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Marcher jusqu'au lieu où tarit la source

Et attendre, assis, que se lève le nuage.

Wan Guei

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Abbreviations and Acronyms

ABARES	Australian Bureau of Agricultural and Resource Economics and Sciences
ABS	Australian Bureau of Statistics
AIC	Akaike's Information Criterion
AUD	Australian dollar
AUP	Autorisation Unique de Prélèvement
BIC	Bayesian Information Criterion
BoM	Bureau of Meteorology
CACG	Compagnie d'Aménagement des Coteaux de Gascogne
CAP	Common Agricultural Policy
CBAG	Comité de Bassin Adour-Garonne
CEWH	Commonwealth Environmental Water Holder
CLE	Commission Locale de l'Eau
EDF	Electricité de France
ENGO	Environmental NGO
EPMP	Etablissement Public du Marais Poitevin
FAO	Food and Agriculture Organization
FPE	Final prediction error
FTSE	Financial Times Stock Exchange
GDP	Gross Domestic Product
GMID	Goulburn-Murray Irrigation District
GL	Gigaliter (1000ML; 10^6 m^3)

GW	Groundwater
HQIC	Hannan Quinn Information Criterion
IC	Information Criteria
IIO	Irrigation Infrastructure Operator
IIBSN	Institution Interdépartementale du Bassin de la Sèvre Niortaise
IPCC	Intergovernmental Panel on Climate Change
IRF	Impulse-Response Functions
KPSS	Kwiatkoswki-Philipps-Schmidt-Shin
MAE	Mesure Agro-environnementale
MDB	Murray-Darling Basin
MDBA	Murray-Darling Basin Authority
MFR	Minimum Flow Requirements
ML	Megaliter; 10^3 m^3
NRM	Natural Resource Management
NVRM	Northern Victoria Resource Manager
NWC	National Water Commission
NWI	National Water Initiative
OUGC	Organisme Unique de Gestion Collective
PE	Potential Evapotranspiration
PNMGP	Parc Natural Marin de l'estuaire de la Gironde et de la mer des Pertuis
PNRMB	Parc Naturel Régional du Marais Poitevin
RBA	Reserve bank of Australia
SAGE	Schéma d'Aménagement et de Gestion des Eaux
SBIC	Schwarz-Bayesian Information Criterion

SDAGE	Schéma Directeur d'Aménagement et de Gestion des Eaux
SEC	Securities and Exchange Commission
SIEMP	Système d'Information sur l'Eau du Marais Poitevin
SRWUI	Sustainable Rural Water Use and Infrastructure
SW	Surface Water
TE	Technical Efficiency
UN	United Nations
USA	United States of America
USD	United States dollar
VAR	Vector Auto-Regressive
VIF	Variance Inflation Factor
WEF	World Economic Forum
WMRA	Water Market Readiness Assessment
WWAP	World Water Assessment Programme
ZRE	Zone de Répartition des Eaux
2SLS	Two-Stage Least Squares

Résumé en Français

Chaque année, le Forum Economique Mondial publie une cartographie des risques mondiaux : le Global Risk Landscape. Tous les ans, le risque lié à des crises de l'eau apparaît imperturbablement parmi les 5 risques mondiaux à plus fort impact (WEF, 2019).

Sous l'effet de pressions démographiques, du développement socio-économique et de l'évolution des modèles de consommation, la demande mondiale en eau augmente de 1% par an depuis les années 1980 (WWAP, 2019). Dans certains cas, l'augmentation globale de la température moyenne (IPCC, 2018) et des tendances vers une hausse de l'évapotranspiration potentielle (voir, par exemple, Dinpashoh et al., 2019) pourraient accélérer ce phénomène.

Les ressources en eau disponibles varient grandement dans l'espace. Si les ressources en eau par habitant représentaient 519 264 m^3 par an en Islande en 2014, elles se limitaient à $3m^3$/an au Bahreïn (FAO-AQUASTAT, 2014). L'offre en eau varie aussi dans le temps : le stress hydrique peut se faire ressentir à une période spécifique de l'année, par exemple l'été dans le cas Français, quand les besoins en irrigation sont élevés (Barthélémy et Verdier, 2008). La demande en eau peut donc approcher ou dépasser l'offre disponible dans différents contextes.

Ainsi, le déséquilibre entre demande et offre en eau peut générer des épisodes de stress hydrique. On définit généralement le stress hydrique au travers de l'indice proposé par Falkenmark et al. (1989). Un pays est considéré comme étant en situation de stress hydrique si les ressources en eau renouvelables par habitant y sont inférieures à 1700 m^3/an. En dessous de $1000m^3$/an/habitant, l'indice considère une situation de rareté de l'eau chronique. Falkenmark et al. définissent un seuil de $500m^3$ en dessous duquel la capacité de gérer les ressources en eau

n'est pas assurée, suggérant l'émergence de conflits liés à l'eau. Une définition alternative de la rareté de l'eau compare la demande au volume total disponible (Raskin et al., 1997). Selon cette définition, plus de 2 milliards de personnes vivraient aujourd'hui dans des pays subissant un stress hydrique élevé, et environ 4 milliards de personnes vivraient un épisode majeur de rareté de l'eau au moins un mois par an (WWAP, 2019). Dans ces circonstances, les outils de politique publique permettant une gestion améliorée de la rareté des ressources en eau constituent un enjeu majeur.

Deux types de mesures sont généralement envisagés pour gérer le risque lié à la rareté de l'eau : l'augmentation de l'offre et la gestion de la demande. L'augmentation de l'offre implique l'utilisation d'infrastructures de mobilisation de la ressource en eau (barrages, pompage…), de manière à augmenter le volume d'eau disponible en période d'étiage ou de rareté. La gestion par la demande peut référer à des mesures éducatives, réglementaires et/ou de planification, ainsi qu'à l'usage d'incitations économiques (Wheeler et al., 2017). Depuis les années 1950, l'augmentation de l'offre a souvent prédominé de façon à satisfaire une demande croissante pour l'eau (Grimble, 1999 ; Saleth, 2011). Au-delà d'un certain stade, toutefois, l'économie de l'eau atteint une phase décrite par Randall (1981) comme 'mature'. Dans cette situation, les coûts liés à une augmentation de l'offre (par un nouveau pompage, barrage…) dépassent les bénéfices d'une augmentation de la consommation d'eau. En d'autres termes, le bénéfice marginal obtenu par la mise à disposition d'une unité d'eau supplémentaire est supérieur au bénéfice marginal obtenu par sa consommation. Des mesures de gestion de la demande en eau peuvent donc être requises dans des situations de rareté de l'eau.

Les marchés de droits d'eau sont des outils économiques permettant de gérer la rareté de l'eau du côté de la demande. Un marché de droit d'eau, parfois également appelé marché de l'eau, est un système où des droits d'eau peuvent être prêtés, achetés ou vendus entre des individus, ou des institutions, de façon temporaire ou permanente. La détention d'un droit d'eau permet à son détenteur d'accéder à un volume d'eau (ou à son équivalent en débit ou temps) chaque saison, pour un usage généralement défini par le droit (irrigation, industrie, eau potable…). Dans le cas de la gestion de l'eau en France par exemple, les droits d'eau pour l'irrigation sont matérialisés par des autorisations de prélèvement annuelles, accordées aux agriculteurs via des Organismes Uniques de Gestion Collective (OUGC), souvent les Chambres d'Agricultures locales.

Les marchés de droits d'eau peuvent être formels, c'est-à-dire encadrés par un cadre législatif dédié, ou informels (Easter et al., 1999). En pratique, ils peuvent être établis en autorisant des transactions de gré à gré ou au travers de banques de l'eau, qui centralisent alors les transactions (Montilla-Lopez et al., 2016). Les droits d'eau échangés sur un marché peuvent être liés à un même usage pour l'eau : c'est le cas par exemple des marchés de droits d'eau liés à l'irrigation. Les marchés peuvent également encadrer des transferts entre usages différents, impliquant l'agriculture, l'industrie, les usages environnementaux et les usages urbains.

Les marchés de droits d'eau sont conçus en deux temps. Un plafond (*cap*) est d'abord établi sur les droits d'eaux accordés, c'est-à-dire sur les volumes totaux prélevés chaque année. Il devient ensuite autorisé d'acheter ou vendre des droits d'eau. Certains marchés se sont développés en l'absence d'une limite claire et respectée sur les volumes prélevables, mais ils sont souvent associés à des phénomènes de surexploitation de la ressource (voir, par exemple, Bitran et al., 2014, pour le cas du Chili).

Des marchés de droits d'eau ont été établis dans des contextes culturels et économiques variés. Des marchés formels ont été établis en Australie (Grafton et al., 2016), dans l'ouest des Etats-Unis (Colby, 1990), au Chili (Bitran et al., 2014), en Espagne (Palomo-Hierro et al., 2015) et en Chine (Zhang, 2007). Divers marchés informels ont été décrits par la littérature, notamment en Inde (Mukherji, 2007) et au Pakistan (Razzaq et al., 2019). Dans la mesure où l'établissement de marchés de droits d'eau a été envisagé dans divers autres contextes (Shatanawi et Al-Jayousi, 1995 ; Wheeler et al., 2017 ; Mellah, 2018), le nécessaire débat sur leurs avantages et inconvénients potentiels se doit d'être informé par des études empiriques fondées sur des exemples de marchés fonctionnels.

Cette thèse a pour but d'améliorer la compréhension du rôle que peuvent jouer les marchés de droits d'eau comme outils de gestion de la rareté de l'eau. Elle aborde d'abord les bénéfices économiques associés à l'usage de marchés de droit d'eau dans l'agriculture, considère ensuite deux dysfonctionnements possibles liés à leur établissement en pratique, puis conclut en questionnant leur potentiel dans un contexte Français.

Bien que divers exemples de marchés de droits d'eau fonctionnels aient été présentés par la littérature, les études empiriques sur les marchés de droits d'eau sont souvent limitées par la rareté des données existantes, en particulier liées au marché. Un autre obstacle fréquent est lié à un nombre souvent faible de transactions constatées. Pour tenter de contenir ces problèmes, les trois premiers chapitres de cette thèse se basent sur les marchés de droits d'eau formels en Australie, et ce pour trois raisons. Premièrement, les premiers marchés Australiens ont été établis dans les années 1980, dans le bassin de Murray-Darling. Cet historique de fonctionnement relativement long permet un retour d'expérience sur les succès et échecs liés à l'établissement de marchés de droits d'eau en pratique, qui peut être exploité dans d'autre contextes si les marchés sont considérés comme des outils potentiels. Deuxièmement, l'existence d'une large zone hydrologiquement connectée dans le sud du bassin de Murray-Darling permet des études de cas impliquant un grand nombre d'acteurs potentiels. Au cours du temps, l'usage du marché par les irrigants y a considérablement augmenté : en 2015, environ la moitié des irrigants avaient effectué au moins une transaction permanente de droits d'eau et

78% des irrigants avaient été impliqués dans au moins une transaction temporaire. Le Bassin de Murray-Darling est donc souvent considéré par la littérature empirique sur les marchés de droits d'eau : il constitue un laboratoire pour l'usage de ces outils dans un contexte de stress hydrique croissant et de rareté régulière de la ressource en eau. Troisièmement, l'existence de données publiques en lien avec les achats et ventes de droits d'eau publiés par l'Office Australien des Statistiques (Australian Bureau of Statistics, ABS) et le Bureau météorologique (Bureau of Meteorology, BoM) permet des analyses empiriques de marchés fonctionnels. De façon générale, les études de cas portant sur les marchés Australiens peuvent donc fournir des éléments utiles à la connaissance de ces systèmes d'échanges, et pouvant informer le débat sur les marchés de droits d'eau dans d'autres contextes. Le chapitre 4 de cette thèse en fournit une illustration, en questionnant la transférabilité des marchés de droits d'eau à deux contextes Français (le bassin du Marais Poitevin, et le système Neste) via un cadre d'analyse proposé par la littérature Australienne (Wheeler et al., 2017).

L'usage du marché en matière de gestion des ressources en eau a été proposé par la littérature économique comme un moyen d'améliorer l'efficience des usages en eau. Différentes définitions de l'efficience peuvent être envisagées. L'efficience technique renvoie à la capacité d'une unité de production d'opérer sur la frontière de production, c'est à dire de produire le maximum possible pour une quantité donnée de facteur de production (Coelli et al., 2005). Dans le cas de l'eau, l'efficience technique renvoie donc au fait de produire un maximum pour une quantité d'eau donnée. L'efficience allocative renvoie à l'allocation de l'eau basée sur un usage générant un revenu plus élevé (Wheeler et al., 2014). Les marchés de droits d'eau peuvent augmenter l'efficience allocative en réallouant l'eau depuis des usages à moins forte valeur ajoutée vers des usages à plus forte valeur ajoutée (Dinar et al., 1997), et vers des activités plus productives (Hodgson, 2006). Ils peuvent également améliorer l'efficience technique en permettant l'accès à l'eau à des nouveaux usagers très efficients, l'adoption de technologies visant à économiser l'eau et la diminution des usages peu efficients pour l'eau (Qureshi et al., 2009). La plupart des études empiriques dédiées à la mesure de l'impact économique des marchés de droits d'eau recourent à la méthode de l'équilibre général (Peterson et al., 2005 ; NWC, 2012). Le premier chapitre de cette thèse tente de mesurer les gains de productivité dans l'agriculture liés à l'utilisation de marchés de droits d'eau dans le contexte Australien via un modèle de frontière stochastique (Battese et Coelli, 1995). Deux questions de recherches sont abordées dans ce chapitre. Premièrement, l'existence de marchés de l'eau est-elle associée à une efficience plus grande des usages en eau, et donc de la production agricole ? Deuxièmement, des marchés plus développés – donc des volumes échangés plus importants – traduisent-ils un gain d'efficience plus élevé ? Un modèle de frontière stochastique est appliqué à des données annuelles sur la production agricole, les circonstances climatiques, l'existence d'un marché et l'intensité des transactions éventuelles à l'échelle de régions Australiennes, entre 2011 et 2017. Notre modèle mesure l'efficience de chaque région dans son utilisation de deux facteurs de production : l'eau et la surface agricole. Pour chaque observation, nous mesurons l'inefficience comme la distance à la frontière de production, c'est-à-dire la différence de production à utilisation de facteurs égale vis-à-vis de l'observation la plus efficace de la base de données. L'étude du lien entre existence du marché d'une part, définie par une variable binaire égale à 1 lorsqu'un marché existe dans une région pour une année donnée, et inefficience d'autre part révèle une association positive entre présence du marché et efficience de la production agricole. En d'autres termes, les régions disposant d'un marché utilisent leurs facteurs de production (dont l'eau) de façon plus efficace en moyenne. Dans un deuxième temps, nous remplaçons la variable d'existence du marché par l'intensité de transactions, définie comme le volume d'eau acheté dans chaque région là où un marché existe. Afin de prendre en compte le biais de sélection lié au fait que nous ne pouvons observer l'intensité des transactions que lorsqu'un marché existe, nous utilisons la méthode des résidus généralisés

(Gourieroux et al., 1987). Les résultats n'indiquent pas de lien significatif entre intensité des transactions et efficience. Nos résultats confirment donc l'existence d'une relation positive entre existence du marché et efficience des usages en eau, mais pas entre intensité et efficience. Des analyses basées sur des données plus complètes seraient intéressantes pour renforcer et approfondir ce résultat.

