} = z(1-z)\left[q(\cdot)\Delta\Pi_C^N - \Delta\Pi_v^N\right] \tag{49}$$

$$\dot{S} = n\{x(\Delta S)[ze_v + (1-z)Ee_L(q(\cdot))] + (1-x(\Delta S))e_o\} - bS \tag{50}$$

Thus, the CPSTS behaves as in the case where $q = q(z)$, or $q = q(z, \Delta S)$. Based on the conceptual framework developed in the previous sections we conclude that under a flexible partially fine-financed budget constraint, the behaviour of the system is similar to the behaviour under state dependent auditing probabilities.

The most notable difference between the present and previous CPSTS is that under the flexible budget described above, there can be no commitment to a fixed auditing probability and polymorphic EE are expected instead of monomorphic. Of course since one component of the budget is exogenous, then commitment to a certain fixed amount K is equivalent to commitment to a certain fixed auditing probability

To explore the impact of the exogenously amount K on the critical auditing probability $\overset{=}{q}(B(K, z_3^*, F))$ and compliance fraction z of the GAS polymorphic EE described in sections 5.2.1 and 5.2.2 respectively, we consider the following derivatives.

$$\frac{d\overset{=}{q}(B(K, z_3^*, F))}{dK} = -\frac{\partial \overset{=}{q}(B(K, z_3^*, F))}{\partial B}\frac{\partial B}{\partial K} < 0 \text{ and } \frac{dz}{dK} = -\frac{\partial B/\partial K}{\partial B/\partial z} > 0$$

It follows that as the amount K increases, the critical audit probability value decreases and the compliance proportion increases. The second derivative in particular implies that as the amount K increases, the number of financially feasible inspections increases, inducing more participating farmers to comply with the VA at the equilibrium. Under these circumstances the polymorphic steady state z_3^* shifts upwards, closer to the full compliance critical point. However, full compliance can not be achieved given the repelling property of the full compliance S-S.

7. Concluding Remarks

The purpose of this chapter is to analyze the long-run structure of a rural development program, in the form of a public VA, regarding participation and compliance of farmers and to specify certain characteristics that a VA should possess in order to induce the majority of, or even all, polluting farmers to participate in and comply with the VA. In this context we examine the evolution of participation in and compliance with the public VA, along with the evolution of nitrate pollution stock. Individual polluting farmers' decisions about whether or not to participate in and comply with the VA were based on the evolutionary processes of comparing expected profits associated with the different decisions, and were modelled by replicator dynamics operating in fast and slow time scales.

The main finding is that the structure of the legislation and auditing probability, and the levels of legislative emissions and non-compliance fines are the main factors characterizing the evolutionary equilibria and evolutionary stable strategies. If the legislation probability is fixed in fast time, and is set higher than a critical value, then the equilibrium outcome is monomorphic implying that all the farmers participate in the agreement. On the other hand, if the legislation probability depends jointly on emission stock and participation proportion, the evolutionary equilibrium is polymorphic, implying partial participation. In this case the regulator can lead the equilibrium outcome sufficiently to full participation through the proper design of the legislation mandate and particularly through the magnitude of the legislative emissions $\boldsymbol{e_L}$.

By committing to a fixed auditing probability higher than a critical value, the regulator can achieve full compliance of participating farmers. The same outcome can be achieved under certain initial conditions when the auditing probability depends on the nitrate pollution stock and the complying proportion. In this case however the dynamic system describing the evolution of compliance and the nitrate pollution stock can alternatively converge to a partial compliance steady state, either monotonically or oscillating. Under certain conditions the compliance-nitrate pollution stock system is characterized by multiple equilibria and irreversibilities. The introduction of a budget constraint to cover monitoring costs, with partial financing through the collection of fines, leads the compliance-nitrate pollution stock system to a polymorphic evolutionary equilibrium, implying partial compliance of participating farmers with the agreement's provisions.

In conclusion, the more complex the structure of the legislation and audit probability is, the more likely that the evolutionary equilibrium is polymorphic, and depends largely on the initial conditions. With no binding budget constraint regarding monitoring costs, commitment to legislation and auditing probabilities along with properly chosen legislative mandate and non compliance fines can induce full participation and compliance with the public VA. If these conditions are not fulfilled or the available budget is limited, then partial participation, partial compliance with multiple equilibria and irreversibilities, and even fluctuation in the nitrate pollution stock are possible evolutionary outcomes.

PART III:
"Conclusions, Contribution to Bibliography and Potential Extensions"

Undoubtedly agricultural activities are a decisive factor in the maintenance of the viability and diversity of rural communities, landscape and habits, as well as in the protection of the ambient environment. However despite the recorded beneficial environmental services, European agriculture has been associated with a series of adverse environmental effects, summarised in:

- *Loss of biodiversity*, *landscape diversity and quality,* as well as *deterioration of important habitants*.
- *Threats to high natural value farming systems* and *traditional forms of agriculture in marginal areas*.
- *Degradation of soil, air and water quality*.

Such pollution problems are also associated with uncertainty regarding the identity of polluting farmers and the degree of each agent's contribution to total pollution, resulting mainly from:

- The stochastic influences that affect the fate and transport of pollutants,
- The great number of static polluting sources, and /or
- The regulator's inability to infer individual emissions from ambient pollution levels or inputs used.

These features have classified agricultural pollution problems into the category of non-point-source pollution problems, a fact that limits the range of feasible agri-environmental policies and sets considerable restrictions in the design of an effective interventory policy. Hence, even though regulatory intervention is justified by the failure of the unregulated competitive market to induce farmers to operate in the socially optimal way, the standard policy instruments - such as Pigouvian taxes, tradeable permits and emission standards - appear to be inadequate to efficiently handle NPS pollution problems thus turning the attention of policy makers to measures that focus on other elements of NPS pollution problems that may be observable, such as polluters' decisions or the consequences of their actions.

Over the last two decades a number of regulatory approaches have been developed in the environmental economics literature, for dealing with such kind of NPS pollution problems. According to the potentially available information set the following policy schemes have been considered:

- ✓ Effluent-based schemes, where emissions, when it is possible for them to be observed or inferred with some accuracy, are the basis for the design of alternative instruments.
- ✓ Input-based schemes, where inputs which contribute to agricultural NPS pollution are the basis for the design of policy instruments.
- ✓ Output-based schemes, where the basis for the instrument design is the output of production processes contributing to pollution.
- ✓ Ambient-based schemes, where in the absence of information about the farmers' individual contribution to pollution, the ambient pollution levels measured at receptor points are the basis for the instrument design.
- ✓ Mixed-based schemes, where both ambient and individual emissions are the basis of regulation.

Even though environmental policy heavily relied initially on command-and-control measures as well as market-based incentives, the non-point-source character of agricultural pollution made necessary the development of new instruments. Indeed in the last decade there has been a noticeable turn towards Voluntary Approaches, a new instrument used in EU agricultural policies, which is considered to be a complement to the conventional regulatory system since it combines both voluntary and mandatory tools, where the basis for regulation is a voluntary agreement between farmers and regulators with the ultimate purpose of reducing agricultural NPS pollution, such as nitrates leaching pollution.

Although there is a considerable body of scientific work in the area of NPS environmental regulation, the review of environmental economic literature indicated strong reliance of the analytical regulatory framework of non-point-source pollution problems on the standard theory of optimizing behaviour. Thus the assumption of unboundedly rationality is used in modeling the agents' decision to comply with regulation or not, or to participate in a VA. Regulated agents are treated "*as if*" they were consciously gathering all the necessary data to consider all possible alternatives and thus solve a complicated problem in order to calculate the optimum response that maximizes their payoff. However, little work has been done in the area of bounded rationality and evolutionary imitation dynamics in modelling compliance and participation decisions. In practice there is a finite limit to the amount of information agents can possess and process. Boundedly rational players learn, imitate and adapt to the strategies of others in light of payoff experience. Strategies with higher payoff spread within the population at the expense of less successful strategies and the most commonly employed dynamic systems to describe such mass action approaches are the replicator dynamics models.

Given these observations the present study focuses on:

- Voluntary Approaches as an alternative regulatory measure to control agricultural non-point-source pollution problems, as well as
- Bounded rationality for the agents' compliance and participation in VAs decisions as an alternative analytical method designing regulation for agricultural non-point-source pollution problems.

In the above context the Thesis:

- Assesses the effectiveness of existing public voluntary environmental programs dedicated fully to the agricultural sector, as described by the Nitrates Directive and / or the CAP reforms of the European Commission.
- Assesses and compares the dynamic behavior, regarding participation and compliance, of a population of regulated farmers based on the alternative assumptions of unboundedly and boundedly rational economic agents.
- Describes the design of optimal regulation under the optimizing and imitation behavioral assumptions.
- Provides a conceptual framework for the proper design of a public voluntary program and inspection mechanisms.

A review of the main points examined in each chapter of Part II of the Thesis is presented below:

Chapter I:
Regulation of Farming Activities: An Evolutionary Approach

Chapter I examined the potential impact of restrictions on the degree of rationality of decision makers (i.e. farmers) on the compliance incentives of a population of regulated agents. It focused on a public program combining features of the Council Nitrates Directive (91/676/EEC) and the agri-environmental programs of the second pillar of CAP, in order to contrast the dynamics of the population of agents which could be unboundedly or boundedly rational in their decision to participate and / or comply with the program. In this context a problem of both arbitrary and optimal monitoring effort selection was analyzed and further extended to allow for monitoring capital investment decisions.

Under the considered public program individual farmers are required to restrict nitrogen input usage to a predetermined level, while they are offered a subsidy per unit of nitrogen usage reduction beyond this target. Compliance with statutory performance standards involves profit losses, which can be averted by cheating, given the non-point-source characteristics of agricultural activities. If individual actions (i.e. nitrogen usage) remain unobservable to a third party, then individual farmers can deviate from environmental requirements, thus receiving a higher payoff than the compliant farmers. If such a noncompliant behaviour is detected, then a set of sanctions is imposed making deviating farmers worse off in terms of payoff. Thus in the decision to deviate farmers must take into account the impact of monitoring on the structure of payoffs.

The effectiveness of the given policy framework to stimulate adequate compliance incentives is affected by the magnitude of undertaken monitoring effort, as well as by the perceptions that regulated agents form about its impact on the payoff structure. According to the degree of rationality, regulated agents adopt either an optimizing or an imitation behavioural rule in order to decide whether it is beneficial to comply with the suggested nitrogen usage constraint. If agents are fully rational then they behave as though they had perfect information about the impact of monitoring on payoff structure and thus choose their individual strategy in an optimal manner. If agents have limited information then the decision about whether to comply or not is based on individual perceptions about the impact of monitoring and is adapted to the information revealed via their interactions over time. Such passive decision making is based on the imitation of the better-off performing strategy and is modelled by replicator dynamics rule, where more successful strategies gradually increase their share in the population at the expense of less successful strategies.