En parallèle avec la littérature dédiée aux bénéfices associés à l'usage du marché appliqué à la gestion des ressources en eau, différentes préoccupations ont été exprimées dans la littérature quant à leurs inconvénients potentiels. Les limites classiques de l'action des marchés sont souvent amplifiées dans le cas de l'eau : l'eau est une ressource 'massive', et les coûts liés à son transport sont élevés (Turner et al., 2004). En outre, différentes externalités peuvent être associées aux transferts de droits d'eau : une modification de l'hydrologie (localisation des prélèvements et des débits restitués) et l'impact des transferts sur la région où l'eau était utilisée à l'origine sont fréquemment évoquées et peuvent venir limiter voire annuler les gains de l'échange (Garrido Fernandez, 2016). Une externalité en particulier est liée aux infrastructures associées à l'irrigation. Ces infrastructures sont généralement très coûteuses à entretenir, et les irrigants se répartissent ces coûts fixes de façon collective. Si l'un des irrigants décide de vendre son droit d'eau de manière permanente, les coûts de maintenance de l'infrastructure vont devoir être assumés par ceux qui continuent à irriguer, qui sont généralement en compétition avec le vendeur (Chong et Sunding, 2006 ; Heaney et al., 2006 ; Bjornlund, 2008 ; Frontier Economics et al., 2007). De plus, si un irrigant cesse de produire, le manque d'entretien de sa propriété augmente le risque de maladie sur les cultures de ses voisins (Frontier Economics et al., 2007 : Bjornlund, 2008). Dans le cas australien, peu d'éléments ont toutefois été publiés à ce jour attestant que les ventes de droits permanents génèreraient des pertes significatives dans la zone d'origine du droit d'eau (Grafton et al., 2016 ; Haensch et al., 2019).

Le second chapitre de la thèse se penche sur un dysfonctionnement possible du marché : les délits d'initiés. Bien connue sur les marchés financiers, cette pratique peut être définie comme l'achat ou la vente illégale de titres financiers par des individus ou des firmes possédant une information importante et inconnue du public (Meulbroeuk, 1992). Sur les marchés financiers, ces pratiques sont surveillées par des institutions comme la Securities and Exchange Commission (SEC) aux Etats-Unis. Dans le cas des marchés de droits d'eau, cet enjeu n'a encore suscité que peu d'attention. Sur les marchés Australiens, ces excès n'ont fait l'objet d'une régulation spécifique que depuis 2014, au travers de l'introduction de nouvelles règles portant sur les transactions. Des délits d'initiés ont été reportés de manière anecdotique (Hancock, 2008), bien que non publiés dans une revue à comité de lecture. Pour la première fois, nous questionnons l'existence de délits d'initiés sur les marchés de droits d'eau Australiens. Pour ce faire, nous étudions les mouvements de prix autour d'importantes annonces ayant un impact sur le prix de l'eau, en utilisant 10 ans de données de marché quotidiennes associées à des variables connues pour influencer le prix de l'eau par ailleurs. Notre modèle basé sur l'économétrie des séries temporelles montre l'existence de mouvements de prix informés entre 2008 et 2014. Après 2014, la fréquence de ces mouvements de prix suspect diminue fortement, et peut uniquement être ramenée à 3 occurrences. Ces mouvements de prix peuvent être soit liés à des délits d'initiés (Keown et Pinkerton, 1981 ; Meulbroek, 1992 ; Maug et al., 2008), soit à une spéculation rationnelle conduisant certains agents à deviner le contenu des annonces à venir (Jensen et Ruback, 1983 ; Jarrell et Poulsen, 1989 ; Aspris et al., 2014 ; Gu and Kurov, 2018). La diminution de la fréquence des mouvements de prix anormaux après le changement politique de 2014 pourrait constituer un argument en faveur de l'interprétation de délits d'initiés (Gupta et Misra, 1988). Un autre argument en faveur de cette interprétation est lié à nos tentatives de prédire le contenu des annonces pour lesquelles nous détectons des mouvements de prix anormaux après 2014. En utilisant les données à disposition du public, aucun modèle testé ne peut prédire correctement le contenu de toute les annonces en question. Toutefois, la sophistication accrue ainsi que l'accroissement des volumes échangés sur les marchés Australiens dans le bassin de Murray-Darling rendent possible une interprétation en faveur de comportements rationnels de spéculation. Dans tous les cas, l'introduction de régulations interdisant les délits d'initiés semble indispensable dans le cadre d'un marché de droit d'eau, le potentiel pour de telles pratiques étant établi.

Le troisième chapitre de la thèse est consacré à un autre dysfonctionnement potentiel, lié cette fois à la substitution pouvant exister entre les ressources en eau de surface et en eau souterraine. Nous considérons en particulier le cas du Murrumbidgee, en Australie, ou les deux types de ressources sont disponibles et font l'objet de transactions sur des marchés.

Un effet de substitution entre eau de surface et eau souterraine peut en effet survenir et affecter la manière dont les marchés fonctionnent. Dans différents contextes, la littérature rapporte que les irrigants peuvent augmenter leur consommation d'eau souterraine de façon à compenser des réductions liées à leurs droits d'eau de surface (Zhang, 2007; Wheeler et al., 2016). Dans le cadre de politiques visant à réduire les usages dans un contexte de sécheresse ou à augmenter les débits minimums environnementaux (débits objectifs d'étiage en France), cet effet peut conduire à des conséquences inattendues et compromettant la réussite de telles politiques. Dans ce chapitre, nous abordons deux questions de recherche visant à mieux comprendre les dynamiques des marchés de droits d'eau souterraine quand ils coexistent avec des marchés de droits d'eau de surface. D'abord, nous questionnons l'influence du prix de l'eau de surface dans la formation des prix sur le marché de l'eau souterraine. Analysant 10 ans de données mensuelles sur ces deux types de marchés, nous utilisons un vecteur autorégressif avec variables exogènes (VAR-X) pour questionner le rôle du marché de droits d'eau de surface dans la formation des prix. Nous prouvons que l'information est d'abord assimilée par le marché de droits d'eau de surface, puis transmise au marché de droits d'eau souterraine par la suite. En tenant compte de ce phénomène, nous étudions ensuite l'élasticité de la demande en eau souterraine dans un contexte de marché. Nos résultats indiquent qu'une augmentation de 1% du prix de l'eau souterraine conduite à une diminution de 1.05% de la demande, ce qui suggère que la demande en eau souterraine est élastique mais proche de l'unité. De façon générale, nos résultats soulignent la nécessité d'établir des politiques visant à la fois les ressources en eau de surface et en eau souterraine : les marchés sont interconnectés, et l'élasticité de la demande suggère que la demande en eau souterraine réagira à tout changement dans le prix de l'eau. Un effet de substitution en Australie serait donc hautement probable, dans le cas où des politiques affectant uniquement les ressources en eau de surface seraient mises en place.

En dehors du contexte Australien, l'adoption de marchés de droits d'eau a récemment été testée (Zhang, 2007) ou questionnée (Mellah, 2018) dans différents cadres. Toutefois, les marchés de droits d'eau s'inscrivent nécessairement dans un contexte socio-politique et ne mènent pas nécessairement à des solutions efficientes ou effectives en matière de gestion des ressources en eau (Breviglieri et al., 2018). Dans ce contexte, le cadre d'analyse de Wheeler et al. (2017) suggère un ensemble de critères d'analyse afin d'identifier les facteurs facilitants, les obstacles, les bénéfices et coûts éventuels liés à l'établissement de marchés de droits d'eau dans un contexte donné. Le quatrième chapitre de cette thèse applique ce cadre d'analyse à deux études de cas en France : le bassin versant du Marais Poitevin et le système Neste. Dans le cadre de cette étude, 11 entretiens semi-directifs (6 concernant le système Neste, et 5 dans le bassin du Marais Poitevin) ont été réalisés avec des acteurs clef de la gestion de l'eau dans chaque bassin. Dans chaque cas, le chapitre présente le contexte géographique et hydrologique. La France n'est pas un pays en situation de stress hydrique au sens de Falkenmark (1989) et il y est illégal d'acheter ou de vendre les droits d'eau (autorisations de prélèvements). Toutefois, nos deux études de cas sont soumises à des épisodes récurrents de déséquilibre entre offre et demande en eau en été, lorsque les besoins en prélèvements liés à l'irrigation sont les plus forts. Dans la mesure où les politiques d'augmentation de l'offre ont récemment montré leurs limites dans les deux cas, il peut être intéressant de considérer des moyens de gestion de la rareté par la demande. Nous détaillons ensuite les besoins en matière de gestion de la ressource, et les politiques actuellement mises en place pour y répondre. Nous abordons finalement les facteurs facilitants, les obstacles et les bénéfices potentiels associés à l'établissement de marchés de droits d'eau dans nos contextes. De façon générale, des prélèvements excessifs dans certains aquifères, notamment en bordure du Marais Poitevin ont pu aboutir à un drainage des ressources en eau du marais en période estivale. Pour faire face à ce problème, un ensemble de mesures de gestion ont été mises en place par un établissement d'Etat, l'Etablissement Public du Marais Poitevin (EPMP) en concertation avec les acteurs locaux. Des réserves substituant les usages estivaux par des prélèvements en hiver ont en outre été réalisées dans la partie Nord du bassin. Certaines de ces réserves ont soulevé d'importants mouvements de protestation, notamment dans la partie sud aboutissant à des blocages qui persistaient encore au moment de notre étude. Les obstacles à l'installation de marchés de droits d'eau dans le bassin versant du Marais Poitevin incluent l'absence d'un volume prélevable maximum, et donc d'une limite sur les droits d'eau totaux accordés, et une faible acceptabilité sociale des marchés dans le bassin telle que rapportée dans la littérature (Kervarec, 2014) mais également au cours des entretiens. Les nombreuses connections hydrologiques ainsi que la diversité des usages pour l'eau dans le bassin suggèrent pourtant l'existence de bénéfices potentiels importants en cas de réallocation des ressources en eau vers des usages plus créateurs de valeur. Le système Neste est un ensemble de 18 cours d'eau de surface artificiellement réalimentés par un canal détournant une partie du débit de la rivière Neste en provenance des Pyrénées. La Compagnie d'Aménagement des Coteaux de Gascogne (CACG) gère les débits dans le système en ajustant les diversions de la rivière Neste de façon à assurer un respect des droits d'eau accordés aux agriculteurs irrigants ainsi qu'aux autres usagers et à maintenir un débit objectif d'étiage. Depuis la mise en place d'un volume prélevable maximum en 1992, la demande en eau dans le système excède l'offre disponible. Une liste d'attente a donc été créée pour les agriculteurs souhaitant obtenir un droit d'eau. Les obstacles potentiels liés à l'établissement de marchés de droits d'eau dans le système Neste incluent : le cadre actuel, basé sur des autorisations de prélèvement accordées par un OUGC et interdisant les ventes de droits d'eau ; le principe du droit acquis, qui établit qu'un irrigant ayant obtenu un droit d'eau une année est en droit d'obtenir le même droit l'année suivante ; et une opposition culturelle et politique à l'utilisation du marché pour gérer les ressources en eau, déjà retrouvée dans le contexte du Marais Poitevin. Toutefois, les infrastructures considérables permettent des transferts d'eau facilités, et les marchés de droits d'eau pourraient flexibiliser la demande en eau, permettant aux irrigants sur la liste d'attente d'acheter de l'eau aux irrigants ayant des cultures à valeur ajoutée relativement faible (telles que le maïs).

En questionnant l'impact des marchés de droits d'eau sur l'efficience des usages en eau (Chapitre 1), l'existence de délits d'initiés (Chapitre 2), l'articulation entre marchés de droits d'eau souterraine et de surface (Chapitre 3) et en questionnant leur transférabilité à des contextes Français (Chapitre 4), cette thèse contribue à l'amélioration de la connaissance empirique sur l'usage du marché appliqué à la gestion des ressources en eau. Nos résultats peuvent être utilisés pour informer les débats et politiques publiques sur ces systèmes et ce qu'ils peuvent apporter pour gérer la rareté de la ressource en eau, dans la mesure où les épisodes de stress hydriques pourraient gagner en fréquence et en intensité sous l'effet du changement climatique (IPCC, 2018).

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General Introduction

Every year, the Davos World Economic Forum publishes the Global Risks Landscape. Invariably, the occurrence of water crises appears among the top 5 risks with the biggest potential impact (WEF, 2019).

Water demand has been increasing worldwide by about 1% per year since the 1980s. This can be attributed to various influences including population growth, socioeconomic development, and evolving consumption patterns (WWAP, 2019). In many areas, the overall increase in observed monthly global mean surface temperature (IPCC, 2018) and upward trends in potential evapotranspiration (see, for example, Dinpashoh et al., 2019) might lead to even greater water demands in the decades to come.

In parallel to this, the amount of renewable internal freshwater resources available can vary greatly in space: water resources in Bahrein represented 3 cubic meters per capita per year in 2014, and 519,264 m^3/capita/year in Iceland (FAO-AQUASTAT, 2014). They can also vary in time: some countries – as France - can experience water stress at specific times such as summer months, when irrigation water needs are high (Barthélémy and Verdier, 2008). Thus, water demand can approach or exceed water supply in various times and contexts.

As a result, surface and groundwater resources are put under stress in many areas of the world. Water stress is often defined using the water stress index proposed by Falkenmark et al. (1989): a country is said to experience water stress if the available renewable water resources per capita is less than 1700 m^3 per year. Chronic water scarcity is said to occur below 1000 m^3/capita. Finally, Falkenmark et al. define a water barrier (under 500 m^3/capita), under which the capacity to manage water resources is endangered, suggesting the occurrence of water-related conflicts. An alternative measure of water scarcity compares water demand to the total amount of freshwater resources available (Raskin et al., 1997). In this sense, over 2 billion people live in countries experiencing high water stress and about 4 billion people experience severe water scarcity at least one month a year (WWAP, 2019). Considering the potential tools able to help policymakers manage water scarcity is therefore of interest.

Two diverse arrangements are usually considered in order to deal with water scarcity risk: Supply augmentation and demand-side management. Supply augmentation implies to build infrastructure, in order to provide more water in times of needs. Demand-side management refers to educational measures, regulatory or planning processes and economic incentives (Wheeler et al. 2017). Since the 1950s, supply augmentation has been predominantly used in order to satisfy the growing demand for water: usual approaches involve a water development based on the creation of additional water storages and allocations (Grimble, 1999; Saleth, 2011). In many countries, however, the water economy has reached a 'mature' phase (Randall, 1981) where the cost of supply augmentation offsets the potential benefits of an increased water use. In other words, the marginal cost of obtaining an additional unit of water often exceeds the marginal benefit that can be obtained from it. Demand-side management measures have therefore been considered as cost-effective approaches to deal with water scarcity.

In this perspective, water markets emerged as economic tools that can be used in order to manage water on the demand side. By water markets, we mean systems where rights to water can be bought, sold or leased between individuals or institutions, in a temporary or permanent manner. Water markets can be either formal (i.e. with a dedicated legal system) or informal (Easter et al., 1999). In practice, they can function by simply allowing transactions between private individuals or through the use of water banks centralizing transactions within a more institutionalized context (Montilla-Lopez et al., 2016). Water resources can be exchanged within one economic sector (i.e. irrigation) or transferred between different sectors (e.g. rural to urban). Water markets are theoretically designed as cap and trade systems: a 'cap' on water rights (i.e. a maximal total amount of water rights) is first defined, and individuals are then allowed to trade water rights. Some examples of water markets functioning without a clearly defined and enforced cap can be found, but they can be associated with groundwater aquifer depletion (See Bitran et al., 2014, for Chile).

Water markets have been established in various cultural and economic backgrounds. Examples of formal water markets include Australia (Grafton et al., 2016), the western United States (Colby, 1990), Chile (Bitran et al., 2014), Spain (Palermo-Hierro et al., 2015) and China (Zhang, 2007). Examples of informal water markets can be found in India (Mukherji, 2007) or Pakistan (Razzaq et al., 2019). Considering the fact that establishing water markets can be considered in various other contexts (Shatanawi and Al Jayousi, 1995; Wheeler et al., 2017; Mellah, 2018), the debate over the relevance of such tools needs to be informed by empirical research focusing on existing examples of water markets.

This thesis aims to improve the knowledge on water markets as tools to deal with water scarcity. We first focus on the economic benefits associated with water markets, then consider two potential problems arising from their use in practice and conclude by questioning their potential in a French context.

Although different examples of functioning water markets have been presented in the literature, empirical studies on the water markets are often lacking due to limited data availability or insufficient transaction levels. In order to avoid such problems, the first three chapters of this thesis focus on formal water markets in Australia for several reasons. First, Australian water markets were initially established in the 1980s, in the Murray-Darling Basin.

The relatively long history of water markets in Australia allows a review of the successes and failures related to the establishment of water markets, that can be used in many other contexts where the use of water markets is considered. Second, the existence of a large hydrologically inter-connected area in the Southern Murray-Darling Basin allows for a cases study implying a large number of potential actors. Within the basin, irrigators' participation in water trade has consistently increased with time: in the southern MDB, approximately half of all irrigators had made at least one permanent water trade, whereas 78% had conducted at least one temporary water trade by 2015-16 (Grafton and Wheeler 2018). Therefore, the MDB is often used as a case study in the literature, as a laboratory to the use of water markets. Third, the existence of publicly available water market data[1] allows empirical analyses of a functioning water market example. Overall, insights from Australian case studies can be used to inform the debates in other contexts where the use of market mechanisms applied to water resources management is considered. An illustration of this is provided in the fourth and last chapter of this thesis, where we question the potential generalization of water markets – and especially their potential application to the French case – using a general framework published by the Australian water markets literature (Wheeler et al., 2017).

The use of market mechanisms applied to water resources has been promoted by the economic literature as a mean to increase the efficiency of water use. Different definitions of water use efficiency can be used. For example, allocative efficiency refers to water being allocated to where it generates the most income, while technical efficiency refers to improvements in the efficient use of water through technology (Wheeler et al., 2014). In this perspective, Water markets can foster allocative efficiency gains by redirecting water from low-valued to higher valued uses (Dinar et al., 1997), and towards more productive activities

[1] Available online on the Australian Bureau of Meteorology's Website.

(Hodgson, 2006). They can also increase technical efficiency through the expansion of water use by highly efficient new water users, adoption of water conserving technologies and elimination of inefficient uses for water (Qureshi et al., 2009). Most of the studies attempting to measure the economic impacts of water markets at an aggregated level use a general equilibrium approach (Peterson et al., 2005; NWC, 2012). The first chapter of this thesis attempts to measure the corresponding economic benefits in total agricultural production in the context of Australian water markets through the use of a stochastic frontier model (Battese and Coelli, 1995). We attempt to answer two questions. First, is the existence of water markets in a region associated with a higher efficiency of agricultural production, through an increase in water use efficiency? Second, does a higher water trade intensity imply higher efficiency gains? A stochastic frontier model is applied to annual agricultural, climatic and market data in Australia between 2011-12 and 2016-17. We first include a dummy variable noting the existence of water markets in a given region within a conditional mean model of the stochastic frontier's residual inefficiency term, while controlling for various other factors. We find evidence of a positive association between the existence of water markets and the efficiency of agricultural production. Second, we replace the market existence dummy with a variable measuring the intensity of temporary and permanent water trade, while controlling for the potential selection bias through the use of generalized residuals (Gourieroux et al., 1987). We find no evidence to support the hypothesis of a link between trade intensity and efficiency gains. Overall, our results suggest a positive association between water markets and water use efficiency. However, further research using more detailed data would be useful, in order to strengthen this result.

In parallel with the literature dedicated to their economic benefits, various concerns have been expressed in relation to the use of water markets as tools to reallocate water resources in a context of water scarcity. Classical limits to the use of markets are often amplified in the case of water: as water is a massive resource, the costs raising from moving the resource can be high (Turner et al., 2004). Concerns about potential externalities from water trade have been expressed in the literature. Changes in stream flows, return flows and impacts on water's area of origin are frequently cited in that matter and can mitigate the gains obtained by buyers and sellers (Garrido Fernandez, 2016). Furthermore, an externality often described by the literature is the 'stranded asset' problem (Chong and Sunding, 2006; Heaney et al., 2006; Bjornlund, 2008; Frontier Economics et al., 2007): as irrigation water use requires heavy investment in infrastructures, these infrastructures are often shared by different users. If one of these users decides to sell his or her water entitlement, the maintenance costs of the infrastructure will be supported by the remaining users, who generally compete with the leaver. When an irrigator sells his rights permanently, the lack of maintaining work on his property can bring weeds and increase disease risk for the neighbors (Frontier Economics et al., 2007; Bjornlund, 2008) or even cause soil erosion (Chong and Sunding, 2006. In the Australian case, there is only limited evidence to suggest that permanent water sales might generate significant economic losses in the sellers' area of origin (Grafton et al., 2016; Haensch et al., 2019).

The second chapter of this thesis focuses on a different market failure: insider trading. In financial markets, insider trading is defined as the illegal trading in securities by individual or firms possessing important non-public information (Meulbroek 1992). It is subject of intense scrutiny from institutions such as the U.S. Securities and Exchange Commission. In water markets, however, the topic had not been considered yet. In the Australian water markets, the first regulation related to insider trading was established in 2014, through the introduction of new trading rules. However, anecdotal evidence of insider trading practices (e.g. Hancock, 2008) has been reported, although not published in the peer-reviewed literature. For the first time, we question the occurrence of insider trading practices in Australian water markets. To do so, we look for informed price movements around significant market announcements implying changes in water prices, using 10 years of daily trade data and other known market price determinants. Our times-series model detects evidence of informed price movements between 2008 and 2014. This evidence weakens after 2014, with only one specification showing significance at a 10% level. Informed price movements can either be related to insider trading (Keown and Pinkerton, 1981; Moelbreuk, 1992; Maug et al., 2008), or to other factors including an increased sophistication of trading behaviour, i.e. rational speculation (Jensen and Ruback, 1983; Jarrell and Poulsen, 1989; Aspris et al., 2014; Gu and Kurov, 2018). Following a reasoning suggested by Gupta and Misra (1988), the fact that informed price movements almost disappear after the 2014 insider trading regulations could argue in favour of an 'insider trading' interpretation. However, the increased sophistication and volumes exchanged in water markets within the Murray-Darling Basin support a 'rational speculation' interpretation. In any case, introducing insider trading regulations seems like a necessary water market policy, as the potential for such practices clearly exist.

The third chapter considers another potential problem arising from the substitution between ground- and surface water markets. To do so, we consider the case of Australia's Murrumbidgee river region, where both type of water resources are available.

A substitution effect can arise between ground- and surface water and affect the way water markets work. In various contexts, it has been reported that irrigators could increase groundwater consumption in order to compensate reductions in surface water rights (Zhang, 2007; Wheeler et al., 2016). This can lead to unexpected negative consequences of policies aiming to reduce water use in the context of a drought or attempting to increase environmental flows. Analysing 10 years (2008-2018) of monthly surface and groundwater market data, we first use a vectorial autoregression with exogenous variables (VAR-X) to question the way market information is assimilated in ground- and surface water markets. Specifically, we investigate the existence of a price leadership phenomenon. We find that past values of the surface water market price significantly influence the groundwater market price, while the opposite is not true. Accounting for this market interconnection, we then attempt to provide an estimate of groundwater demand elasticity using water market data. We find that a 1% increase in water price is associated with a 1.05 decrease in groundwater demand, suggesting that irrigation groundwater in the Murrumbidgee is elastic but close to the unit elasticity. Overall, our results stress the necessity to design regulations affecting both surface and groundwater resources and markets in the Murrumbidgee river region: surface and groundwater markets are interconnected, and the elasticity of groundwater demand suggests that irrigators are likely to be responsive to any change in water price. Thus, the occurrence of a substitution effect in Australia is highly probable, in case of regulations solely affecting surface water use.

In recent years, water markets have been tested (Zhang, 2007) or considered (Mellah, 2018) as potential tools in different contexts. However, water markets are embedded in various context-dependent socio-political contexts, and do not always lead to efficient or effective solutions for water management (Breviglieri et al., 2018). In this perspective, Wheeler et al. (2017) presented a framework to analyse the reforms necessary to establish water markets in different contexts, by identifying enablers and impediments to the use of markets in a given context but also the potential costs and benefits associated. The fourth chapter applies the Water Market Readiness Assessment (WMRA) to two French case studies: The Poitevin Marsh Wetlands and the Neste system. In order to inform this study, 11 semi-structured interviews (6 in the Neste system, and 5 in the Poitevin Marsh Basin) were held with key local stakeholders. In each case, we first provide an overall presentation of the context's geography, water resources and hydrology. France is not a water scarce country in the sense of Falkenmark (1999), and it is illegal to buy and sell water rights in the French water management system. However, our case studies both experience recurrent episodes of physical water scarcity in summer months (June to September), when irrigation water needs are high and water demand can exceed the available supply, suggesting the use of demand-management tools. In each case, we address the current needs in relation to water management, and the framework in place to answer those needs. Finally, we identify the potential enablers, impediments and benefits associated with the implementation of water markets in our contexts. Overall, irrigation-related water withdrawals in some parts of the Poitevin Marsh Basin have damaged the nearby and hydrologically connected wetlands. In the recent years, a framework of demand management measures has been established by a state authority (Etablissement Public du Marais Poitevin, EPMP) in cooperation with irrigators representatives, alongside with supply augmentation projects (‘substitution reservoirs’) that have been generating political controversy in some parts of the Basin. Important impediments to the use of water markets identified include the absence of a cap on water rights in the Basin, and a low social acceptability of the use of markets applied to water resources (Kervarec, 2014). The existence of large hydrologically connected area within the basin and a diversity of uses for irrigation water, however, suggest significant benefits associated with the reallocation of water towards higher-valued uses. The Neste river system is a surface water system including 18 rivers artificially replenished by a channel diverting water from the Neste river, flowing from the Pyrenees mountains. The system operator (Compagnie d’Aménagement des Coteaux de Gascogne, CACG) monitors water diversions upstream in order to match the granted irrigation water rights each year. However, since the establishment of a cap in 1992, water demand in the system has exceeded water supply, leading to the establishment of a waiting list. Identified impediments to the use of water markets include: the existing water management framework, based on an annual administrative allocation of water extraction authorizations and forbidding water sales; the *droit acquis* principle, implying a priority over water for irrigators who were allocated water rights in previous years; and a cultural and political opposition to the use of markets applied to water resources. However, the extended available infrastructure would considerably facilitate water transfers, and water markets could increase the flexibility of water demand by allowing irrigators in the waiting list to buy water from irrigators growing lower-valued crops (such as maze and other cereals), thus fostering a transition towards a higher water use efficiency.

Overall, by questioning the impact of water markets on water use efficiency (Chapter 1), the potential occurrence of insider trading (Chapter 2), the articulation between ground- and surface water markets (Chapter 3) and their potential establishment in two French contexts (Chapter 4), this thesis attempts to contribute to the empirical knowledge on water markets. Insights from our results can be used by water policymakers and water management stakeholders to inform the debates on the relevance of water markets in order to manage water scarcity.

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Chapter 1[2]:

More market, more efficiency?
Water market impacts on water use efficiency in the Australian agricultural sector

Abstract

Water markets emerged as economic tools to deal with water scarcity. By reallocating existing water resources instead of using costly engineering projects to extend the existing supply, they are expected to increase the efficiency of water resources allocation. In this paper we question empirically the impacts of water markets on the efficiency of agricultural production, as defined by a stochastic frontier approach. Using regional data on agricultural production and climatic factors, we analyze the association between the existence of water markets, the intensity of water trade and the efficiency of agricultural production in Australia, home to some of the most developed water markets in the world. We find that the existence of water markets in a region is associated with a higher agricultural production efficiency, but no significant relationship is identified between the intensity of water trade and efficiency.

Keywords: Water markets; Stochastic frontier; Technical efficiency in agricultural production; Murray-Darling Basin.

JEL Classification: Q56; Q25; Q15

[2] This chapter refers to the article cowritten with Phu Nguyen-Van and Anne Rozan.

1. Introduction

In 2016, the World Economic Forum published the Global Risks Landscape (World Economic Forum, 2015). Among all the risks presented the report rank water crisis as the most important risk in terms of potential impact. Demographic pressures and the expected impacts of climate change endanger the balance between water supply and demand, while the means of increasing water supply become less and less cost efficient.

Water markets have emerged as potential tools to manage the demand for water. Such markets can be defined as systems of rules and regulations that govern the buying, selling and leasing of water use rights (Debaere et al., 2014). They can be used within the agricultural sector; or they can allow inter-sectoral trades, as in the case of rural to urban transfers. The main justification for the use of market mechanisms applied to water resources is that they are expected to increase the overall efficiency of water use. Various forms of water use efficiency can be considered. Technical efficiency refers to the ability of a production unit to operate on the production frontier, i.e. to produce the maximum attainable output from each input level (Coelli et al., 2005). In the case of water, water use technical efficiency thus implies to produce the maximum possible amount for a fixed amount of water. More specifically, water use allocative efficiency refers to water being allocated to where it generates the most income, while other efficiency improvements in the use for water can be obtained through technology (Wheeler et al., 2014). Water markets can foster allocative efficiency gains by redirecting water from low-valued to higher valued uses (Dinar et al., 1997), and towards more productive activities (Hodgson, 2006). They can also increase technical efficiency through the expansion of water use by highly efficient new water users, adoption of water conserving technologies and elimination of inefficient uses for water (Qureshi et al., 2009).

Water markets have been established in various parts of the world. Examples of formal (i.e. regulated and designed by a central authority) water markets include Australia (Grafton et al., 2016), the western United States (Colby, 1990), Chile (Bitran et al., 2014), Spain (Palermo-Hierro et al., 2015) and China (Zhang, 2007). Examples of informal (i.e. transactions happening under limited or no scrutiny from the central authority) water markets can be found in India (Mukherji, 2007) or Pakistan (Razzaq et al., 2019). Recently, the use of water markets in other contexts has been considered, in order to face the challenges induced by water scarcity (Mellah, 2018; Wheeler et al., 2017). As water markets showed a low social acceptability in many contexts as France (Figureau et al, 2015) or Italy (Zavalloni et al., 2014), informing the debate on their empirical effects in the context of existing water markets is important.