The magnitude of monitoring effort (and investment in monitoring capital) can either be selected in an arbitrary way based on the alternative behavioural rule adopted by farmers, or it can be selected in an optimal manner through the minimization of a social cost criterion that is constrained by the full or bounded rationality rules. The analytical framework developed within this section discusses the choice of monitoring effort, as well as investment in monitoring capital which could stimulate long-term compliance. The conceptual framework allows the determination and the comparison of the equilibrium fraction of complying farmers, from a large population of homogeneous farmers under, the alternative rules regarding the degree of rationality and the selection of monitoring mechanism.

The analysis indicated that if the value of monitoring effort is chosen arbitrarily then independent of the considered rationality degree, the population of regulated farmers adopts a monomorphic behavior, involving either full compliance or full non-compliance with established environmental requirements. To guarantee full compliance the monitoring effort value needs both to be fixed and set higher than the critical value, making farmers indifferent between the compliant and deviation strategy under both behavioural rules. The only differentiation is the time occurrence of the long-run behaviour since under unbounded rationality there is instant convergence to the desired steady-state, while under bounded rationality there is gradual convergence to full compliance. If undertaken monitoring effort is chosen optimally then there is a modification in the long-run behavior of the population. Under the conventional optimization problem, constrained by the optimizing behavioural rule, the same monomorphic behaviour emerges, while if the social welfare criterion is minimized conditional to the imitation behavioural rule, then a polymorphic behaviour involving partial compliance of the population is very likely as an evolutionary stable equilibrium. The occurrence of polymorphic equilibria depends on the initial conditions of the problem. Finally, the dynamics of the population display identical properties in the presence of investment in monitoring capital, suggesting that the compliance incentives of a given population are affected by the selection rule of monitoring effort, as well as by the alternative behavioural rules regarding the rationality degree of farmers.

The contribution of the paper consists in

- ✓ Contrasting the long-run behaviour of a population regarding compliance with existing regulation under the traditional assumption of unbounded rationality and the alternative assumption of bounded rationality as modelled by replicator dynamics.
- ✓ Combining a dynamic optimal control problem with proportional imitation behavioural rule modelled by replicator dynamics instead of the conventional optimizing rule.

The current chapter developed a generalized framework for analyzing the dynamic behavior of a population of regulated economic agents operating in a non-point-source pollution context under the presence of a monitoring and enforcement mechanism. Suggestions for the proper design of the monitoring and enforcement mechanism that guarantee at least partial compliance of the population are provided. Given that the examined public voluntary environmental program displays many similarities with the various EU rural development programs, the developed analytical framework can be adapted accordingly to provide helpful insights for the proper design of the monitoring mechanism considered in each case.

The generalized framework developed in the present chapter can be further employed to assess the populations' compliance incentives with given environmental regulations under a context of imperfect monitoring, in the sense that individual decisions (i.e. emissions, inputs usage) may not be inferred correctly and a farmer may be erroneously fined.[283] Furthermore, the long-run behaviour of the farmers' population

[283] For details see Malik (1993).

can also be analyzed under different imitation behavioural rules such as the average profit principle and effective punishment principle, in order to detect potential modifications in the qualitative characteristics of the resulting steady-state equilibriums.[284] Finally, it would be interesting to simultaneously combine, in an optimal regulation problem, both the optimizing and the imitating behavioural rule for different parts of the population.

Chapter II: Modelling of Agricultural Behaviour under the CAP Regime: Assessment of Environmental Impacts and Policy Effectiveness

Chapter II developed a conceptual generalized theoretical model of farming behaviour embodying the basic reforms for the common market organizations and for rural development, as prescribed by the first and second pillars of Agenda 2000. It focused on the assessment of the impact of the different type of CAP measures on the environmental performance of a population of homogeneous farmers through the problem of a representative farmer independent of the assumed degree of rationality. It also evaluated the effectiveness of the given reform to stimulate compliance of the entire population with a predetermined social environmental target, by considering the mechanism that provides the type of optimal CAP instruments which guarantee the achievement of such a target, along with the type of interdependence characterizing them, under the analytical framework of unbounded and bounded rationality.

Under the considered formal public voluntary program, each farmer is eligible for a production subsidy and two types of direct payments, provided on the basis of cultivated and set-aside land. Based on the horizontal regulation, direct payments are conditional to environmental requirements (i.e. horizontal regulation) in the form of a land quality and land usage standard. Environmental aims can also be attained through secondary production choices that are partially financed through a rural development program providing a set of subsidies per unit of established treatments. Given the inherent free-riding incentives associated with the non-point-source pollution characteristics of agricultural activities, direct payments and rural development

[284] For details see Lipatov (2005).

subsidies are subject to the cross-compliance principle, a sanctioning approach incorporated in the horizontal regulation that involves proportional penalties for environmental infringements entailing partial or full removal of aid if deviation from certain farming standards is detected after a random inspection.

The generalized nature of the developed analytical framework allowed the assessment of the relative impacts of the various CAP regimes, as foreseen by the 1999 CAP reform, on the environmental performance of a population of homogeneous farmers in terms of equilibrium primary and / or secondary production choices, by evaluating the optimality conditions of a given CAP subregime at the profit maximizing equilibrium choices of an alternative regime. The compared CAP subregimes were characterised either by CMOs payments (i.e. full coupling, partial and full decoupling regime), RD payments (i.e. rural development regime) or by a combination of CMOs and RD payments (i.e. extended full coupling, partial and full decoupling regime). Using a non-linear system defined by the optimality conditions of the social planner and the representative deviating farmer, the policy effectiveness of Agenda 2000 to induce the entire population of unboundedly rational agents to adopt the socially optimal production choices was discussed by defining, both in a static and a dynamic context, the type of socially optimal Pillar I (and Pillar II) measures, along with the type of correlation characterizing them. Finally, given the assumption of bounded rationality, the long-run viability of the 1999 CAP reform was assessed. The replicator dynamics framework was employed to define the selection mechanism of optimal CAP instruments and thus examine whether the current structure of the reformed CAP can induce the majority, or even the entire population of farmers, to adopt the compliant strategy.

The analysis indicated that direct payments and the compliance enforcement mechanism may not be sufficient to induce deviating farmers to alter their production choices and adopt a strategy approaching (or even matching with) the complying strategy. Nevertheless, the incorporation of farming constraints and rural development measures has enhanced the environmental performance of the regulated population. Nonintervention is preferable on environmental grounds to intervention via production subsidies, while the environmental performance of the partially or fully decoupled regime can not be clearly inferred to be superior to the performance resulting under the unregulated and full coupling regime. Even though intervention via fully decoupled payments, both in the absence and in the presence of farming standards, is environmentally preferable in terms of main production choices to intervention via partially decoupled payments, when the set of production choices is extended with secondary production choices the relative environmental performance of the regulated population becomes ambiguous.

When considering both main and secondary production choices the environmental performance under the initial CAP regime (i.e. full coupling) cannot be clearly inferred as inferior to the relative environmental performance under its successor CAP regimes, as described by the intermediate CAP regimes of partially or fully decoupled payments and the ultimate CAP regime of rural development. In particular, even though the full coupling regime involves higher usage of the main production choices compared to the rural development CAP regime, their relative environmental performance in terms of secondary production choices is ambiguous and can be assessed only under assumptions. Similar are the findings of analysis concerning the relative environmental performance of the full coupling regime compared to the partially and fully decoupled CAP regime. Hence, under the developed theoretical framework describing the structure of farming behaviour under the Agenda 2000 provisions, the perception of the European Commission that the transition initially from the full coupling regime to the regime involving partial or full decoupling of CMOs payments both in the absence and the provision of RD payments, and ultimately to the regime involving solely the provision of RD payments, has induced the population of farmers to restrict main and increase secondary production choices, could not be verified with certainty implying that under certain conditions the old regime can be preferable on environmental grounds its successors.

Finally, the assessment of optimum measures of CAP associated with common markets organizations and rural development, both in an unbounded and a bounded rationality context, indicated that it may be socially desirable on environmental grounds to retain coupled payments, as well as extend the compliance enforcement mechanism with a set of charges on the various aspects of farming activity such as crop yields, land-usage, set-aside-land and / or secondary production choices. Given that such measures are not foreseen in the current structure of CAP and that the attainment of first-best aggregate land quality requires time-flexible policy instruments, suboptimalities occur and both the effectiveness and long-run viability of Agenda 2000 and Mid-term review CAP reforms is doubtful and dependent on existing conditions.

The contribution of the current chapter consists in the:

- ✔ Development of a theoretical model of farm activity under the generalized regime of CAP provision, allowing via simplifying assumptions the definition of the various CAP subregimes.
- ✔ Theoretical assessment and comparison of the environment impacts and the long term viability of the CAP subregimes of the Agenda 2000 reform.
- ✔ Design of the optimal measures of CAP associated with common markets organizations and rural development under unbounded and bounded rationality assumptions.

The generalised conceptual framework developed in this chapter that can be further employed to provide insights into the relative environmental impacts of regulation with similar and conflicting features, as well as into the definition of the type of policy instruments that make feasible the long run attainment of a collective environmental target (i.e. abatement of greenhouse gases or livestock manure) or nonenvironmental target (i.e. investment in productive R&D, reduction of unemployment rates).

The theoretical framework can be further extended to account for more specific features of the Agenda 2000 and Mid term Review such as the "carbon credit" provided to non-food, energy crops grown on set-aside land, as well as the revised cross-compliance principle that is designed to account for negligent and deliberate non-compliance. The environmental performance of the farmers' population under the considered regulatory regime can also be assessed under the presence of uncertainty shocks (i.e. floods) and lobbying pressures.

Chapter III:
Design of Public Voluntary Environmental Programs for Nitrate Pollution in Agriculture: An Evolutionary Approach

Chapter III examined the joint evolution of the participation and compliance incentives with the requirements of a public voluntary program, of a regulated population in the presence of fast-slow selection dynamics in the occurrence of the participating and complying decision. It focused on the development of a public voluntary environmental program in the form of a rural development program of CAP, on the definition of the factors contributing to its environmental sustainability, as well as on the statement of general principles for the attainment of a desirable environmental target both in the presence and absence of a budget constraint.

Under the considered public program a voluntary restriction of individual nitrates emissions was offered to a large number of homogeneous farmers with the ultimate target being the attainment of a predefined ambient pollution level. In the event of limited participation of the population in the public VA, there is a deviation from the target and a positive probability of costly legislation. Participation, however, does not necessarily involve compliance with the program's environmental provisions. Given that the simultaneous verification of compliance status of involved agents is infeasible, the regulatory authority detects non-compliant farmers via random inspections and deters such deviating behaviour through fines. Thus there is a nonzero probability that farmers participating in the public VA will be inspected and assessed a fine if found not in compliance with environmental requirements.