Australia is a good case study for the use of water markets and economic tools in a context of water scarcity. For the most part of its territory, Australia is facing significant physical water scarcity (UN, 2012), as water resources development is approaching or has already exceeded sustainable limits. The first water markets in Australia were established in the early 1980s. Since then, water markets developed through progressive reforms while trading volumes and irrigators' participation in water markets have consistently increased through time (Wheeler et al., 2014) and water markets in the Murray-Darling Basin have been described as some of the most advanced water markets in the world (Grafton et al., 2011).

Different studies have attempted to demonstrate the economic benefits of water markets in Australia, using a general equilibrium approach (Peterson et al., 2005; NWC, 2012) or analyzing market bid and ask transactions at the micro-economic level (Brooks and Harris, 2008). However, no empirical study has considered the impacts of Australian water markets on water use efficiency in practice. This study contributes to the empirical literature focusing on water markets' economic impacts by analyzing the relationship between water markets and the efficiency of water use in Australia. To do so, we used a stochastic frontier approach and agricultural, climatic and market data between 2011 and 2017. Results from this study can be used to inform the debates related to water markets performance in the Australian context and to their potential adoption in other contexts.

2. Literature review: water markets, expected benefits and impacts on water allocation efficiency

Markets emerged in the early literature as a feasible alternative to central water management, described as limited in its ability to reallocate resources efficiently. In this perspective, it focuses on the benefits expected from water transfers. Resorting to the private sector in the field of water allocation decisions was for example advocated by Milliman (1959), or Hartman and Seastone (1970).

Different studies dedicated to water market impacts simulate their existence to estimate potential benefits. Vaux and Howitt (1984) considered the possibility of interregional water transfers in California. Using a general equilibrium approach, the authors compared the costs of such transfers to those of a gradual supply extension in water's area of arrival to meet the expected demand. The net benefits estimated from the transactions for buyers and sellers amount to USD$66 million for the year 1980, and are expected to increase to USD$220 million for the year 2020. Dinar and Letey (1991) estimate profit functions for farmers in the San Joaquin Valley and consider the ability to trade water. Their results show better abilities to invest in irrigation technology, decreased environmental pollution and a potential reallocation of water towards the urban sector. Whittlesey and Willis (1998) analyze different alternatives aimed at maintaining a minimum flow in the Walla Walla River Basin (State of Washington, USA). Using a model predicting agricultural behavior and stream flows in the basin, they find markets as the most cost-effective approach. In Australia, Peterson et al. (2005) use general equilibrium modelling to introduce the ability to trade water in the Australian economy. Their results indicate important gains in Regional Domestic Product where water is traded with a positive global impact on Australia's GDP. This impact is described as particularly important in years of drought (AUD$555 million in a year subjected to important water scarcity, and AUD$201 million in a year subject to a relative abundancy), suggesting water markets might alleviate the economic effect of droughts on the Australian economy.

Another section of the empirical literature attempting to measure water market's economic impacts analyzes actual transaction data at a microeconomic level. Hearne and Easter (1997) analyzed transactions from water markets in Chile in the agricultural sector. They compared water values determined by crop budget to prices included in water trades. They found gains from trade varying from $1000 per share to $10 000 per share, depending on the time and location of trades. In Australia, Bjornlund (1999) focused on transactions in two specific areas of the Murray-Darling Basin and related them to the characteristics of the irrigators involved. He found that water was in average moving towards more efficient buyers that were also growing higher-valued crops. Brooks and Harris (2008) analyze data from three trading zones in northern Victoria to determine consumer and producer surplus. They find surpluses of $20 000 a week in the Greater Goulburn area.

Besides gains from trade, different empirical studies showed that water markets are used by irrigators to improve their risk management. Farmers tend to be risk averse, under different modalities (Nauges, Wheeler and Zuo, 2015); water markets can provide a reliable source of water in times of needs or an additional source of income, thereby positively affecting farm budgets (Wheeler et al., 2014). This has been shown empirically in Australia, particularly in the horticultural sector as permanent trees and vines could die if they are exposed to excessive water stress (Loch et al., 2012). Besides, farmers experiencing a high variability in profits have incentives to trade more on water markets (Cristi, 2007; Calatrava and Garrido, 2005). Therefore, water markets are expected to improve farmer's ability to manage their water related risks (Zuo et al., 2015).

In parallel to these benefits, limits to the use of water markets that could prevent them to improve efficiency in the use of water resources have been widely commented, often in a context of limited market development. Classical limits to the use of markets are often amplified in the case of water: as water is a massive resource, the costs raising from moving the resource can be high (Turner et al., 2004). Some of the transaction costs related to water trading are analyzed by Colby (1990) in the western United States, who concludes that the administrative costs are not to be considered as 'overly burdensome' to transactions in the western United States water markets around 1990. Moreover, the potential for externalities is important. Changes in streamflows, return flows and impacts on water's area of origin are frequently cited in that matter and can mitigate the gains obtained by buyers and sellers (Garrido Fernandez, 2016). Furthermore, an externality often described by the literature is the 'stranded asset' problem (Chong and Sunding, 2006; Heaney et al., 2006; Bjornlund, 2008; Frontier Economics et al., 2007): as irrigation water use requires heavy investment in infrastructures, these infrastructures are often shared by different users. If one of these users decides to sell his or her water entitlement, the maintenance costs of the infrastructure will be supported by the remaining users, who generally compete with the leaver. When an irrigator sells his rights permanently, the lack of maintaining work on his property can bring weeds and increase disease risk for the neighbors (Frontier Economics et al., 2007; Bjornlund, 2008) or even cause soil erosion (Chong and Sunding, 2006).

In relation to these market failures, different authors notice the very limited development of water markets in terms of transactions between 1980 and 2000, mainly in the United States. Some attempt to explain this phenomenon, as Rosen and Sexton (1993) who suggest the low level of transactions is due to a lack of cooperation between market actors and operational institutions actually owning the water. Saliba et al (1987) also question the limited amount of water trade that was undertaken at the time, as compared to the potential benefits that could be realized from it according to Vaux and Howitt (1984). They conclude that the interdependencies and the public good characteristics of water make perfectly competitive markets purely infeasible in practice.

This paper questions the ability of water markets to enhance water use efficiency. We apply a panel data stochastic frontier model to regional Australian data on agricultural production, climatic factors, and market variables in order to analyse the relationship between water markets and efficiency of water use.

3. Research hypotheses

In the Australian case, Bjornlund (1999) studies two specific areas presenting water markets in the Murray-Darling Basin. He noticed that water was sold to more efficient farmers in terms of water use and value generated. In a similar perspective, Wheeler et al. (2014) reported that in the decade preceding 2014, water has been sold from annual crops (rice, cotton, mixed farming) to horticultural crops, due to a more inelastic demand from vegetables and perennial horticultural activities. These transactions implied a higher value-added use per unit of water, considering marginal contribution of irrigation water to profit of $547/ML and $61/ML, for horticulture and broadacre crops respectively (Nauges, Wheeler and Zuo, 2015).

Generalizing these arguments at the regional level, we expect water market transactions from lower-valued uses towards higher valued uses to increase the allocative efficiency overall. Furthermore, we expect water markets to generate incentives from higher technical efficiency users to buy water from lower technical efficiency users (Qureshi et al., 2009). Thus, we formulate our first research hypothesis:

H_1: In regions where water markets have been established, water use efficiency (i.e. as measured by the output value generated by one unit of water) of agricultural water use is greater.

Water markets have developed in different scales throughout Australia. As described in Figure 3, the MDB represents about 85% of all water market transactions in Australia. This is related to the fact that the southern MDB represented a large hydrologically connected area, unlike other parts of Australia, thus involving more potential users (Wheeler et al., 2014). Besides, more active water markets imply an increased access to market infrastructure and information. Therefore, we expect more active water markets such as markets within the southern MDB to facilitate water use efficiency enhancement:

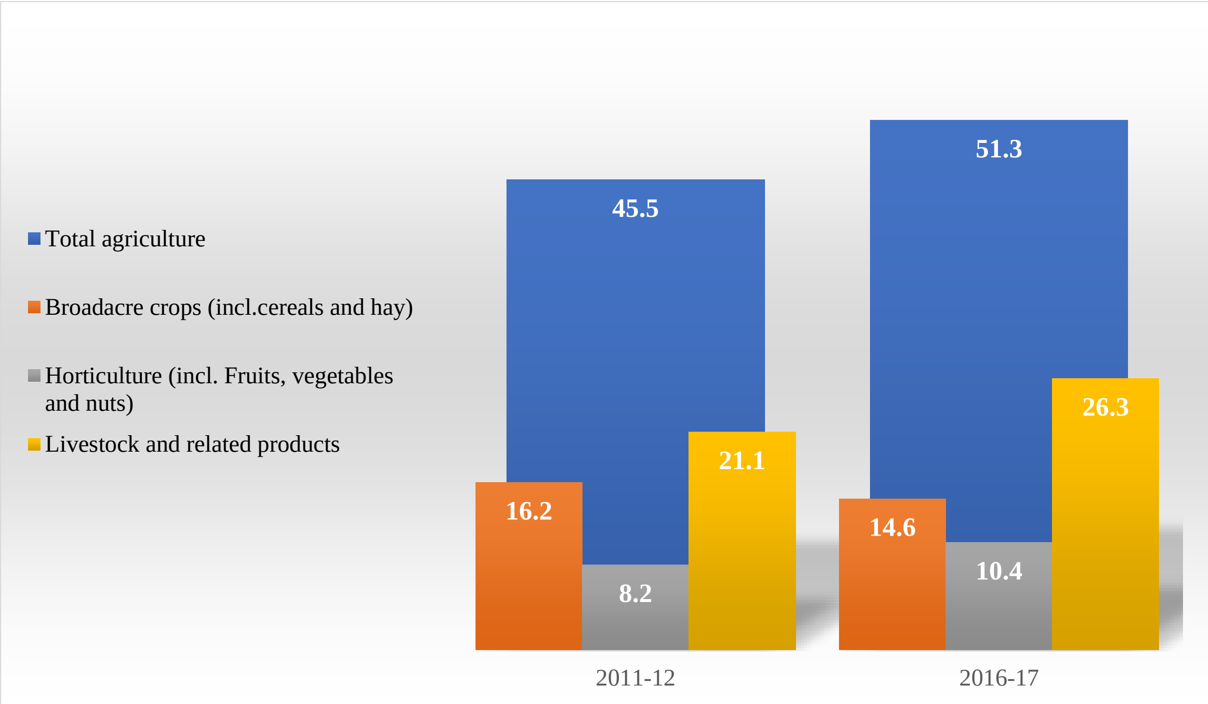
H_2: In regions where more active water markets are in place (i.e. more transactions occur), water use efficiency should be higher.

This paper therefore questions the impact of water markets existence (H_1) and intensity (H_2) on water use efficiency between 2011-12 and 2016-17 in Australia. To do so, we use a stochastic frontier model at a regional level, and Australian data on market existence and intensity, agricultural production, inputs, and climatic circumstances.

4. Background: Agriculture and water markets in Australia

In the last decades, agriculture in Australia has been evolving under the impact of the Millenium Drought, that occurred between 2002-03 and 2010-11. Our period of study begins in 2011-12, in a relatively wet year marking the end of the Millenium Drought. Between 2011-12 and 2017-18, the total Australian agricultural production value increased from 45.5 to 51.3 billions AUD$:

Figure 1: Total agricultural production value in Australia, overall and by category, 2011-12 and 2016-17

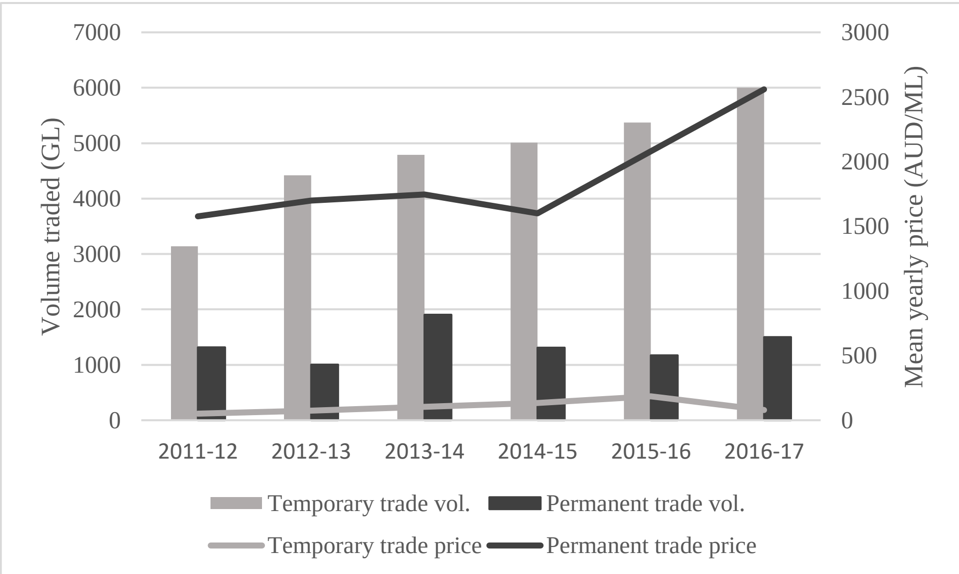


Source: data from the Australian Bureau of Statistics (2013; 2018). Figures are in billion $AUD, corrected for inflation using constant 2011 prices.

The overall 11% increase in total production value is related to a strong development of horticulture (the fruits and nuts industry in particular) and livestock, in spite of a decline the production value associated with broadacre crops. In particular, cereal production value dropped by about 15% (ABS, 2013; 2018). Thus, over our period of study, a decline in lower-valued crops (as cereals) and a development of higher valued crops (fruits and nuts, vegetables) can be noted.

Water trade is, for logistical and juridical reasons, only possible between hydrologically connected zones. As a consequence, there is not one national water market in Australia but many trading zones based on hydrological connectivity. There are two types of market transactions ongoing in the Australian water markets. Entitlement trading implies the exchange of ongoing rights to exclusive access to a share of water otherwise known as permanent water. Water allocations trading involves the exchange of a specific volume of water allocated to water entitlements in a given season otherwise known as temporary water (Haensch et al., 2019). During the fiscal year 2016-17, approximately 7500 GL were traded in Australian water markets, representing a global turnover of AUD$131 millions (ABARES, 2018):

Figure 2: Temporary and permanent water trading prices and volumes in Australia, 2011-12 to 2016-17



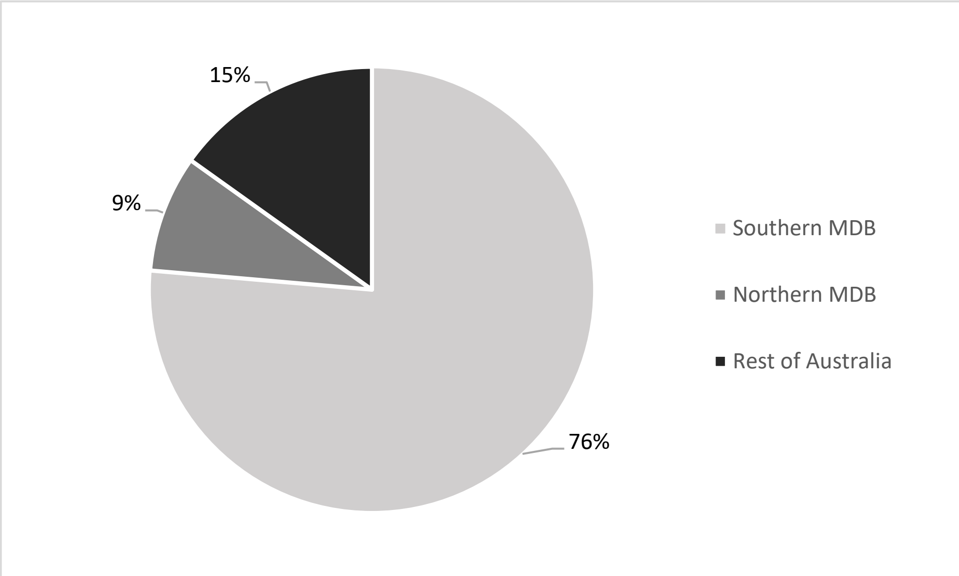
Source: data in ABARES (2018)

Between 2011-12 and 2016-17, the volume of temporary water rights traded (allocations) has consistently increased, while allocation prices fluctuated depending on climatic circumstances. Besides, although the volume of permanent water rights traded remained globally stable, the price of permanent water rights also increased, under the joint influence of water scarcity and federal environmental water buyback programs.

Australian water markets historically involved irrigators as the most important actors of water trade. Other actors involved in the process of exchanging water rights in Australia include water brokers who provide market information and trading platforms to irrigators, federal and national authorities who launched an important buyback program destined to restitute water to the environment, and Irrigation Infrastructure Operators (IIOs) who typically own blocks of water rights on behalf of irrigators, and redistribute these rights to their members. These actors trade under federal, national and sometimes local regulations that have been progressively adapted to increase irrigators' participation to water markets.

The process historically establishing Australian water markets implied different steps. Australian water markets were historically created around the agricultural sector in the Murray-Darling Basin (MDB) (Maziotis et al., 2013) and it is where water trade is the most developed and established, as illustrated by Figure 2:

Figure 3: Proportion of Australian water trades (temporary and permanent) occurring within and outside the Murray-Darling Basin, 2016-17



Source: data in ABARES (2018)

The basin involves parts of four Australian States: New South Wales, Victoria, Queensland, and South Australia. It also includes the Australian Capital Territory. As the MDB is subject to a climate favoring irrigated agriculture in comparison with the semi-arid climate found northwards, agriculture covers 67% of its territory and represents about 40% of the total Australian agricultural production. In 2015, the ratio of water demand to available water resources was superior to 0.4 in most of the basin's area, defining a "high" water stress (UN Water report 2015[3]). This and the prevalence of irrigated agriculture contribute to explain the emergence of water markets in the area, as market for water resources potentially appears when water demand approaches water availability (Debaere et al., 2014). The important volume of water trade and the institutional framework fostering water markets in the southern MDB led

[3] Source: UN Water report 2015, cited by *Le Monde* (March 20th, 2015).

Grafton et al. (2011) to describe water markets in the Murray-Darling Basin as the most advanced in the world.

In 1994, a cap was established on total water extraction in the Murray-Darling Basin. This decision set the maximum level of water extraction in the basin at the 1994 extraction level. This step caused a large increase in the water traded on the market, as additional needs for water had to be fulfilled through the market. In 2004, the National Water Initiative (NWI) precisely defined the generic terms 'entitlement' and 'allocation', common to all Australian States, in an effort to unify the existence of many different water markets. It recognized the need for better designed water markets to improve efficiency in water uses, in a context of low participation to such markets. In 2007, the national 'Water Act' took additional steps to decrease barriers to trade. In 2012, the Murray-Darling Basin Plan defined freedom of trade as the norm and restrictions to trade in the Basin as exceptions, while establishing an authority in the Basin responsible for the management of water resources. Towards the end of the Millenium drought, the Australian Federal government dedicated AUD$3.1 billion to buy water rights from about 4500 willing irrigators in order to increase environmental flows in the MDB (Wheeler and Cheeseman, 2013). Furthermore, the SRWUI program planned an additional AUD$5.8 billion for water-related investments (Haensch et al., 2019). While the 'buyback' program reduced the overall water use in some areas within the Murray-Darling Basin (Department of Land, Water and Environment, 2018), investments aiming to develop on-farm water use efficiency (Haensch et al., 2019) have been widely criticized by economists for various reasons, including higher costs (Grafton et al., 2015) and a lack of accounting for return flows (Williams and Grafton, 2019) that could eventually increase consumptive use at the expense of environmental flows (Loch and Adamson, 2015).

5. Data

The data analyzed in the next sections was obtained through different sources than can be found in Appendix 1, along with descriptive statistics. The analysis was conducted on 54 Australian Natural Resource Management Regions, as defined by the ABS, between the fiscal years 2011-12 and 2016-17.

Agricultural data on water use and total agricultural area was extracted from the Australian Bureau of Statistics (ABS). As climate has been described as the most important determinant of agricultural productivity, mainly through its influence on temperature and water regimes (Kang et al, 2009), we included rainfall and potential evapotranspiration to the analysis. Such variables were sourced from the Australian Bureau of Meteorology. As estimates of rainfall or temperature at the NRM region level were not available, the data has been computed based on the rainfall, latitude and temperature of 5 (temperature) to 10 individual stations across each natural resource management region in Australia. In particular, the mean monthly temperature was defined based on the mean maximum temperature (defined as the average of daily maximum temperatures in a given month) and the mean minimum temperature (the average of daily minimum temperatures in a given month), following Allen et al. (1998):

$$Mean\ Temperature = \frac{Mean\ Max\ Temperature + Mean\ Min\ Temperature}{2}$$

As potential evapotranspiration (PE) is often described as a better predictor than temperature and is widely used in the literature (see Webb, 2006 or Blanc et al., 2014 for examples), we computed the mean monthly PE based on the FAO Penman-Monteith equation, as recommended by Allen et al. (1998). Some missing climatic data (wind speed, radiations, etc.) was simulated according to Allen et al.'s advice.

Finally, two market variables were defined at the region level, based on our two research hypotheses. First, the existence of a functioning water market in region i (i.e the occurrence of at least one recorded transaction in the past) was coded through a binary variable., Second, we used the volume of the additional water bought through water markets in each region as a proxy for water trade intensity.

6. Econometric framework

6.1. A panel data stochastic frontier model

This section presents the stochastic production frontier model applied to our data. Widely used in the literature dedicated to the analysis of technical efficiency in agriculture (see, for example, Nguyen-Van and To-The (2016)), such frontiers have been previously applied to the Australian grape production by Hughes (2011) or Coelli and Sanders (2012). Specifically, we use the inefficiency frontier model for panel data presented by Battese and Coelli (1995).

We assume that output y_{it} of farmer $i, i = 1,2, \ldots, n$ at time t, $t = 1,2, \ldots, T$ is subject to random shocks v_{it} and a degree of technical efficiency $TE_{it} \in (0,1]$:

$$y_i = f(x_{it};\ \beta) TE_{it} \exp(v_{it}),\ \ i = 1,2, \ldots, n, \qquad (1)$$

where x_i is a Kx1 vector of inputs, β a Kx1 vector of parameters to be estimated.

By assuming $TE_{it} = \exp(-u_{it})\ \ with\ u_{it} \geq 0$, we obtain

$$y_i = f(x_{it};\ \beta) \exp(v_{it} - u_{it}), i = 1,2, \ldots, n, \qquad (2)$$

Note that v_{it} corresponds to the usual error term capturing random variation in output due to factors beyond the control of producers and is assumed to be independent and identically distributed $N(0, \sigma_v^2)$. Technical inefficiency is captured in u_{it} which is assumed to be independent and identically distributed non-negative truncations of the $N(\mu, \sigma_u^2)$ distribution. The condition $u_{it} \geq 0$ ensures that all observations lie on or beneath the production frontier.

Applying log transformation to equation (2) we get

$$lny_{it} = lnf(x_{it};\ \beta) + v_{it} - u_{it} \tag{3}$$

Note that, following Battese and Coelli (1995), we can specify a conditional mean model for u_{it} as $\mu = z_{it}\delta$, or equivalently

$$u_{it} = z_{it}\delta + \varepsilon_{it} \tag{4}$$

where z_{it} is a Jx1 vector of explanatory variables. This vector includes the existence or intensity of water markets in the considered NRM region and climatic variables (potential evapotranspiration and Rainfall) and year dummies. ε_{it} is defined by the truncation of the normal distribution with zero mean and variance σ^2, such that $\varepsilon_{it} \geq -z_{it}\delta$ (see Battese and Coelli, 1995, for details).

We simultaneously estimate the technical inefficiency u_{it} and a conditional mean model for u_{it} using a vector of explanatory variables in order to analyze their respective impacts on technical inefficiency. Note that we are especially interested in the sign of our market variable's parameter in this regard.

In this model, the technical efficiency of a given region i at time t is defined as the ratio of its production to its corresponding production if the region used its inputs in a perfectly efficient way. An estimation for technical efficiency $TE_{it} = \exp(-u_{it})$ can be given by (see Battese and Coelli, 1993, for panel data, or Jondraw et al, 1982 for cross-sectional data):

$$TE_{it} = E\{\exp(-u_{it})\,|v_{it} - u_{it}\} = \left\{\frac{\Phi\left[\left(\frac{\mu_*}{\sigma_*}\right) - \sigma_*\right]}{\Phi\left(\frac{\mu_*}{\sigma_*}\right)}\right\} \exp\left[-\mu_* + \frac{1}{2}{\sigma_*}^2\right] \ ,$$

where: $\mu_{*} = \frac{[z\delta\sigma_v^2 - (v_{it} - u_{it})\sigma^2]}{\sigma_v^2 + \sigma^2}$, $\sigma^{*2} = \frac{\sigma^2{}_v\sigma^2}{\sigma_v{}^2 + \sigma^2}$, and $\Phi(.)$ is the distribution function of the standard normal distribution.

In order to compute the technical efficiency scores, we need to estimate the parameters from the equations (3) and (4). This can be performed by Maximum Likelihood (See Battese and Coelli, 1993 for a detailed equation of this model's log-likelihood). However, in order to estimate the vector of parameters β, we have to specify the f function. As described with our data, we consider 2 inputs in the production function (agricultural area and water use) and a range of control variables including climatic variables (rainfall, temperature, potential evapotranspiration) and other variables (existence of a water market, location within the Murray-Darling Basin…).

Two different specification strategies were tested in this paper. We consider a Cobb-Douglas function, i.e.:

$$\ln f(x_{it}, \beta) = \beta_0 + \beta_1 \ln AREA_{it} + \beta_2 \ln Wateruse_{it},$$

and a more general function (Translog), i.e.:

$$\ln f(x_{it}, \beta) = \beta_0 + \beta_1 \ln AREA_{it} + \beta_2 \ln Wateruse_{it}$$
$$+ \beta_3(\ln AREA_{it})^2 + \beta_4(\ln Wateruse_{it})^2 + \beta_5 \ln AREA_{it} \ln Wateruse_{it}$$

Akaike and Schwarz's Bayesian Information criteria suggest a higher goodness of fit of the Translog specification, confirmed by the likelihood ratio test. Consequently, the translog model is used in the final analysis.

6.2. *Endogeneity issues*

It should be noted that the problem of endogenous regressors may arise with the specification above. This issue is especially related to the water trade intensity variables. As we can only observe production where a water market exists, a selection bias can arise.

Water markets tend to be established in areas suffering from high water stress (Breviglieri et al., 2018). Thus, rainfall and potential evapotranspiration are likely predictors of the existence of water markets in a region. Besides, historically, the Murray-Darling basin hosted the first water markets in Australia and has developed an extended institutional framework for the use of water markets (Grafton et al., 2016). The geographic location of a region (inside or outside the MDB) can therefore influence the probability of finding a water market.

We first performed a probit regression of our market existence variable on the set of explanatory variables w, which includes z, as well as MDB_i, $Rainfall_{it}$ and $PotentialEvap_{it}$. We then computed the generalized residuals (Gourieroux et al., 1987):

$$\hat{g}r_i = Market_i \lambda\left(w_i' \hat{\gamma}\right) - (1 - Market_i)\lambda\left(-w_i' \hat{\gamma}\right),$$

where $\lambda(.)$ is the inverse Mills ratio, $\lambda(.) = \phi(.)/\Phi(.)$. Finally, we simultaneously estimate the production frontier model in (3) and (4) as explained above, but with an additional regressor corresponding to the estimated generalized residuals $\hat{g}r_i$. As recommended by Woolridge (2014), we test the existence for endogeneity of $MarketExistence_{it}$ by using a robust t-test for the significance of coefficient of $\hat{g}r_i$ in this regression.

Market existence and trade intensity are closely related. In order to avoid collinearity, we ran the analysis using market existence and trade intensity separately. The first analysis runs the model while including a dummy for market existence in the mean conditional inefficiency model, in order to test the validity of H_1. The second analysis includes a continuous trade intensity variable and residuals based on a linear regression of trade intensity on potential determinants instead, in order to test the validity of H_2.

7. Results

Results from the probit and linear regression estimations can be found in Appendix 2. The robust t-test (Woolridge, 2014) shows that the generalized residual's coefficient is not significant at the 5% level, indicating that $MarketExistence$ is not subject to endogeneity. In other words, regression with endogenous *Market* gives qualitatively the same results than that with exogenous *Market*. Therefore, generalized residuals were not used in the final regressions.

7.1. Questioning H1: Market existence and technical efficiency of agricultural production

First, we ran the analysis by including our market existence variable in the stochastic frontier conditional mean inefficiency model. The frontier's results appear below:

Table 1: Stochastic frontier estimation of the Australian agricultural production using Market Existence, 2010-2017

	Total agricultural production	
	Coefficient	Std. Error
Frontier inputs		
Total agricultural area	1.541***	0.531
Total water use	0.731	0.447
Total water use (squared)	0.00663	0.0108
Total agricultural area (squared)	-0.0286	0.0282
Interaction	-0.0546**	0.0231
Intercept	-0.134	1.389
N	302	
AIC	447.9	
BIC	492.4	
Log-likelihood	-211.9	

Standard errors in parentheses
* p<0.1, ** p<0.05, *** p<0.01

Agricultural area has a significant positive impact on agricultural production, while the parameter of water use is positive but not significant. The interaction between water use and agricultural area has a significant negative impact, indicating some substitution between these two inputs. However, the size of this effect is much lower than the impact of agricultural area.