Given the assumption of bounded rationality, regulated agents adopt an evolutionary dynamic framework in order to decide whether to participate in and comply with the provisions of the agreement. Such a passive decision making is based on the imitation of the best-performing strategy in terms of payoff. To model modifications in the composition of the population regarding participation in and compliance with the public VA, the replicator dynamics framework is employed. It is also considered that the participation and compliance decision evolves in different time scales. Legal time constraints induce the participation decision to evolve fast, while the decision to comply is unrestricted and evolves slow. Such fast-slow selection dynamics imply that the evolutionary equilibrium composition of farmers regarding participation is reached faster than the equilibrium composition of compliant farmers.

The developed evolutionary framework allows the joint determination of the steady-state equilibrium fraction of signatory and complying farmers, as well as the corresponding steady-state ambient pollution. Analysis indicated that the characteristics of the evolutionary stable steady states and their approach dynamics are both affected by the value and type of the legislation and inspection probability, as well as by the presence or not of a budget constraint. Under different assumptions about the structure of the legislation probability, the fast system can alternatively converge to a polymorphic or monomorphic steady-state characterized either by partial or full (or zero) participation in the public VA. Similarly, the slow system can converge to a steady-state characterized either by partial or full (or zero) compliance depending on the structure of the inspection probability. The more complex the structure of the considered probabilities is, the more likely it is that the evolutionary equilibrium involves both partial participation and partial compliance. There is also a possibility that the system experiences multiple equilibria and irreversibilities, while the convergence to steady states can either be monotonic or oscillating. Full participation and full compliance can be achieved if the regulator precommits to both fixed inspection and fixed audit probability or through the proper selection of the legislation mandate and noncompliance fine. The same outcome can be reached under certain initial conditions and properly selected fines, when the audit probability is dependent on the state variables of the problem. However, if such conditions are not satisfied or the budget constraint is limited, then partial participation and partial compliance is the possible evolutionary outcome.

The contribution of the current chapter lies in the fact that it:

- ✔ Combines successfully into a unified analytical framework of regulation design through VAs the notions of bounded rationality as modeled using the proportional imitation rule and replicator dynamics, and the time-differentiation in the decision making as modeled through the fast and slow selection dynamics.

This chapter developed a generalized framework for analyzing the behavior of regulated economic agents operating in a typical non-point-source pollution problem. The methodological framework renders feasible the simultaneous evaluation of the different motives of a large population of agents towards existing regulations, such as voluntary environmental agreements. It elicits conclusions regarding the impact of the various policy elements in the long-run evolutionary equilibrium composition of the population, allowing the definition of policy implications for the proper design of regulations.

The proposed public voluntary environmental program displays many similarities to EU programs for the development of rural areas, provided by the CAP regime. Hence, a form is provided for the design of rural development programs that guarantee at least partial participation and compliance of the population, given the budgetary restrictions of CAP.

In this generalized context the results obtained might provide some insights related to the expected efficiency and long run outcome regarding participation in and compliance with the EU Nitrate Directive (91/676/EEC). It seems that the voluntary attainment of the Directive's target depends on the existence of a credible threat of mandatory regulation which would imply implementation of action programmes and extension of vulnerable zones. Crucial to the attainment of compliance is also the existence of some non-compliance penalty, or some mechanism that will effectively decrease the profits of non-complying farmers. Nevertheless, more precise analysis and prediction regarding the long-run impacts of the EU Nitrate Directive, requires a less general model that is however more specific to the directive structure and entails the principle of non-compliance of aid.

Areas for Further Research

The current thesis deliberately focused on certain aspects of the agricultural pollution problems and intervention in order to provide some insights about the potential differentiation in the long run behaviour of a population of regulated agents under the alternative assumption of unbounded and bounded rationality (Chapter I), the environmental efficiency of existing regulations and the structure of the optimal policy intervention (Chapter II), along with the structure of effective public environmental programs and audit systems (Chapter III).

There exist, however, a number of noticeable features of agricultural pollution problems and agri-environmental regulations that differentiate them from the conventional type of pollution problems and policy intervention, which could be embodied as further extension of the analytical framework developed in this thesis. Hence, it would be interesting to consider areas of further research, which include:

- ✓ Uncertainty, given the fact that both the emission and production function are affected by stochastic factors (i.e. weather, equipment malfunctions).
- ✓ The case of imprecise inspections and considerable budgetary restrictions.
- ✓ A setting of incomplete information, dual information asymmetry and heterogeneity by type or distinctive characteristics of polluting agents.
- ✓ A differentiated evolutionary context where each individual agent interacts in each time period with two or more agents, such as the average profit principle and effective punishment principle.
- ✓ A policy framework involving negotiated or unilateral voluntary approaches.
- ✓ A situation where lobbying pressures from regulated agents may influence the policy parameters (i.e. monitoring, sanctions).

These could be considered as the subsequent step of ongoing research, which would entail a more specific tailoring of the general concepts and mechanism developed in this thesis to the structure of public voluntary programs designed for the European agricultural sector.

Appendices

Appendix I

The state-costate MHDS (18) - (19) defines three potential socially-optimal equilibrium pairs $\left(x_i^*, \lambda_i^*\right)$, implying either full compliance $\left(x_1^*, \lambda_1^*\right)$, noncompliance $\left(x_2^*, \lambda_2^*\right)$ or partial compliance $\left(x_3^*, \lambda_3^*\right)$ with ND. To characterize the equilibrium type of each steady state the linearization matrix J around each critical point is evaluated, along with their traces $Tr(J) = \frac{d\dot{z}}{dz} + \frac{d\dot{S}}{dS}$, determinants $Det(J) = \frac{d\dot{z}}{dz}\frac{d\dot{S}}{dS} - \frac{d\dot{z}}{dS}\frac{d\dot{S}}{dz}$ and discriminants $\Delta = \left[Tr(J)\right]^2 - 4Det(J)$.

The linearization matrix J is given by:

$$J_i^* = \begin{bmatrix} (1-2x_i^*)\Omega(\beta_i^*) + x_i^*(1-x_i^*)\frac{\partial p}{\partial \beta}\frac{\partial \beta^*}{\partial x}\Upsilon & x_i^*(1-x_i^*)\frac{\partial p}{\partial \beta}\frac{\partial \beta^*}{\partial \lambda}\Upsilon \\ 2\lambda_i^*\Omega(\beta_i^*) - \lambda_i^*(1-2x_i^*)\frac{\partial p}{\partial \beta}\frac{\partial \beta^*}{\partial x}\Upsilon & \rho - (1-2x_i^*)\Omega(\beta_i^*) - \lambda_i^*(1-2x_i^*)\frac{\partial p}{\partial \beta}\frac{\partial \beta^*}{\partial \lambda}\Upsilon \end{bmatrix}$$

It can be seen that:

- Full compliance $\left(x_1^*, \lambda_1^*\right)$

In this case the Jacobian matrix is:

$$J_1^* = \begin{bmatrix} -\Omega\left(\beta_1^*\right) & 0 \\ 2\lambda_1^*\Omega\left(\beta_1^*\right) & \rho + \Omega\left(\beta_1^*\right) \end{bmatrix}$$

since $\frac{\partial \beta^*}{\partial x}\Big|_{x_1^*}, \frac{\partial \beta^*}{\partial \lambda}\Big|_{x_1^*} = 0$. Given that $\Omega(\beta_1^*)) > 0$ the trace and determinant around $\left(x_1^*, \lambda_1^*\right)$ are:

$$Det\left(J_1^*\right) = -\Omega\left(\beta_1^*\right)\left(\rho + \Omega\left(\beta_1^*\right)\right) < 0 \text{ and } Tr\left(J_1^*\right) = \rho > 0$$

indicating that the full compliance steady state $\left(x_1^* = 1, \lambda_1^*\right)$ satisfies the saddle point property.

- Full noncompliance $\left(x_2^*, \lambda_2^*\right)$

The Jacobian matrix is:

$$J_2^* = \begin{bmatrix} \Omega(\beta_2^*) & 0 \\ 2\lambda_2^*\Omega(\beta_2^*) & \rho - \Omega(\beta_2^*) \end{bmatrix}$$

since $\frac{\partial \beta^*}{\partial x}\Big|_{x_2^*}, \frac{\partial \beta^*}{\partial \lambda}\Big|_{x_2^*} = 0$. Hence, given that $\Omega(\beta_2^*)) < 0$ it holds:

$$Det(J_2^*) = -\Omega\left(\beta_2^*\right)\left(\rho + \Omega\left(\beta_2^*\right)\right) < 0 \text{ and } Tr\left(J_2^*\right) = \rho > 0$$

indicating that the non compliance steady state $\left(x_2^* = 0, \lambda_2^*\right)$ satisfies also the saddle point property.

- Partial compliance $\left(x_3^*, \lambda_3^*\right)$

In this case $\Omega(\beta^*(x_3^*, \lambda_3^*)) = 0$, $\frac{\partial \beta^*}{\partial \lambda}\Big|_{x_3^*} < 0$ and $\frac{\partial \beta^*}{\partial x}\Big|_{x_3^*} > 0$ if $x_3^* \in (0,1/2)$, while $\frac{\partial \beta^*}{\partial x}\Big|_{x_3^*} < 0$ if $x_3^* \in (1/2,1)$. The Jacobian matrix around the polymorphic steady state is given by:

$$J_3^* = \begin{bmatrix} x_3^*(1-x_3^*)\frac{\partial p}{\partial \beta}\frac{\partial \beta^*}{\partial x}\Upsilon & x_3^*(1-x_3^*)\frac{\partial p}{\partial \beta}\frac{\partial \beta^*}{\partial \lambda}\Upsilon \\ -\lambda(1-2x_3^*)\frac{\partial p}{\partial \beta}\frac{\partial \beta^*}{\partial x}\Upsilon & \rho - \lambda(1-2x)\frac{\partial p}{\partial \beta}\frac{\partial \beta^*}{\partial \lambda}\Upsilon \end{bmatrix}$$

where the associated trace and determinant are given by:

$$Det\left(J_3^*\right) = \rho x_3^*(1-x_3^*)\frac{\partial p}{\partial \beta}\frac{\partial \beta^*}{\partial x}\Upsilon$$

$$Tr\left(J_3^*\right) = \rho + \frac{\partial p}{\partial \beta}\Upsilon\left\{x_3^*(1-x_3^*)\frac{\partial \beta^*}{\partial x} - \lambda_3^*(1-2x_3^*)\frac{\partial \beta^*}{\partial \lambda}\right\}$$

If $x_3^* \in (0,1/2)$ then $Det\left(J_3^*\right) > 0$, while the sign of $Tr\left(J_3^*\right)$ is uncertain. If the structure of marginal social benefits and costs is such that the stability requirement:

$$\rho + x_3^*(1-x_3^*)\frac{\partial p}{\partial \beta}\frac{\partial \beta^*}{\partial x}\Upsilon < -\lambda_3^*(1-2x_3^*)\frac{\partial p}{\partial \beta}\frac{\partial \beta^*}{\partial \lambda}\Upsilon$$

is satisfied and $Tr\left(J_3^*\right) < 0$ then (x_3^*, λ_3^*) is a stable steady state and, depending on the sign of the discriminant Δ, it can be a stable proper node $\left(if\ \Delta = 0\right)$, a stable improper node $\left(if\ \Delta > 0\right)$, while if $\Delta < 0$ it is stable focus. In the special case that $Tr\left(J_3^*\right) = 0$ and $\Delta < 0$, then the polymorphic steady state is center.[285]

If $x_3^* \in (1/2,1)$ then the polymorphic steady state is a saddle point given that $Det\left(J_3^*\right) < 0$, while in the special case that $x_3^* = 1/2$ then the dynamic system experiences a nonhyperbolic point.

[285]For details see Xepapadeas (1997), pages 267-266.

Appendix II

Table 1: The relative environmental performance of the CAP regimes g and h in terms of input usage (x_i) and labour usage (ℓ).

$\Delta(x)_h^g = x_g - x_h$ and $\Delta(\ell)_h^g = \ell_g - \ell_h$													
$g \backslash h$	2	3*a*	3*b*	4*a*	4*b*	5*a*	5*b*	6*a*	6*b*	7*a*	7*b*	8*a*	8*b*
1	−	−	?	0	+	−	?	−	?	0	+	0	+
2		0	+	+	+	0	+	0	+	+	+	+	+
3*a*			+	+	+	0	+	0	+	+	+	+	+
3*b*				?	+	−	0 (?)	−	0 (+)	?	+	?	+ (?)
4*a*					+	−	?	−	?	0	+	0	+
4*b*						−	− (?)	−	− (?)	−	0 (+)	−	0 (?)
5*a*							+	0	+	+	+	+	+
5*b*								−	0 (+)	?	+	?	+
6*a*									+	+	+	+	+
6*b*										?	+	?	+ (?)
7*a*											+	0	+
7*b*												−	0 (+)
8*a*													+

Table 2: The relative environmental performance of the CAP regimes in set-aside terms (b^f).

$\Delta(b^f)_h^g = b_g^f - b_h^f$													
$g \backslash^h$	2	3*a*	3*b*	4*a*	4*b*	5*a*	5*b*	6*a*	6*b*	7*a*	7*b*	8*a*	8*b*
1	+	?	?	?	?	+	?	?	?	?	?	0	−
2		?	?	?	?	0	−	?	?	?	?	−	−
3*a*			− (?)	−	− (?)	?	?	0	− (?)	−	− (?)	?	?
3*b*				?	−	?	?	+ (?)	0 (−)	?	− (?)	?	?
4*a*					− (?)	?	?	+	?	0	− (?)	?	?
4*b*						?	?	+ (?)	+ (?)	+ (?)	0 (−)	?	?
5*a*							−	?	?	?	?	−	−
5*b*								?	?	?	?	?	−
6*a*									− (?)	−	− (?)	?	?
6*b*										?	−	?	?
7*a*											− (?)	?	?
7*b*												?	?
8*a*													−

Table 3: The relative environmental performance of the CAP regimes g and h in terms of input usage treatment (t^x), land usage treatment (t^c) and set-aside treatment (t^{nc}).

$\Delta(t^x)_h^g, \Delta(t^c)_h^g$ and $\Delta(t^{nc})_h^g$													
g\h	2	3*a*	3*b*	4*a*	4*b*	5*a*	5*b*	6*a*	6*b*	7*a*	7*b*	8*a*	8*b*
1	0	0	–	0	–	–	–	–	–	–	–	–	–
2		0	–	0	–	–	–	–	–	–	–	–	–
3*a*			–	0	–	–	–	–	–	–	–	–	–
3*b*				+	0	?	– (?)	?	–	?	–	?	– (?)
4*a*					–	–	– (?)	–	–	–	–	–	– (?)
4*b*						?	– (?)	?	–	?	–	?	– (?)
5*a*							–	0	–	0	–	0	–
5*b*								+	0 (–)	+	0 (?)	+	0
6*a*									–	0	–	0	–
6*b*										+	0	+	0 (+)
7*a*											–	0	–
7*b*												+	0
8*a*													–

Table 4: The relative environmental performance of the CAP regimes g and h in terms of labour usage treatment (t^{ℓ}).

$\Delta(t^{\ell})_h^g$													
$g\backslash^h$	2	3*a*	3*b*	4*a*	4*b*	5*a*	5*b*	6*a*	6*b*	7*a*	7*b*	8*a*	8*b*
1	−	−	−	0	−	−	−	−	−	0	−	0	−
2		0	−	+	?	0	−	0	−	+	?	+	?
3*a*			−	+	?	0	−	0	−	+	?	+	?
3*b*				+	+	+	0 (?)	+	0 (−)	+	+ (?)	+	+ (?)
4*a*					−	−	−	−	−	0	−	0	−
4*b*						?	− (?)	?	−	+	0 (−)	+	0 (?)
5*a*							−	0	−	+	?	+	?
5*b*								+	0 (−)	+	+ (?)	+	+
6*a*									−	+	?	+	?
6*b*										+	+	+	+
7*a*											−	0	−
7*b*												+	0 (+)
8*a*													−

where (1) unregulated regime (UN), (2) full coupling regime (FC), (3) partial decoupled regime (PD), (4) full decoupled regime (FD), (5) extended full coupling regime (EFC), (6) extended partial decoupled regime (EPD), (7) extended full decoupled regime (EFD), (8) rural development regime (RD). Let (a) denote the absence and (b) the presence of performance standards within the examined CAP regime.

The indication $(-)$ in $\Delta_h^g(x), \Delta_h^g(\ell)$ and $\Delta_h^g(t^x), \Delta_h^g(t^c)$, as well as in $\Delta_h^g(t^{nc}), \Delta_h^g(t^{\ell})$ tables, implies that regime h involves higher usage of the given main and secondary production choices, while the same indication in $\Delta_h^g(b^f)$ table denotes that regime h sets aside more land. If the indication is modified under the deviating strategy compared to the compliant strategy, then the altered indication is shown in parentheses.

Appendix III

In order to characterize the way the STCPS converges to the equilibrium the linearization matrixes J around the S-Ss are defined along with their traces $Tr(J) = \frac{d\dot{z}}{dz} + \frac{d\dot{S}}{dS}$, determinants $Det(J) = \frac{d\dot{z}}{dz}\frac{d\dot{S}}{dS} - \frac{d\dot{z}}{dS}\frac{d\dot{S}}{dz}$ and discriminants $\Delta = [Tr(J)]^2 - 4Det(J)$.

- *Fixed Auditing Probability*

The STCPS is defined as:

$$\dot{z} = z(1-z)\left[\overline{q}\Delta\Pi_C^N - \Delta\Pi_v^N\right]$$
$$\dot{S} = n\{ze_v + (1-z)Ee_L(\overline{q})\} - bS$$

where $\Phi = \overline{q}\Delta\Pi_C^N - \Delta\Pi_v^N$ and $Ee_L(\overline{q}) = \overline{q}e_L + (1-\overline{q})e_o$, and the linearization matrix J is:

$$J = \begin{bmatrix} (1-2z)\Phi & 0 \\ n\{e_v - Ee_L(\overline{q})\} & -b \end{bmatrix}$$

with $\frac{d\dot{S}}{dS} < 0$ and $\frac{d\dot{S}}{dz} < 0$. If $\overline{q} > \overset{=}{q}$ then $\frac{d\dot{z}}{dz} < 0$ for the full compliance critical point z_1^*. Therefore $Tr(J) < 0$, while $Det(J) > 0$. The discriminant $\Delta \gtreqless 0$, , thus the critical point z_1^* can be a stable focus or node. The same conclusion holds for the non-compliance critical point z_2^* if $\overline{q} < \overset{=}{q}$. □

- *Compliance Dependent Auditing Probability*

The STCPS is defined as:

$$\dot{z} = z(1-z)\left[q(z)\Delta\Pi_C^N - \Delta\Pi_v^N\right]$$
$$\dot{S} = n\{ze_v + (1-z)Ee_L(q(z))\} - bS$$

where $\Phi = q(z)\Delta\Pi_C^N - \Delta\Pi_v^N$ and $Ee_L(q(z)) = q(z)e_L + (1-q(z))e_o$ and the linearization matrix J is:

$$J = \begin{bmatrix} (1-2z)\Phi + z(1-z)\frac{\partial q(z)}{\partial z}\Delta\Pi_C^N & 0 \\ n\{e_v - Ee_L(q(z)) + (1-z)\frac{\partial q(z)}{\partial z}(e_L - e_o)\} & -b \end{bmatrix}$$

For $z_1^* = 1$, $Tr(J) \lesseqgtr 0$, $Det(J) < 0$, for $z_2^* = 0$, $Tr(J) \lesseqgtr 0$, $Det(J) < 0$, for $z^* = z_3^* \in (0,1)$, $Tr(J) < 0$, $Det(J) > 0$. Thus z_1^*, z_2^* correspond to unstable S-S since the matrix J has at least one positive eigenvalue. Then the S-S corresponding to z_3^* is GAS. Since the determinant of the linearization matrix does change sign in the interval $(0,1)$ the S-S (z_3^*, S_3^*) is unique by the index theorem. Since the discriminant $\Delta \gtreqless 0$ the partial compliance S-S (z_3^*, S_3^*) can either be a stable focus, or a stable node.□

- *Emission Stock Dependent Auditing Probability*

The CPSTS is defined as:

$$\dot{z} = z(1-z)\left[q(\Delta S)\Delta\Pi_C^N - \Delta\Pi_v^N\right]$$
$$\dot{S} = n\{ze_v + (1-z)Ee_L(q(\Delta S))\} - bS$$

where $\Phi = q(\Delta S)\Delta\Pi_C^N - \Delta\Pi_v^N$ and $Ee_L(q(\Delta S)) = q(z)e_L + (1-q(z))e_o$, and the linearization matrix J is:

$$J = \begin{bmatrix} (1-2z)\Phi & z(1-z)\frac{dq(\cdot)}{dS}\Delta\Pi_C^N \\ n\{e_v - Ee_L(q(\Delta S))\} & n(1-z)\frac{dq(\cdot)}{dS}(e_L - e_o) - b \end{bmatrix}$$

with $\frac{d\dot{S}}{dS}, \frac{d\dot{S}}{dz} < 0$ and $\frac{d\dot{z}}{dS} > 0$ for $z \in (0,1)$, $q(\Delta\widehat{S})\Delta\Pi_C^N - \Delta\Pi_v^N = 0$. We examine the linearization matrix at the following cases:

- $z_1^* = 1$, $\widehat{S} < S_1^* < S_2^*$, the CPSTS has two isolated S-S. Furthermore $q(\Delta\widehat{S}) < q(\Delta S_1^*) \Rightarrow \Phi > 0$. Then $Tr(J) < 0$ and $Det(J) > 0$. The S-S $z_1^* = 1$ with $S_1^* = (ne_v / b)$ is GAS. The S-S with $z_2^* = 0$ is not stable since $Det(J) < 0$.