Following the frontier estimation, we generated mean regional technical efficiency scores through $\{\exp(-u_{it}|e_{it})\}$. Table 2 below reports the 5 highest and 5 lowest scores:

Table 2: Five highest and five lowest technical efficiency scores (exp[-u|e]) following a Translog specification, averaged over 2011-2017

NRM region	Mean Technical Efficiency (exp{-u|e})
Five highest technical efficiency scores:	
Avon	0.915
Riverina	0.887
Port Philipp and Westernport	0.882
North West NSW	0.881
Glenelg Hopkins	0.866
Five lowest technical efficiency scores:	
SA Arid Lands	0.198
Kangaroo Island	0.148
Cape York	0.040
Cooperative Management area	0.033
Alinytjara Wilurara	0.014

Non-parametric mean comparison tests were applied in order to identify distinctive characteristics of the 5, 10 and 15 regions showing the highest technical efficiency levels. Results from Kruskall-Wallis tests appear below:

Table 3: Results from Kruskall-Wallis mean comparison tests on groups formed by the 5, 10 and 15 regions showing the highest technical efficiency score

Variable	Top 5	Top 10	Top 15
Mean yearly temperature (°C)	-2.53***	-1.61**	-2.02***
Mean yearly rainfall (mm/year)	-	-193.41***	-150.92*
Daily potential evapotranspiration	-0.47***	-0.30**	-0.33***
Total agricultural production (million AUD$)	7.46***	6.21***	6.26***
Total agricultural area (million ha)	-	-	-
Total water use, (GL)	-	33.50**	-
Probability to be located in MDB (%)	-0.23**	-0.18**	-
Probability that a water market exists (%)	0.19**	0.19***	0.22***
Extra temporary water volume bought (GL)	-22.20**	17.21***	-
Extra permanent water volume bought (GL)	-	-	-

Note: Each parameter can be interpreted as the mean difference between observations in the selected group (top 5, 10 or 15 regions with the highest technical efficiency levels) in terms of the considered variable (left column). Significance levels: ***1%, **5%, *10%.

On average, high technical efficiency regions are subject to lower temperatures (-1.61 to -2.53 °C) and potential evapotranspiration (-0.30 to -0.47 mm/day). They also produce AUD$6.2 million to AUD$7.5 million more in terms of production value. Interestingly, the probability of finding a water market is about 20% higher among the most efficient regions. Agricultural area, rainfall or variables measuring the intensity of market transactions do not appear to be clear distinctive characteristics. Thus, mean comparisons tests seem to support H_1 (technical efficiency is higher where water markets can be found) but not H_2 (more transactions imply a higher technical efficiency). Evidence supporting the validity of H_1 was also found in the conditional mean inefficiency model:

Table 4: Results of the mean conditional inefficiency model using Market Existence, 2011-2017

	Total agricultural production	
	Coefficient	Std. Error
Technical inefficiency determinants		
Rainfall	0.805*	0.421
Potential evapotranspiration	0.0158	0.42
Market existence	-2.249***	0.784
Intercept	1.435*	0.838
σ_u	-0.435	0.426
σ_v	-3.541***	0.366
Observations	302	
AIC	447.9	
BIC	492.4	
Log-likelihood	-211.9	
Significance levels: * 0.1, ** 0.05, *** 0.01		

The existence of a water market is found to decrease technical inefficiency, confirming the mean comparison test results and supporting the validity of H_1. Potential evapotranspiration is expected to increase water use, thus decreasing technical efficiency if water use is set constant. However, it also provides clear incentives for technical efficiency investments. In our case, no clear association was found between potential evapotranspiration and technical efficiency. Rainfall has an ambiguous impact on agricultural productivity: on one side, it increases a crop's access to water, therefore facilitating its development. On the other side, it increases disease risk and therefore decreases crop yield (Webb, 2006). In our case, the latter effect seems to be predominant, as rainfall is associated with a higher technical inefficiency.

7.2. Questioning H_2: Water trade intensity and technical efficiency of agricultural production

In order to test the validity of H_2, the stochastic frontier with conditional mean inefficiency model was ran while including two proxies for water trade intensity instead of market existence. The total volumes of temporary and permanent water rights bought in each region were used as indicators of the temporary and permanent water trade intensity. Results from the frontier estimation appear below:

Table 5: Stochastic frontier estimation of the Australian agricultural production using Water Trade Intensity, 2010-2017

	Total agricultural production	
Frontier inputs		
Total agricultural area	2.584**	2.450***
	(1.007)	(0.675)
Total water use	0.949	-0.284
	(1.419)	(0.979)
Total water use (squared)	0.0227	0.0193
	(0.0187)	(0.0291)
Total agricultural area (squared)	-0.0468	-0.0821**
	(0.0576)	(0.0341)
Interaction	-0.0913	-0.00445
	(0.0799)	(0.0361)
Intercept	-10.46	-0.497
	(7.662)	(0.768)
Observations	201	148
AIC	243.2	183.0
BIC	282.9	218.9
Log-likelihood	-109.6	-79.49

Standard errors in parentheses
Significance levels: * 0.1, ** 0.05, *** 0.01

As less observations related to the intensity of water market transactions were available, results from the water trade intensity analysis were found less stable than results related to market existence. Some parameters of the production frontier were found insignificant using the full translog specification. We suggest that a potential explanation is the high correlation (.9) between the squared inputs terms and the input variables. Dropping the squared terms generate results close to those found in the previous sections, although the input parameters were slightly lower. Results from the conditional mean model appear below:

Table 6: Results the mean conditional inefficiency model using Water Trade Intensity, 2011-2017

	Technical inefficiency	
Water trade considered	Temporary	Permanent
Technical inefficiency determinants		
Rainfall	-0.273	0.799
	(0.405)	(0.526)
Potential evapotranspiration	1.585*	-0.416
	(0.932)	(0.632)
Water trade intensity (Vol. of water bought)	-20.76	-0.00789
	(60.03)	(0.0420)
Intercept	-3.774**	-0.106
	(1.862)	(1.082)
σ_u	-6.492	-0.646
	(17.57)	(0.733)
σ_v	-1.739***	-3.283***
	(0.238)	(1.039)
Observations	201	148
AIC	243.2	183.0
BIC	282.9	218.9
Log-likelihood	-109.6	-79.49

Standard errors in parentheses
Significance levels: * 0.1, ** 0.05, *** 0.01

The parameters of trade intensity variables are insignificant across all specifications. This result holds when we consider temporary or permanent trade. Thus, we find no evidence supporting the validity of H_2: a higher trade intensity is not associated with a higher technical efficiency between 2010 and 2017 in Australian NRM regions, according to our stochastic frontier estimation.

Overall, our results are in line the expectations formulated by the literature on water market impacts (Bjornlund, 1999; Grafton et al., 2016), as well as the predictions made by general equilibrium modelling (Peterson et al., 2005; NWC, 2012). Our findings confirm that these impacts can be noticed at a regional aggregated level: the existence of water markets in a region is associated with higher technical efficiency scores according to our stochastic frontier estimation between 2010 and 2017. However, we find no association between a higher intensity of market trade and technical efficiency. Thus, we find evidence supporting the validity of H_1 (the existence of water markets in a region is associated with a higher technical efficiency) but not H_2.

8. Robustness tests

In order to improve the validity of our results, different robustness and sensitivity tests were conducted. First, we considered a potential bias in relation to the collection methodology for some of the variables used. All variables sourced from the ABS have been collected by random sampling. However, in 2015, the ABS has changed its data collection methodology by excluding economic agents whose (agricultural) income is under AUD$40 000 from the collection process (this threshold was AUD$5000 previously). Thus, the two last years of our sample are potentially affected by this methodological change. In order to avoid the potential bias arising from this new random sampling methodology, Kruskall Wallis mean comparison tests by groups were applied to all variables sourced from the ABS, in order to see whether a significant difference could exist. All tests were negative (no significant mean difference), except for the extra volume of permanent water bought, where a significant increase in trading was detected after 2015. We suggest that this difference does not undermine our results in a major way for two reasons: first, an alternative proxy free of the previous problem (no significant mean difference after 2015) used instead: the total cost of extra permanent water bought. The estimation generated identical results (no significance of permanent water trade intensity and parameters of a similar magnitude). Second, the results of both estimations related to permanent water trade intensity are similar to those using temporary trade, that show no significant mean difference after 2015.

VIFs were generated using linear regressions after the frontier estimation. No VIF under 5 was detected in the conditional mean inefficiency model. However, the squared input and interaction terms related to the Translog specifications generated high VIFs. Regressions excluding squared input terms and the Translog interaction (Cobb-Douglas specifications) were also tested. Similar results were found.

Finally, in order to check the influence of potential outliers, Cooks distances and leverages were generated following linear regressions of technical inefficiency scores. No Cook's distance over 1 was detected. However, we ran the analysis while excluding observations whose leverage values were found over the (K+1/N) threshold. The results were qualitatively the same.

9. Conclusion

The purpose of this paper was to question the effect of water markets on water use efficiency in Australia, as a complementary analysis to the General Equilibrium approach (Peterson et al., 2005) that has generally been used in that matter. To our knowledge, this paper is the first to use a stochastic frontier approach and regional data in order to measure the impact of water market's existence and trade intensity in Australia. We gathered a database crossing agricultural data from the Australian Bureau of Statistics (ABS), climatic data from the Bureau of Meteorology (BoM) and market data from the National Water Commission (NWC). We find a positive impact of the existence of water markets in a NRM region on technical efficiency in the Australian agricultural sector, between 2011 and 2017. However, we found no evidence showing that a higher trade intensity would be associated to a higher water use efficiency.

Important limits to our results have to be stated. We measured market impacts at an aggregated regional level: it would be interesting to conduct the analysis at a farm level, which would require more detailed data. Due to limited data availability, we do not control for inputs such as labor or capital other than agricultural area. Further empirical research on this topic in other contexts, using more detailed data where available, could confirm our results and would be of interest, given the fact that the economic benefits associated with water markets will be of major interest to the future debates on water markets and policy.

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<u>Reports used in the constitution of the data (Source: Australian Bureau of Statistics):</u>

For each year from 2011-12 to 2016-17 included:

‘Value of Agricultural Commodities Produced’

‘Water Use on Australian Farms’

11. Appendix 1: Summary statistics and data sources

Variable	Description	Source	Obs.	Mean	Std. Dev.	Min	Max
Total agricultural production	Total annual agricultural production value (100mAUD$), deflated using the annual ABARES index of prices received by irrigators	ABS; ABARES	302	6928.63	4152.45	18.63	2000
Total water use	Total annual water use dedicated to agricultural production (GL)	ABS	302	186.29	275.44	0.144	1499.93
Total agricultural area	Total area used for agricultural production (1000ha), yearly.	ABS	302	7086.53	13100	0.89	71400
Rainfall	Mean yearly rainfall at the region level (mm). Computed as an average of monthly rainfall measurements in 5 to 10 stations across each region.	BoM	302	723.94	404.07	169.76	2888.62
Potential evapotranspiration	Mean potential evapotranspiration (mm/day) in each region. Computed based on the guidelines published by Allen et al. (1998)	BoM; Allen et al.(1998)	302	1.97	0.73	0.79	3.73
Mean temperature	Mean annual temperature (°C). Computed based on the mean monthly temperature estimates of about 5 stations across each NRM region. Mean monthly temperature based on the average of mean minimum temperature and mean maximum temperature.	BoM; Allen et al.(1998)	302	18.27	3.99	12.49	27.20
MDB	Dummy variable equal to 1 for regions located within the Murray-Darling Basin. Defined by crossing GIS data on the MDB and NRM regions boundaries	Murray-Darling Basin Authority (MDBA); ABS	302	0.32	0.47	0	1
Market existence	Dummy variable equal to 1 for regions where at least one (temporary or permanent) water trade has been recorded in the current or past fiscal years.	ABS	302	0.85	0.36	0	1
Volume of extra temporary water bought	Volume of extra temporary water bought in each region, per year. Expressed in gigaliters (GL).	ABS	201	39.29	77.11	0.01	479.35
Volume of extra permanent water bought	Volume of extra permanent water bought in each region, per year. Expressed in gigaliters (GL).	ABS	148	3.47	5.12	0.00	32.09

ABS: Australian Bureau of Statistics; ABARES: Australian Bureau of Agricultural and Resource Economics and Sciences; BoM: Bureau of Meteorology.

12. Appendix 2: Results from the first step probit and linear regressions

Regression type	Market existence probit	Temporary water bought linear	Permanent water bought linear
MDB	0.308	0.0910***	2.333**
	(0.210)	(0.0104)	(0.963)
Rainfall	0.934***	-0.000666	0.0887
	(0.268)	(0.0119)	(1.135)
Potential evapotranspiration	-0.931***	-0.0132*	-0.243
	(0.137)	(0.00698)	(0.659)
Intercept	2.222***	0.0335**	2.953**
	(0.359)	(0.0159)	(1.484)
N	316	202	149
R-sq		0.322	0.048
AIC	239.0	-534.4	908.4
BIC	254.0	-521.1	920.4

Standard errors in parentheses
* p<0.1, ** p<0.05, *** p<0.01

Chapter 2[4]:

Is there insider trading in Australian water markets?

Abstract

Insider trading is a much studied form of market manipulation in the financial markets literature. However, studies addressing the issue of insider trading in resource markets, and in particular water markets, are rare. This study investigates the occurrence of insider trading practices around important water market allocation announcements in the Goulburn temporary water market trading zone in the Murray-Darling Basin, Australia, which is one of the largest and longest operating water market districts in the world. Nine years of daily water allocation volume and price transactions between 2008 and 2017 are modelled, with some evidence of abnormal price movements in the three or five days preceding water allocation announcements, especially before the introduction of insider trading rules in 2014. However, although the results do provide some very weak statistically significant evidence to suggest insider trading may still be present in Murray-Darling Basin water markets post 2014, it is just as feasible that our results may also reflect an increased sophistication of trader behaviour over time.

Keywords: Insider trading; Murray-Darling Basin; Water allocations; Water markets.

[4] This chapter refers to the article published in *Australian Journal of Agricultural and Resource Economics 63* (2019) cowritten with Alec Zuo and Sarah Ann Wheeler.

1. Introduction

Where there are strong institutions and secure property rights, water markets have long been promoted by economists as one of the most efficient ways to share water (Brooks and Harris 2008; Peterson *et al.* 2005; Randall 1981; Vaux and Howitt 1984; Crase *et al.* 2000; Wheeler *et al.* 2017). Australia has established the most extended water markets in the world (Grafton *et al.* 2011; 2016), especially in the Murray-Darling Basin (MDB), and within this area markets have increasingly been used as means to reallocate water among irrigation enterprises as well as other consumptive users to the environment (Qureshi *et al.* 2007; Lee *et al.* 2009; Quiggin *et al.* 2010). The development and adoption of water markets as a key instrument for water reallocation in Australia have played an integral role in water policy implementation (Wittwer and Griffith 2011); farm risk management (Brooks and Harris 2008; Connor *et al.* 2012; Nauges *et al.* 2015); farm and structural adjustment within the irrigation sector (Bjornlund and McKay 1998); and off-farm (non-production) income supplementation (Loch *et al.* 2012). Despite markets' key importance in improving efficiency, there has been limited academic analysis of the impact of institutional and policy changes in water markets, nor how a number of well-known financial market risks and behaviour (such as insider trading) have potentially influenced water market outcomes. The main reason for this lack of investigation is the paucity of water market data (and its time coverage).