- $z_3^* \in (0,1)$, $S_1^* > \widehat{S} > S_2^*$ the CPSTS has three isolated S-S. The S-Ss with $z_1^* = 1$, $z_2^* = 0$ are not stable since for $q(\Delta\widehat{S}) > q(\Delta S_1^*) \Rightarrow \Phi < 0$, and for

$q(\Delta\widehat{S}) < q\left(\Delta S_2^*\right) \Rightarrow \Phi > 0$, therefore $Det(J) < 0$, at both $z_1^* = 1$, $z_2^* = 0$. For the point $z_3^* \in (0,1)$ we have $\Phi = 0$ and $Tr(J) < 0$, $Det(J) > 0$. Therefore the S-S at z_3^* is GAS for $z \in (0,1)$. Qualitative analysis of the phase diagram in Figure 9b suggests that z_3^* is a stable focus, implying that compliance and the nitrate pollution stock fluctuate with the nitrate pollution stock converging to $S_3^* = \left(n\left(z_3^* e_v + \left(1 - z_3^*\right) Ee_L\left(q_3(\Delta S)\right)\right)\right)/b$.

- $z_2^* = 0$, $\widehat{S} > S_2^* > S_1^*$, the CPSTS has two isolated S-S. Furthermore $q(\Delta\widehat{S}) > q\left(\Delta S_2^*\right) \Rightarrow \Phi < 0$. Then $Tr(J) < 0$ and $Det(J) > 0$. The S-S $z_2^* = 0$ with $S_2^* = nEe_L\left(q_2(\Delta S)\right)/b$ is GAS. The S-S with $z_1^* = 1$ is not stable since $Det(J) < 0$. □

- *Joint Dependence of Auditing Probability on Compliance and Nitrate Pollution Stock*

The CPSTS is defined as:

$$\dot{z} = z(1-z)\left[q(\Delta S, z)\Delta\Pi_C^N - \Delta\Pi_v^N\right]$$
$$\dot{S} = n\{ze_v + (1-z)Ee_L(q(z))\} - bS$$

where $\Phi = q(\Delta S, z)\Delta\Pi_C^N - \Delta\Pi_v^N$, $Ee_L(q(z)) = q(\Delta S, z)e_L + (1 - q(\Delta S, z))e_o$, $\Delta e_L^o = (e_L - e_o)$, and the linearization matrix J is:

$$J = \begin{bmatrix} (1-2z)\Phi + z(1-z)\frac{\partial q(\cdot)}{\partial z}\Delta\Pi_C^N & z(1-z)\frac{dq(\cdot)}{dS}\Delta\Pi_C^N \\ n\{e_v - Ee_L(q(z)) + (1-z)\frac{\partial q(\cdot)}{\partial z}\Delta e_L^o\} & n\{e_v - Ee_L(q(z)) + (1-z)\frac{dq(\cdot)}{dS}\Delta e_L^o\} - b \end{bmatrix}$$

with $\dfrac{d\dot{z}}{dS} > 0$ and $\dfrac{d\dot{S}}{dS} < 0$, $\dfrac{d\dot{S}}{dz} \gtrless 0$ depending on the assumption made about the slope of the isocline $\dot{S} = 0$. Along the isocline $z = l(S)$ that determines the potential z_3^* S-S, the probabilities $\widehat{q}(\Delta S, z)$ satisfy the equality $\Phi = 0$. Every other combination outside the isocline switches the sign of Φ. In particular, since $\dfrac{\partial q}{\partial z} < 0$

and $\frac{\partial q}{\partial S} > 0$ for combinations located on the right of the isocline we have $q(\Delta S, z) > \widehat{q}(\Delta S, z)$ and $\Phi > 0$, while on the left of $l(S)$ we have $\Phi < 0$ since $q(\Delta S, z) < \widehat{q}(\Delta S, z)$.

Under a sufficiently vertical isocline $z = l(S)$, so that the intersection of $z = l(S)$ with $\dot{S} = 0$ provides a z_3^* in the non feasible region of $z > 1$ to the left of the $(z_1^* = 1, S_1^*)$ point, the linearization matrix J around the S-S $z_1^* = 1$ gives $Tr(J) < 0$, and $Det(J) > 0$ since $\frac{d\dot{S}}{dS}, \frac{d\dot{S}}{dz} < 0$ and $\frac{d\dot{z}}{dz} < 0$. The full compliance EE is stable. Since the discriminant $\Delta \lesseqgtr 0$ the full compliance EE z_1^* can either be a stable focus or a stable node.

Under a flat enough isocline $z = l(S)$ so that the intersection of $z = l(S)$ with $\dot{S} = 0$ provides a $z_3^* \in (0,1)$, the linearization matrix J around z_3^* has $\frac{d\dot{z}}{dz} < 0$. In this case $Tr(J) < 0$, while $Det(J) > 0$, if $\frac{d\dot{S}}{dz} < 0$, which means that the $\dot{S} = 0$ isocline has a negative slope in the neighborhood z_3^*. Then the (z_3^*, S_3^*) S-S is an asymptotically stable EE with monotonic or fluctuating approach dynamics. If the S-S is unique in $(0,1)$ then it is GAS and partial compliance is the ES strategy. If there is more than one S-S in $(0,1)$, resulting from an $\dot{S} = 0$ isocline with decreasing and increasing parts, we expect locally asymptotically stable and unstable EE. Furthermore if $z_3^* \in (0,1)$ then the $z_1^* = 1$ and $z_2^* = 0$ S-Ss are not stable. □

List of Figures

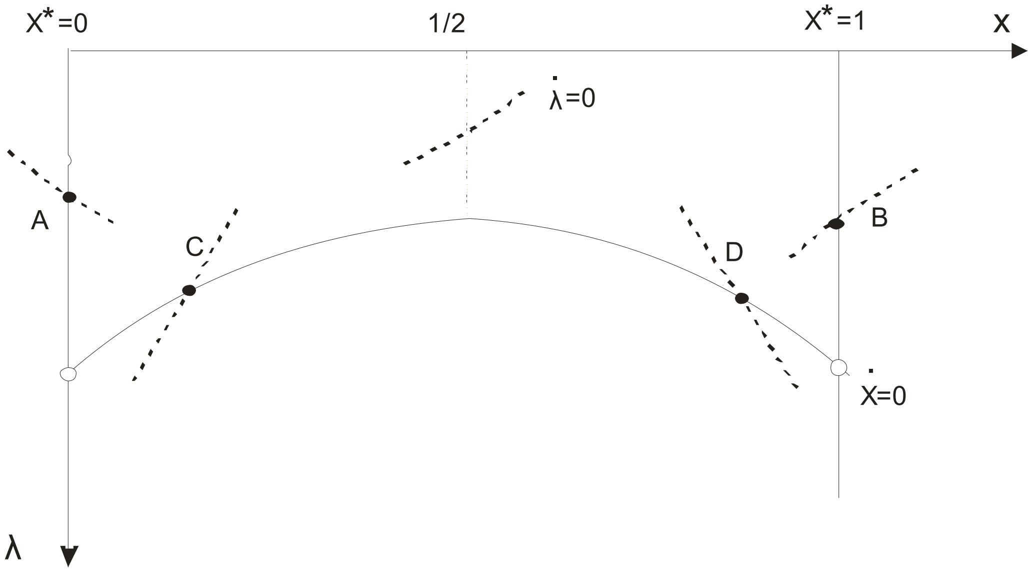


Figure 1

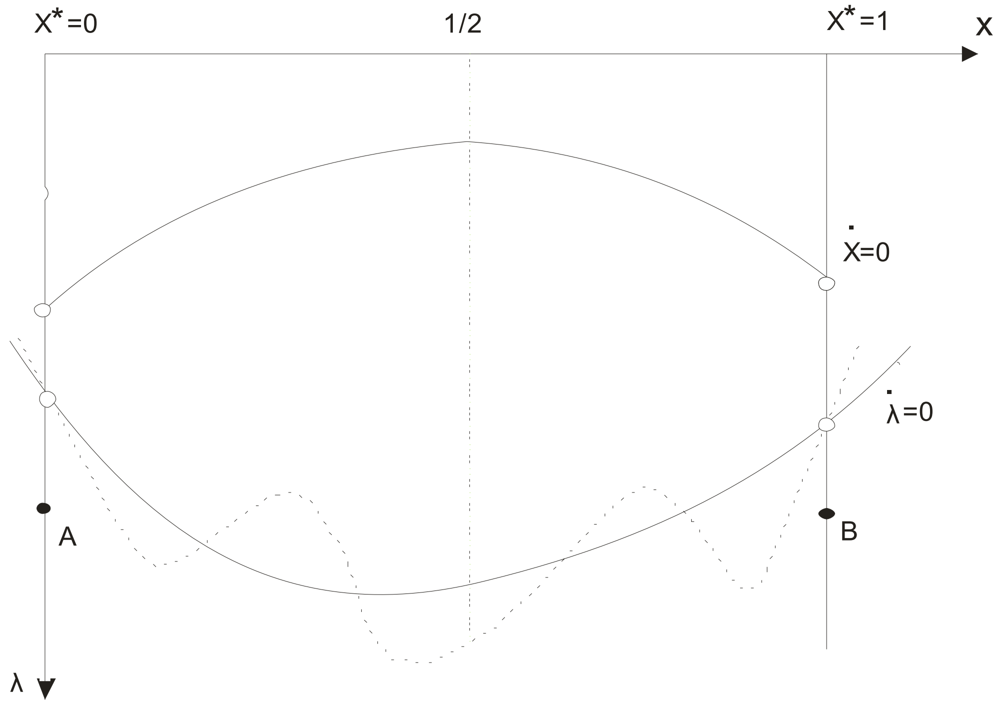
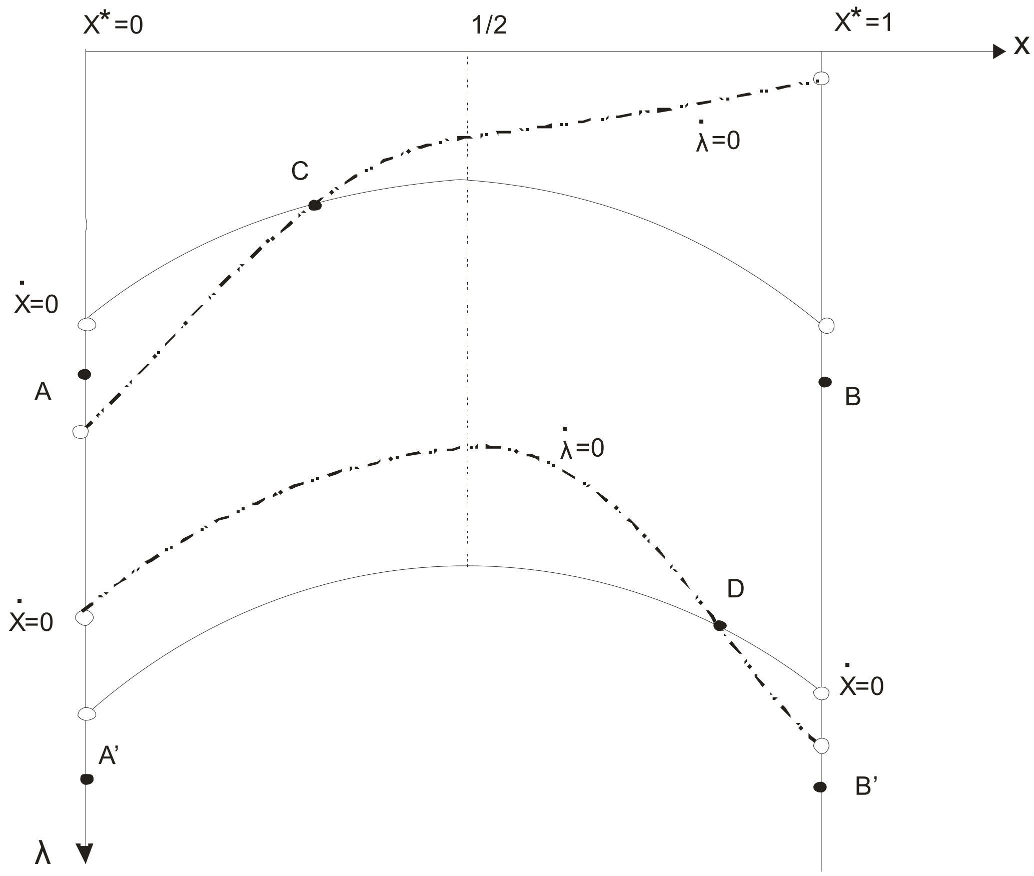


Figure 2



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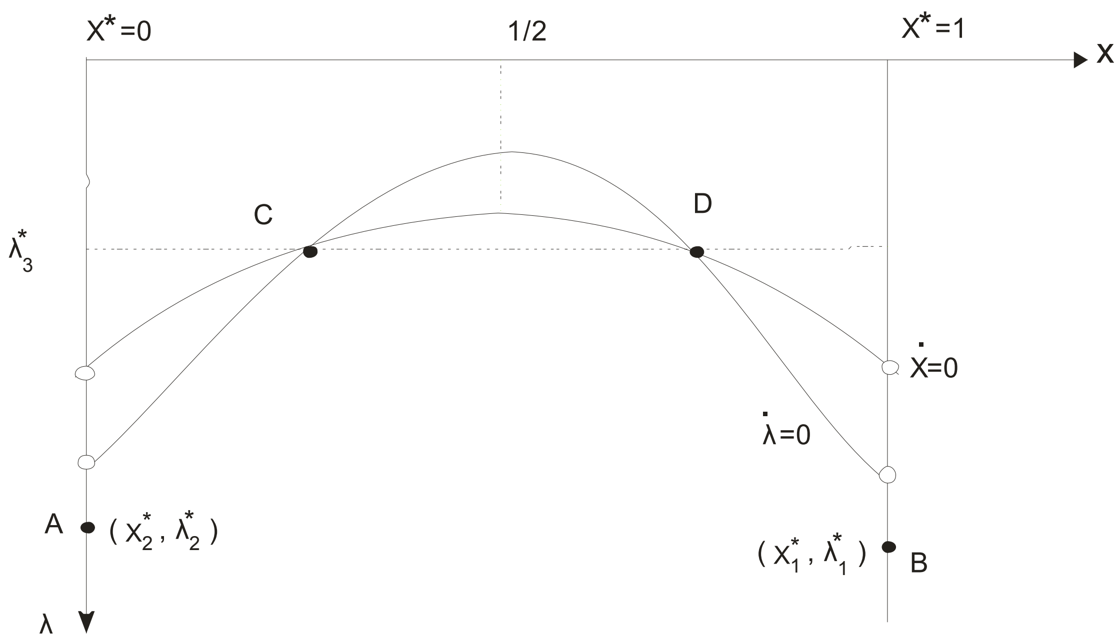