Since their early implementation in the 1980s, water markets in the MDB have evolved considerably. Water trade in the Goulburn-Murray Irrigation District (GMID), the current biggest and most active trading zone in the MDB, was initially relatively low (Tural *et al.* 2005). Since then, markets have been increasingly adopted by farmers. By the year 2002-03 more than 60% of all farm businesses had been active on either buying or selling water (Bjornlund 2006). Trading volumes consistently increased in the following years under the impacts of the

Millennium Drought (common time-frame of 2002-03 to 2009-10) and the progressive reduction of trading restrictions. In the southern MDB, approximately half of all irrigators had made at least one water entitlement trade, whereas 78% had conducted at least one water allocation trade by 2015-16 (Grafton and Wheeler 2018). In the GMID, temporary water markets have been found to generate significant efficiency gains (Brooks and Harris 2008). In addition to that, water markets in the MDB have become increasingly sophisticated with the emergence of additional market products, such as future contracts and leasing (Bayer and Loch 2017), evidence of price clustering (Brooks and Harris 2012; Brooks *et al.* 2013), as well as improved market information sources from the Australian Bureau of Meteorology (BoM). These findings and developments underline the fact that water markets are similar to financial markets. As such, they may be subject to the same market failures. Particularly, where there is a context of asymmetrical information, diverse forms of market manipulations might affect water markets.

One of the most studied and debated financial market manipulations is insider trading. Insider trading is defined as the illegal trading in securities by individual or firms possessing important non-public information (Meulbroek 1992). On the one hand, insider trading can undermine participation in a market and decrease liquidity (Leland 1992), and socially it is considered unfair if some people lose when other people win from having inside knowledge. On the other hand, it has been argued that insider trading allows for all information to be reflected in a security's price, and overall increases market efficiency as prices start moving quicker than they would have otherwise (Grossman and Stiglitz 1976). Hence, different countries have different rules in regard to the legality of insider trading (Bhattacharya and Daouk 2002**).** In Australia it is an offence under the *Corporations Act 2001* (Commonwealth of Australia 2001, p.202-220) to trade or communicate inside information.

In the case of Australian temporary water markets, which have been in operation since the early 1980s, a number of authors have reported anecdotal evidence of insider trading occurring (Hancock 2008; NWC 2011; BDO 2014). The potential for insider trading in Australian water markets arose because traditionally information was available to a number of people regarding important upcoming fortnightly announcements that explicitly changes the amount of water available for irrigation, which directly impacts on the demand for, and supply of, water in the water market and consequently the equilibrium price for that water (NWC, 2011).

Two types of water rights are traded in the MDB: water entitlements (or permanent water rights), which are an exclusive access to a share of the water resources within an area, and water allocations (or temporary water rights), which are the actual volume (or allocations) of water assigned to the permanent water access entitlement. Allocations vary depending on water availability and expected inflows, and also depend on the reliability of the water entitlements owned. Announcements are made fortnightly regarding the volume of water represented by water allocations, from the start of the water season. The total volume of water announced to be available is called the water allocation level and is expressed as a percentage of the water provided from water entitlements (Wheeler *et al.* 2008).

If water is scarce at the beginning of the season, each fortnight authorities can either announce an increase in water allocations, i.e., an increase in the size of the pool of available water, or they can announce that water allocations remain unchanged, i.e., no additional water is made available. In Victoria, water allocation announcements are currently made by the Northern Victoria Resource Manager (NVRM). Allocation announcements change water supply and/or demand: if water allocations increase, farmers receive additional water that they can use for irrigation purposes. This may decrease the need to buy water on the market, and therefore decreases water demand overall. Thus, allocation announcements can have major impacts on water price (Wheeler *et al.* 2008).

The National Water Commission (2011, p.72) stated that there was 'a need for all market participants to have equivalent opportunity of access to market-sensitive information and at the same time, to guard against insider trading or other situations in which some traders gain a market advantage by having prior access to allocation decisions'. Hence, water allocation announcements represent a key area where there can be a leak of insider information. Various irrigation organizations over time have put different voluntary codes in place to deal with insider information. For example, in 2007 the irrigation organization Sunwater introduced a voluntary code of conduct including ring-fencing practices to prevent the leakage of market-sensitive information (BDO 2014). Officially, insider trading only became illegal after the new trading rules for the MDB Plan in July 1st, 2014 (MDBA 2014) were introduced.

To date there has not been a comprehensive study that has sought to investigate if evidence of insider trading can be detected from water market data, in Australia or around the world, despite legislation having been put in place in part to address the issue. Questioning the occurrence of insider trading on water markets is particularly important, as such markets are less liquid than financial markets. Therefore, water market trades are less diluted and the consequences of insider trading are potentially greater. This study investigates the occurrence of insider trading within Australian water markets in relation to water allocation announcements and any observed price movements, in two key time-periods (before and after the 2014 MDB trading rules on insider trading). The findings of this study provide insights for institutional property rights, monitoring and governance for resource markets and for other jurisdictions around the world that are considering implementing water markets.

2. Literature review

2.1. Insider trading and financial markets

As already commented, it is important to note that trading as an insider[5] is not necessarily illegal. In most cases, insiders are allowed to trade on the market. Transactions made by insiders can become illegal if insiders use important, non-public information to inform their trades (Meulbroek 1992). Before 1990, the issue of insider trading was mostly ignored. In 1998, out of the 103 countries with stock markets, 87 of them had insider trader regulation, although only 38 of them regulated insider trading rules (Bhattacharya and Daouk 2002).

The potential impacts of insider trading have been widely debated in the financial literature, although empirical analyses are often lacking due to the absence of reliable data. Studying litigation cases on actual insider trading potentially suffers from selection bias (Bhattacharya and Daouk 2002). The downside of insider trading includes the fact that it may increase the cost of issuing new shares, as investors demand a premium over the risk-free rate to compensate for the risk of trading with informed traders in the future (Grégoire and Huang 2008), and decrease market confidence and hence market liquidity (Leland 1992; Fishe and Robe 2004). From a social equity point of view, insider trading is seen as benefitting insiders and owners of investment projects (e.g. the wealthy and powerful), and harming outside investors and liquidity traders. As a final potential benefit, insider trading might increase real investment as it improves the market incorporation of information and thus reduces risk for investors (Leland 1992).

Insider trading can impact stock prices, trading volumes or trade count ahead of significant announcements. Kyle (1985) elaborated a theoretical trading model in the presence

[5] The term 'insider' can refer to a variety of situations. In the water markets case, we refer to any individual or entity possessing information about the content of a future announcement that is unrelated to rational speculation.

of private information and found that trade made by informed parties moved stock prices, which was also found by Chakravarty (2001). As information leakage moves stock prices in the same direction as the announcement (Sinha and Gadarowski 2010), it is possible to analyse market returns to investigate the existence of insider trading. Some studies therefore use abnormal returns ahead of announcement as potential evidence of insider trading. Based on litigation cases from the US Securities and Exchange Commission (SEC), Meulbroek (1992) models stocks prices in presence of insider trading and finds a mean 3% abnormal return due to insider trading activity ahead of significant announcements. Keown and Pinkerton (1981) analyse abnormal returns ahead of merger announcements. Olmo *et al.* (2011) used an asset pricing model and developed structural break tests in the intercept in order to detect insider trading activity. They applied it to 250 announcements in the FTSE 350 index and found suspicious breaks for 38 of them. Park and Lee (2010) defined three detection criteria based on parameter characteristics estimated from an autoregressive moving-average time series model of stock returns, and suggested that 19% of major shareholder transactions in the Korean Exchange are based on undisclosed information.

Detection of insider trading in stock markets can therefore be undertaken by analysing abnormal returns related to price movements ahead of major announcements (Keown and Pinkerton 1981; Meulbroek 1992; Park and Lee 2010). However, interpreting the occurrence of pre-announcement abnormal price movements as insider trading evidence implies that such price movements cannot be caused by other factors than insider trading. Several studies have been published on the link between price movements ahead of major market announcements and insider trading, particularly in the case of corporate take-overs. Keown and Pinkerton (1981) found that half of the price movements related to take-over announcements in their US sample happens before the actual announcement. They interpret it as prima facie evidence of insider trading. A similar point is made by Meulbroek (1992**)**. Gupta and Misra (1988) analysed a major insider trading scandal attracting considerable public concern around the topic of insider trading. Under the assumption that insider trading behaviour should therefore decrease, price run-ups before and after the scandal were analysed, with no significant differences found. Bernile *et al.* (2016) find significant evidence of informed trading 30 minutes before important macro-announcements were made, in a context where information was provided to selected news organizations ahead of the announcements under embargo agreements. They interpret this result as a sign of information leakage or superior forecasting ability based on public information. Indeed, other public aspects such as media speculation and the friendly or hostile characteristic of the takeover (Jarrell and Poulsen 1989) have consequently been shown to influence pre-announcement price run-ups, which argue for a market anticipation theory (Aspris *et al.* 2014). Jensen and Ruback (1983) find that market speculation of industry dynamics can explain pre-announcement price run-ups related to take-overs. Aspris *et al.* (2014) control for different major market announcements for 450 takeover announcements and find toehold investments and their timing explain a significant part of pre-announcement run-ups. The influence of other public information is also stressed by Gu and Kurov (2018), who find that public forecasts made by analysts with a superior historical forecasting ability explain a significant part of the pre-announcement price run-ups before major gas inventory announcements. However, as noted by Beny and Seyhun (2012), public rumours and/or public information sources might be synonymous with insider trading as traders obtaining illegal information are incentivized to spread rumours in the financial press to increase the value of their position. Maug *et al.* (2008) analysed price run-ups in 48 countries and 18,752 takeover announcements. They found that passing insider trading legislation affects the pre-bid stock price run-ups: these run-ups explain less of the total price movements once insider trading legislation is in place. This would suggest that at least some of the pre-announcement price movements are caused by insider trading practices.

2.2. Other influences on water prices

Price and volume determinants of water markets in the MDB have been well documented in the literature, particularly for the GMID. There are a number of main price determinants; including: i) rainfall which decreases water demand as farmers substitute irrigation water for rainfall, while irrigation water is often acquired through markets (Bjornlund and Rossini 2004; Bjornlund 2006; Wheeler *et al.* 2012);[6] ii) water allocations or dam storages which represent (or provide a proxy of) the total amount of seasonal water received, where an increase in either negatively impacts water prices, as it increases water supply (Brennan 2006; Wheeler *et al.* 2008; Loch *et al.* 2012); iii) irrigation agriculture output prices are usually positive significant drivers of water prices (Brennan 2006; Wheeler *et al.* 2012) through their impact on farm income; iv) some irrigation commodity input prices where certain inputs can be used as a substitute for water, e.g. such as purchasing feed barley instead of using water to grow pasture for dairy farmers or rising electricity prices can reduce irrigation water demand, especially groundwater pumping; v) output dryland commodity prices (e.g. cattle for dairy) as a land substitute for irrigation can be a negative driver of water prices; vi) policy intervention can also positively or negatively impact market prices (Tisdell 2010; Loch *et al.* 2012); and vii) macroeconomic drivers such as exchange rates and GDP growth (Bjornlund and Rossini 2004) can influence water market prices.

To summarise, detecting abnormal price movements ahead of significant market announcements while controlling for other influences is one necessary condition to detect the

[6] In this perspective, drought (e.g. lack of rainfall) has been identified as a significant driver of water prices, as well as the time within the water season (Wheeler et al., 2008).

possibility of insider trading practices in the water market. The following section outlines more water market background and formulates insider trading hypotheses.

3. Water Markets Background

Water markets have been present in Australia since their early implementation in the 1980s. Following the establishment of a cap on total water extractions in 1995, the National Water Initiative and wide-scale government involvement in the market in the 2000s and the MDB Plan in 2012, markets have become a common tool of water policy management in Australia (Wheeler *et al.* 2014). Insider trading in MDB water markets was not officially regulated before 2014. On July 1st, 2014, new trading rules for the MDB formally forbid the use of undisclosed information in relation to allocation announcements in the MDB (MDBA 2014).

As discussed previously, fortnightly announcements are made throughout the water year that can either increase the percentage of water allocations attached to particular water entitlements or leave it unchanged. This is of particular importance in periods of water scarcity; in the drought year 2008-09, many water allocations to high security entitlements in a number of districts started at 0% and only reached up to 35% at the end of the year with many fortnightly announcements during the season keeping the allocation % unchanged. At the start of the year, farmers had limited information in regard to what the final water allocation may be, nor when it may next increase. When faced with this situation, farmers have a choice to use water allocations from their water entitlements; if this is not enough, within the southern MDB they can enter the water market to buy water (either temporary or permanent) - see Wheeler *et al.* (2014) for more discussion on the Australian water market. Consequently, changes in water allocations can have a direct impact on the supply and demand of water on the temporary market

(Brennan 2006; Loch *et al.* 2012). Within the water allocation market, there are sellers of water (usually farmers who are not farming that year or have seasonal surplus water that is not needed), and buyers of water (usually those who do not own any water entitlements or do not have enough water allocations to use at a point in time and need to enter the market to buy seasonal water).

When analysing a whole season, generally an increase in water allocation levels increases water allocation supply offered for sale and decreases demand for water allocations. However, the impact within a season can be different, especially if it is early in the season and the increase in water allocations was much less than expected (increasing demand and reducing supply overall). In general, water allocation demand is stronger in the first half of the season and weaker in the second half of the season when full water allocations are often reached (Wheeler *et al.* 2008). Hence, an increase in water allocation increases supply and decreases demand, and the water market price decreases (Loch *et al.* 2012).

Therefore, water allocation announcements, especially in times of drought and early season, can have significant impacts on the water market. When analysing the past history of Australian water markets, it is often claimed that disclosure of non-public information about future water allocation announcements has occurred before the official announcement release. Consultations and decisions about water allocation level changes do provide a select number of actors with prior information about future water allocation announcements (NWC 2011). However, these claims have been of an anecdotal nature only, with no formal evidence.

In the financial literature it has been shown that insider trading impacts on stocks market prices (Chakravarty 2001) and pushes prices in the same direction as the return surprise due to the announcement (Sinha and Gadarowski 2010). As water markets are less liquid than stock markets (Crase *et al.* 2000; Brooks *et al.* 2009), this impact may be even more pronounced as trades by insiders may be less diluted by trades of uninformed traders. If insider trading did occur historically in water markets, it is expected that prices will move ahead of announcement in the same direction as the announcement's impact. Therefore, if insider trading is occurring, we expect to detect a price drop in the days preceding an increase in water allocation levels, hence we hypothesise:

H_1: A decrease in water allocation prices will be detected in the days before an increase in water allocation level is announced, ceteris paribus.

Another situation that may occur is that an announcement is made that water allocations will remain unchanged. Such announcements are less frequent, excluding the cases when water allocations are already at their maximum possible level (100%). In this case, water availability itself does not change but water allocation demand can increase and water allocation supply in the market can decrease as farmers need more water as the season progresses. Therefore, if insider trading is occurring, there may be a price increase in the days preceding an announcement of no change in the allocation level as agents with inside information would purchase water earlier or postpone selling water, in order to avoid or take advantage of an increased price later. We hypothesise:

H_2: An increase in water allocation prices will be detected in the days before an unchanged water allocation level announcement is made, ceteris paribus.