Figure 4

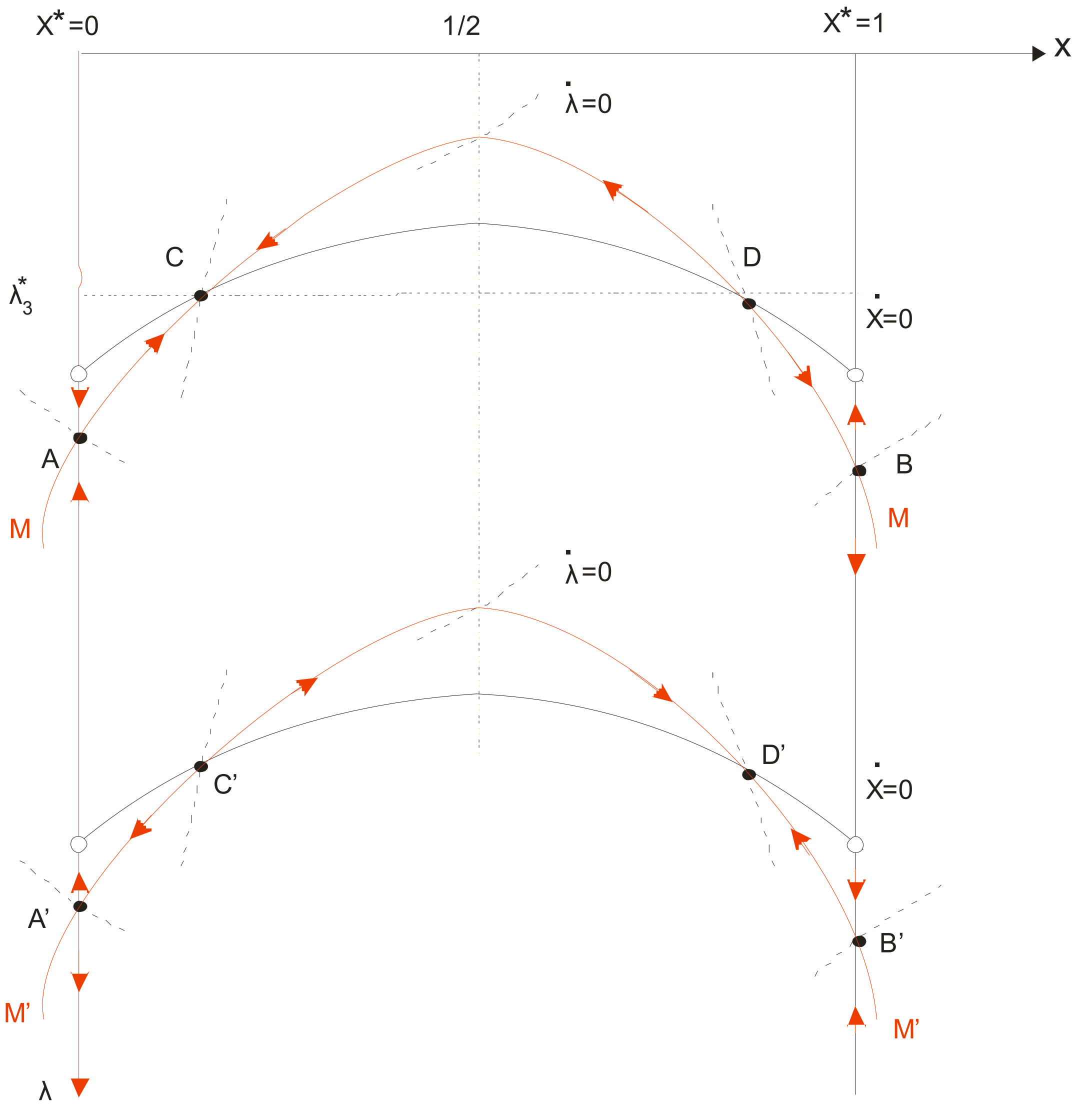


Figure 5a

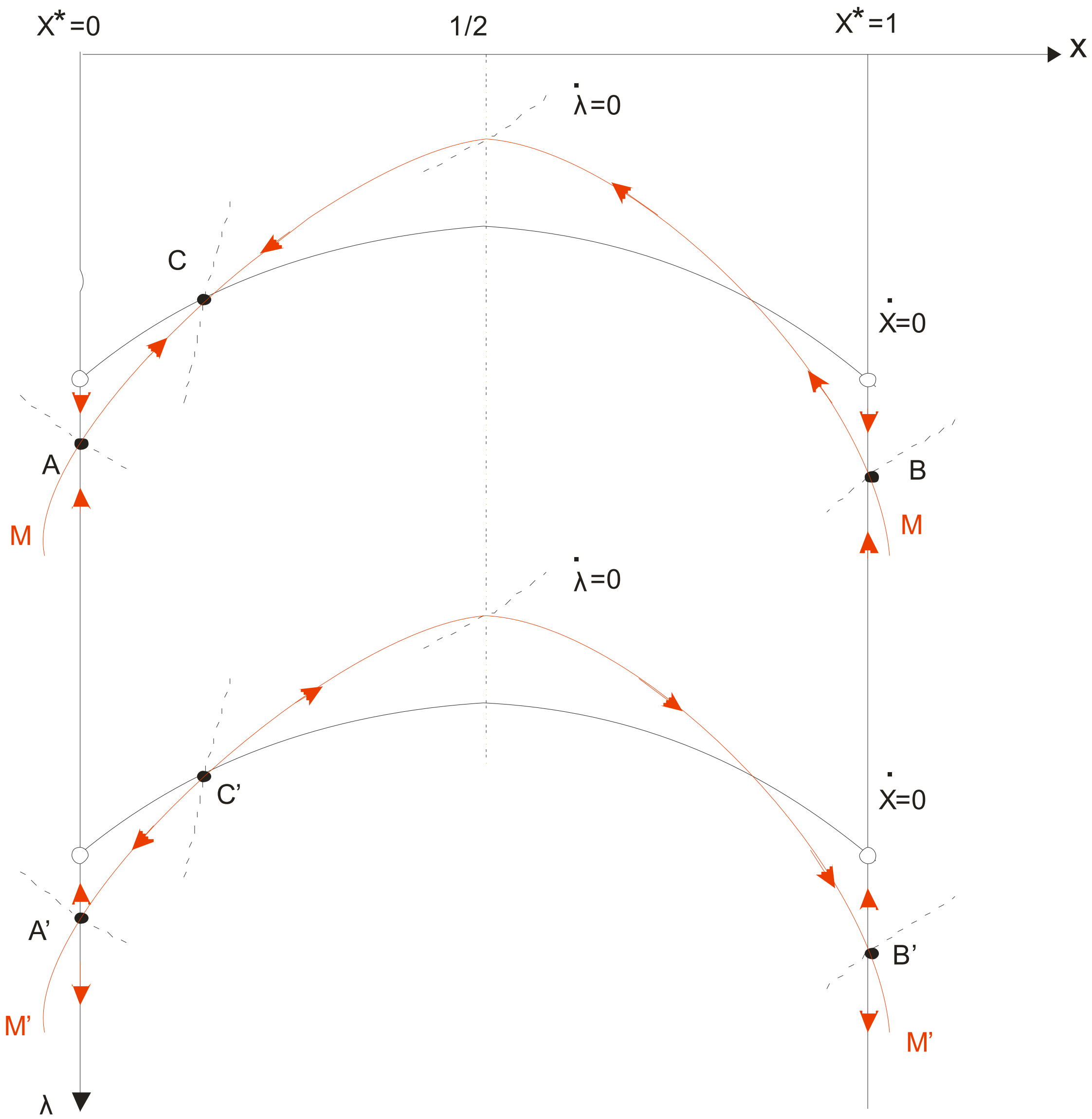
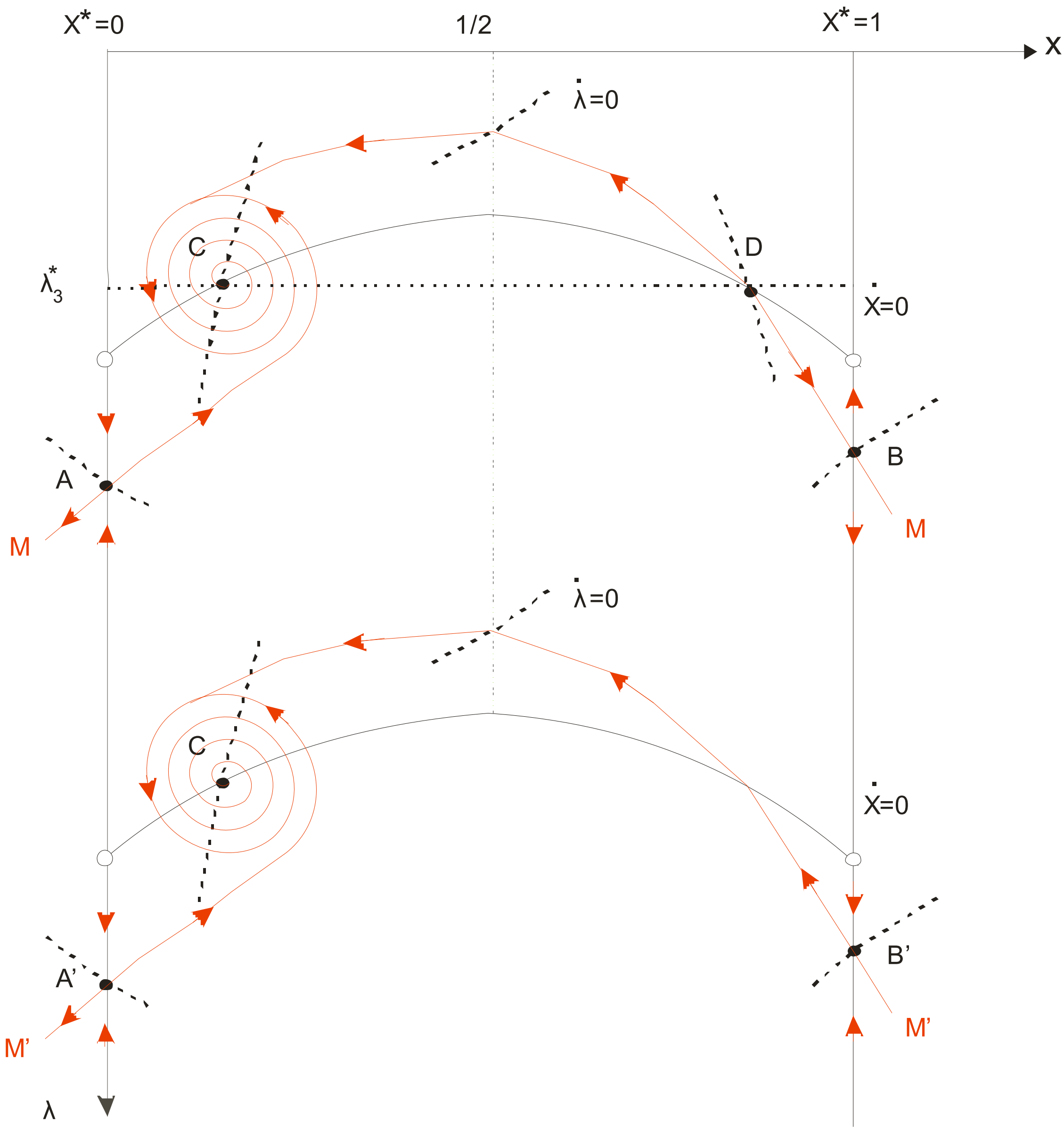


Figure 5b



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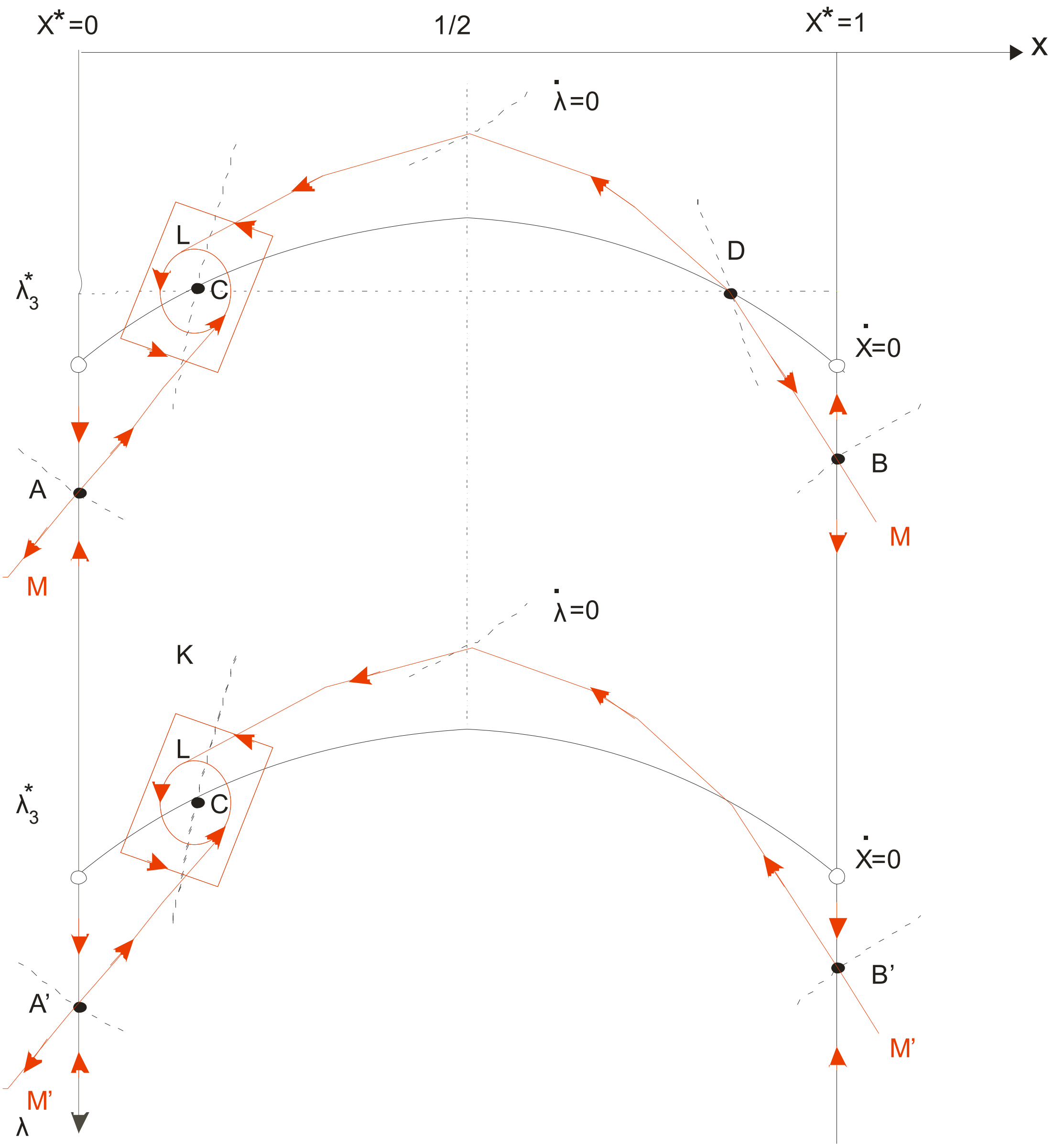

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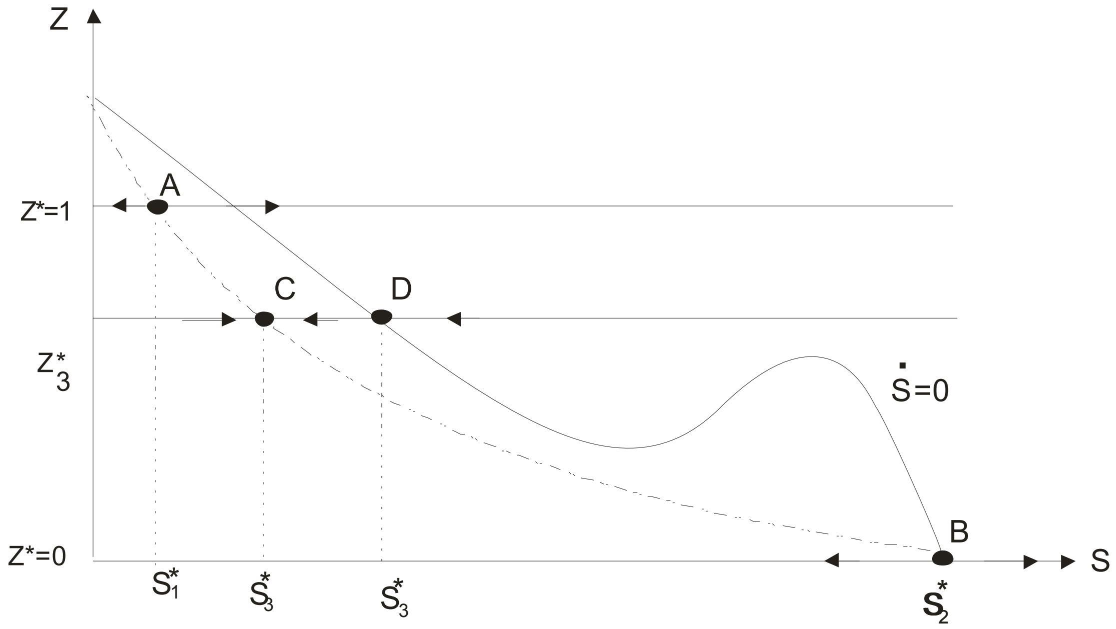

Figure 8

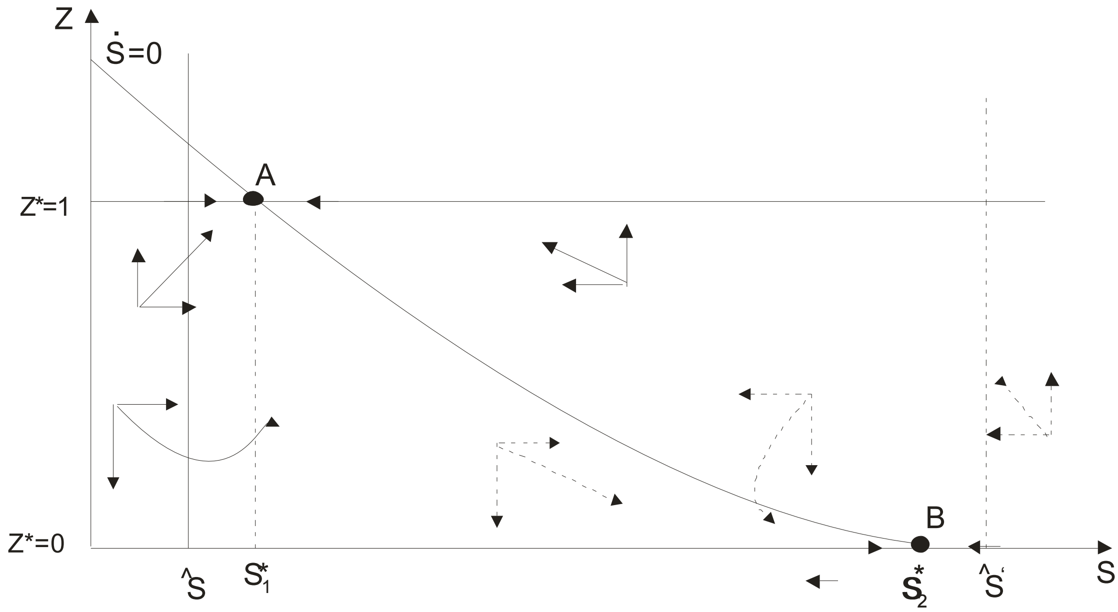

Figure 9a

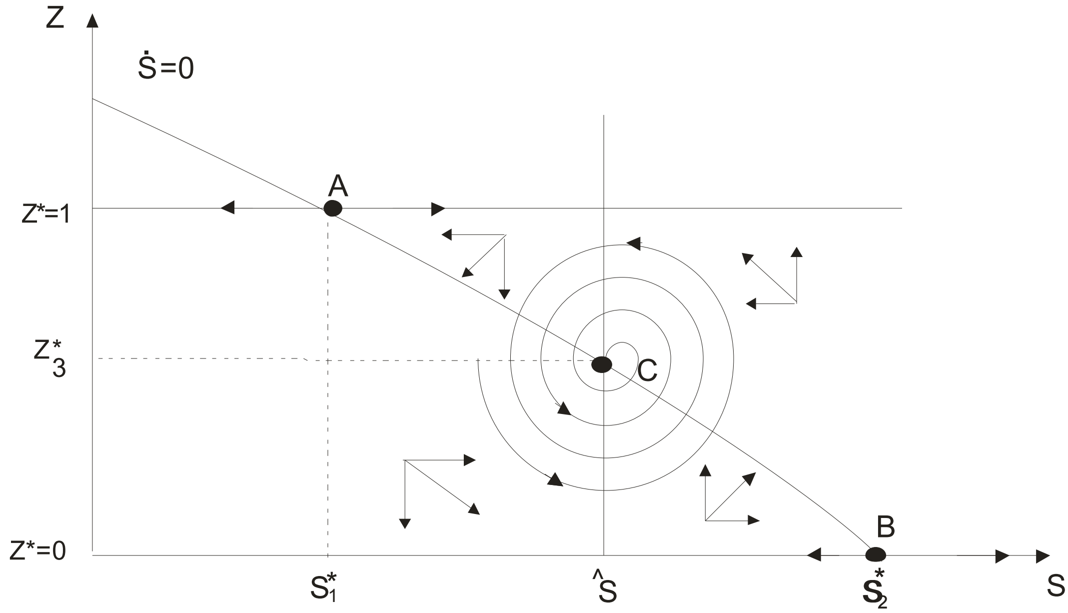

Figure 9b

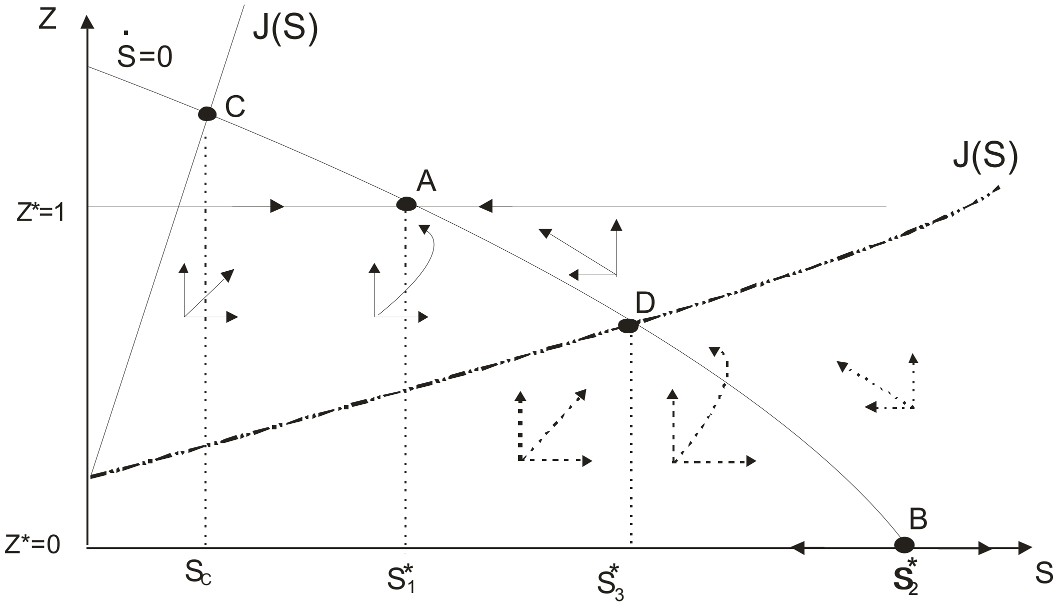

Figure 10

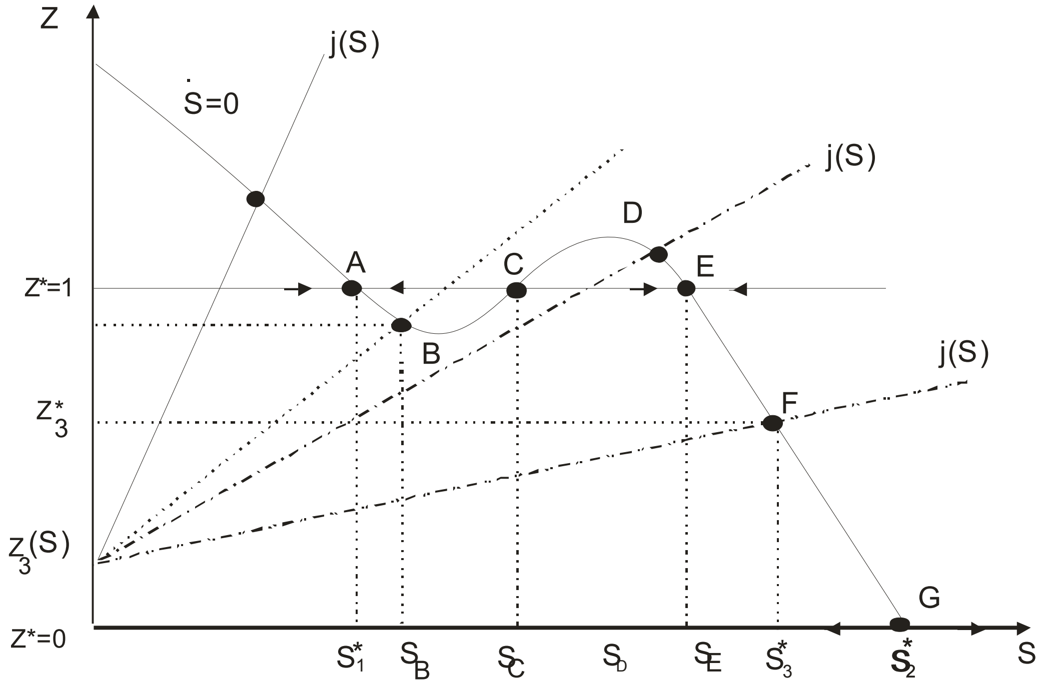

Figure 11a

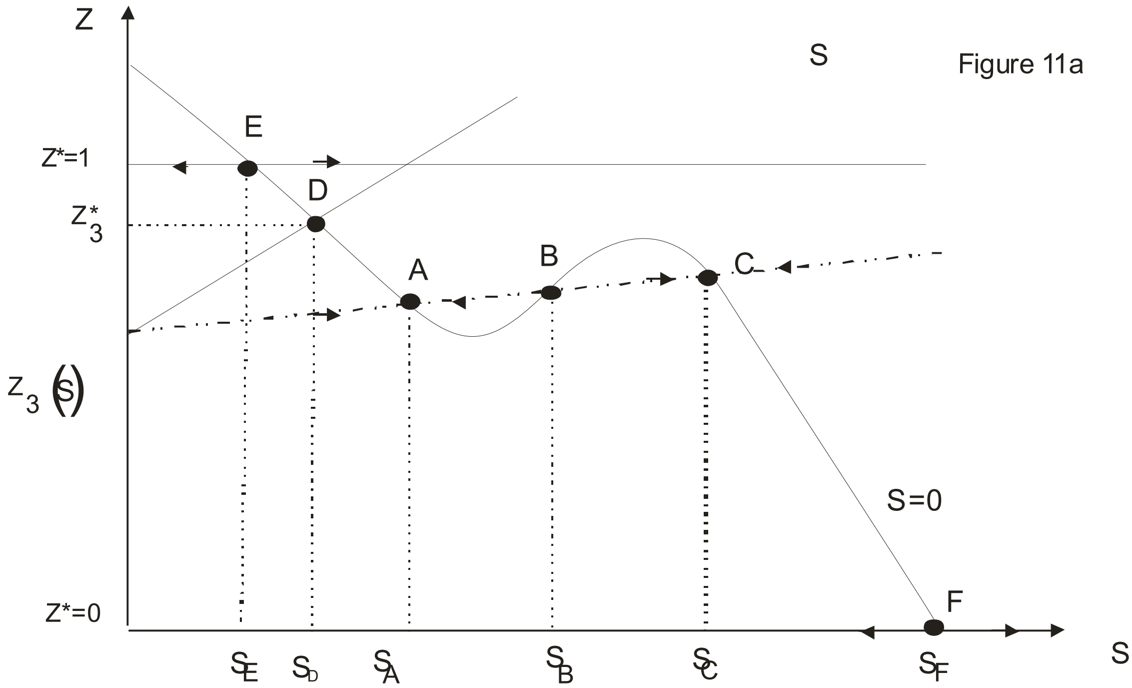

Figure 11b

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