Both H_1 and H_2 generally assume that irrigators do not plan ahead within a season and only buy (or sell) water allocations when water is needed (or not needed). This assumption is more likely to hold when it is anticipated to be a normal/wet year, when irrigators perceive a lower level of water scarcity risk and adopt a wait and see strategy in water trading. However, these assumptions are not likely to hold in the presence of market expectations. In addition, in the situation of H_1, an increase in water allocations results in a physical increase in available water supply, which in turn may reduce water prices. But, in the situation of a no change in water allocation prices, where physical water supply does not change to irrigators, changes in water market prices will be driven significantly by market expectations. Therefore, the same impact of insider trading under this circumstance may be more difficult to detect.

It is also important to note that the occurrence of a price drop (increase) in the days before an announcement increases (or does not change) water allocations does not provide conclusive evidence of the occurrence of insider trading on water markets. If market participants can accurately predict the announcement outcome, an abnormal price movement may still be observed earlier than the announcement date. Although some literature considers the occurrence of unusual price movements (abnormal returns) as evidence of insider trading practices (e.g. Keown and Pinkerton 1981; Meulbroek 1992); other literature also suggests that such price movements can also be related to early and informed market reactions to other public information sources (Gupta and Misra 1988).

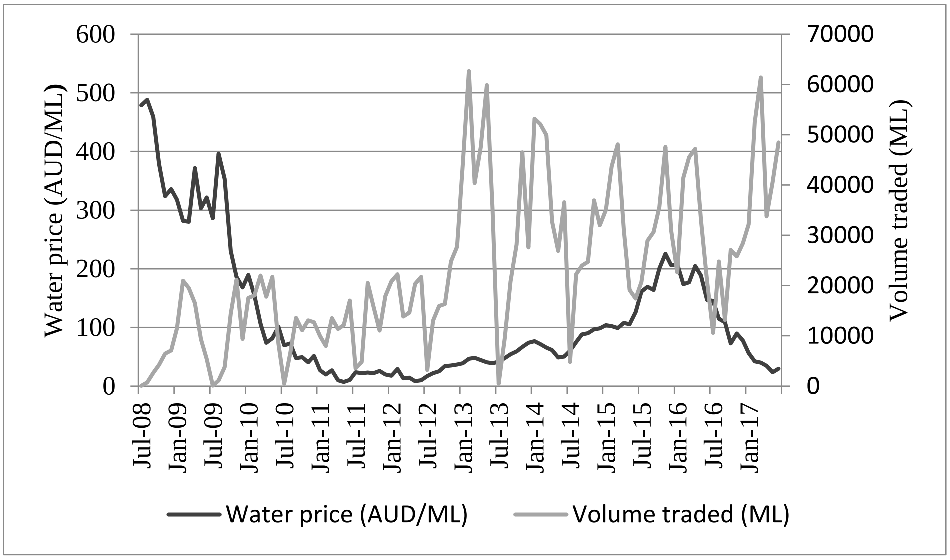
4. Method

4.1. Data and area

This study analyses nine years of available daily water trade representing 28,983 transactions on the water allocation market for the trading zone 1A Greater Goulburn, from July 1st, 2008 to June 30th, 2017, collected from BoM. The Greater Goulburn trading zone is located in Northern Victoria, along the Goulburn and Loddon rivers and within the Goulburn-Murray Irrigation District (GMID). Although allocation trading was initially low in the area (Tural *et al.* 2005), the GMID became the most active trading zone in the southern MDB (Wheeler *et al.* 2008). Greater Goulburn is of particular importance in the southern MDB, with evidence of price leadership across trading zones (Brooks and Harris 2014). Information was also collected on all other drivers of water allocation market prices, such as commodity input and output prices; water storage levels, rainfall, temperature, allocation announcements and percentages and other macroeconomic variables. These variables are included in the model in order to limit detection of price movements related to changes in price determinants such as rainfall that could bias our results. All data sources and descriptive statistics can be found in Appendix I, Table I.1.

The price of a water allocation is particularly sensitive to rainfall and drought circumstances. Historical water prices and total volume traded are presented in Figure 1.

Figure 1: Mean monthly water allocation prices (AUD$/ML) and total water allocation volumes traded (ML) in the Goulburn trading zone, 2008-2017



Source: BoM[7].

The early years of our sample include the end of the Millennium Drought. As a result, 2008 and 2009 show substantially high prices. By contrast, price is considerably lower for 2011 and 2012, due to higher rainfall amounts. Volumes traded on the market also tend to increase

[7] Note: Prices are adjusted and expressed in constant 2008 AUD$. We use the terminology 2008-09 for the water year starting on July 1st, 2008, and ending on June 30th, 2009.

after the end of the Millennium Drought. There is a clear seasonal pattern, as volumes traded are lower in July, as irrigators face a higher uncertainty at the start of the water year. This trend is also found if we consider the time-period of our dataset as a whole, the mean monthly water price increases from July (AUD$127.7/ML) to September (AUD$141.6/ML), then decreases until the end of a water year in June (AUD$95.5/ML). This pattern supports the statement that farmers tend to hold more water than necessary at the start of the water year (Bjornlund 2003; Brennan 2006; Brooks and Harris 2008) until the uncertainty related to water availability decreases. Therefore, a premium is paid by those buying water early in the water year. This is perceived as an insurance-related premium by farmers (Loch *et al.* 2012).

Note that many trades in our database are registered with a price equal to zero. These "zero-priced" trades represented 37% of the total GMID transactions. There are two kinds of explanations for this phenomenon. First, the most common reason for zero-priced trades are those trades where water is transferred between accounts without a valid contract to govern the transfer. This can occur when individuals transfer water between accounts they own, family members transferring between each other, intra-company transfers, or the Commonwealth Environmental Water Holder (CEWH) transferring water between accounts (CEWH trades make up the majority of zero-priced trades). Second, zero-priced trades can be trades where price has not been reported. Although the trading rules introduced in 2014 formally require water traders to report prices, there is a lack of enforcement in this matter (albeit the MDBA is currently focusing more attention on water price reporting compliance (MDBA 2018)). Motives for not reporting the price include the fact that it is not compulsory and hence just not provided, but it may also include hiding prices from competitors, and the desire to remain anonymous. Trades with zero prices were excluded from the database.[8]

[8] Note that mean comparison tests were applied to the number of zero priced trades in the days before an announcement was made, and it was found that they do not appear with a higher frequency in the five days before

4.2. Regression

Insider trading detection methodologies have been largely studied in the case of stocks markets (e.g. Meulbroek 1992; Jackson 2007; Park and Lee 2010; or Olmo *et al.* 2011). However, there are major differences between stocks markets and water allocation markets that need to be considered. First, the dates of water allocation announcements are usually known by market participants. Before the announcement, the unknown part is the allocation outcome (either remain unchanged or increase). Therefore, we cannot use detection methods based on unexpected events, as in Monteiro *et al.* (2007) or Park and Lee (2010). Second, trades from insiders are not recorded by any water market authority. Thus, we cannot use insiders' activity on the market as an indicator of interest, as in Beneish and Vargus (2002).

We chose to analyse water allocation price movements in the days preceding water allocation announcements, to investigate the existence of potentially abnormal price movements. Different observation windows have been used in the literature (e.g. Monteiro *et al.* 2007), hence we chose to study both the five and three day time-period before official announcements, similar to other literature (e.g. Park and Lee (2010) used a five day observation window).[9] Kwiatkowski-Phillips-Schmidt-Shin (1992) stationarity tests (see Appendix I, Table I.2) suggested that our dependent variable and many of our independent variables were not stationary and their first difference series become stationary. Further co-integration tests suggested there was no co-integration relationship between the dependent variable and any of the non-stationary independent variables. Therefore, the first difference series were used for

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an announcement is made, hence we do not believe there is any evidence to suggest those who are inside trading are more likely to try and hide their prices on water registers.

[9] As many water market announcements take place on Mondays and trades are less frequent during week-ends, we also used a three day window.

these variables in the regression models. We defined the first differences of the daily mean water allocation price WP_t as:

$$d.WP_t = WP_t - WP_{t-1} \quad (1)$$

An analysis of the autocorrelation function and partial autocorrelation function for the first difference of daily mean water allocation price (see Figures I.1 and I.2 in Appendix I) suggests the use of a moving average (MA) specification for lag 1. Using maximum likelihood estimation, we obtain parameters from the following model:[10]

$$d.WP_t = \alpha_0 + \alpha_1 d.Q_t + \alpha_2 d.Rfall_t + \alpha_3 d.DamStorage_t + \alpha_4 IrrigPrices_t + \alpha_5 Drought_t + \alpha_6 IncreaseAnn_t + \alpha_7 UnchangedAnn_t + \alpha_8 MI_t + \alpha_9 SMI_t + \mu_t \quad (2)$$

with $\mu_t = \theta\varepsilon_{t-1} + \varepsilon_t$

The daily mean water allocation price WP_t was regressed on our variables of interest and on a range of control variables. This includes first differences (FD) of i) the daily total amount of water traded (Q_t), ii) total storage in major dams in the northern Victoria area ($DamStorage_t$)[11], iii) rainfall ($Rfall_t$), and iv) an index of commodity output prices received by irrigators[12]. Additional control variables were kept in levels: a dummy denoting drought circumstances ($Drought_t$) and seasonal indicators (month index MI_t and squared month index SMI_t). Our independent variables were also first differenced, with the exception of time indexes and dummies that were kept in levels. Summary statistics and variable description are provided

[10] Alternative specifications were used as robustness tests, including a MA(1)-GARCH(1) specification to account for conditional heteroscedasticity. Overall, results were consistent regarding the variables of interest.
[11] Current water allocation percentages for high security GMID entitlements were also tested, but due to high collinearity with dam storage, were not used in the final model.
[12] A variety of input and output prices were included, with the index of commodity output prices included in the final model.

in Appendix I, Table I.1–which also provides details of other variables that were collected and tested (but were not used either due to collinearity or were always insignificant).

Our key variables of interest are the two dummies related to time-periods before water allocation level announcements. $IncreaseAnn_t$ is a dummy equal to one for each of the five days preceding an announcement that increases water allocations. $UnchangedAnn_t$ is a dummy equal to one for each of the five days preceding an announcement that leaves water allocations unchanged.[13] Any statistical significance of $IncreaseAnn_t$ (where allocation levels are increased) and/or $UnchangedAnn_t$ (where allocation levels are unchanged) parameters will imply that significant water allocation price movements were detected in the three to five days preceding the announcement. As new water trading rules were established on July 1st, 2014, we ran three separate regressions: i) overall (whole time-period 2008-2017); ii) before the new trading rules (before July 1st, 2014); and iii) after the rules were introduced (July 1st, 2014 to June 30th 2017).

4.2. Robustness and sensitivity

All models were conducted with robust standard errors. In addition, different robustness and sensitivity tests were conducted on our results. The residuals were checked to ensure that serial correlation was not present (for an example, see Figure I.3 in Appendix I for autocorrelations of the residual in the main regression). No serious multicollinearity was present (e.g. no VIFs above five or correlation factors above 0.7). We added macroeconomic control variables to check whether interactions between water markets and global market conditions could bias our results. Similar sensitivity tests have been used for ongoing federal buybacks

[13] Note that once water allocations reach 100%, the $UnchangedAnn_t$ dummy takes the value 0 for the season remainder, as it becomes certain that allocations will remain unchanged.

(periods when federal authorities were buying permanent water entitlements on the market to return to non-consumptive use – see Grafton and Wheeler (2018) for further explanation), the percentage of water allocations, major output prices (cheese, milk, feed barley) in the area, and fixed monthly and yearly effects. Results remained robust to different specifications and testing.

5. Results

Table 1 presents the results of the moving average time-series regressions.

Table 1: Results of moving average time-series regression for change in daily water allocation prices in the Greater Goulburn from 2008-2017

	Water price (first difference)					
	Model One		*Model Two*		*Model Three*	
Independent variables	*All years (2008-2017)*		*Before July 1st, 2014*		*After July 1st, 2014*	
	5 days	*3 days*	*5 days*	*3 days*	*5 days*	*3 days*
Quantity traded (FD)	-0.0005	-0.0004	-0.002***	-0.002***	0.0008	0.0009
	(-0.83)	(-0.77)	(-2.75)	(-2.72)	(0.91)	(0.92)
Storage in Northern Victorian Dams (FD)	-0.03***	-0.03***	-0.003	0.003	-0.06**	-0.06**
	(-2.76)	(-2.64)	(-0.11)	-0.15	(-2.52)	(-2.55)
Rainfall in the last 30 days (FD)	-0.03	-0.04	-0.02	-0.04	-0.07	-0.08
	(-0.60)	(-0.66)	(-0.35)	(-0.58)	(-0.71)	(-0.78)
Drought (dummy)	0.12	0.09	0.18	0.06	0.19	0.22
	(0.29)	(0.22)	(0.21)	(0.07)	(0.85)	(0.98)
Index of Irrigator Commodity Prices (FD)	1.10	1.01	-0.27	-0.04	3.02**	2.46**
	(1.02)	(0.84)	(-0.17)	(-0.02)	(2.54)	(2.09)
Month index	-0.68***	-0.68***	-0.43	-0.47	-0.71***	-0.63***
	(-3.12)	(-3.06)	(-0.96)	(-1.03)	(-3.47)	(-2.82)
Month index (squared)	0.04***	0.04***	0.03	0.03	0.04***	0.04***
	(3.03)	(2.97)	(1.06)	(1.11)	(3.28)	(2.84)
Year index	0.05	0.05	0.09	0.09	-0.07	-0.12
	(0.73)	(0.79)	(0.68)	(0.75)	(-0.80)	(-1.26)
$IncreaseAnn_t$: Allocations increase in next 5 days	-2.32***		-3.09**		-1.42	
	(-2.71)		(-2.24)		(-1.14)	
$UnchangedAnn_t$: An announcement will be made in next 5 days, but allocations remain unchanged	-1.23		-3.18		1.46	
	(-0.39)		(-0.44)		(0.99)	
$IncreaseAnn_t$: Allocations will increase in next 3 days		-4.22***		-6.91***		0.09
		(-2.71)		(-3.12)		(0.04)
$UnchangedAnn_t$: An announcement will be made in next 3 days, but allocations remain unchanged		-0.74		-4.77		3.70*
		(-0.17)		(-0.44)		(1.72)
Constant	1.90**	1.88**	0.88	1.15	2.86***	2.72***
	(2.17)	(2.08)	(0.46)	(0.58)	(4.44)	(4.15)
MA term	-0.90***	-0.90***	-0.91***	-0.91***	-0.89***	-0.90***
	(-43.16)	(-44.88)	(-35.15)	(-38.58)	(-32.11)	(-32.43)
Sigma constant	47.76***	47.75***	57.13***	57.05***	26.12***	26.12***
	(9.09)	(9.07)	(8.08)	(8.02)	(11.18)	(11.08)
N	2,059	2,059	1,264	1,264	795	795
BIC	21864.9	21864.3	13908.5	13905.0	7532.2	7532.5

Notes: t statistics in parentheses; * p<0.1, ** p<0.05, *** p<0.01.

5.1. *Insider trading evidence*

Overall this study has sought to test whether there was evidence for insider trading because of: H_1) a decrease in water allocation prices in the three or five day period before an increase in water allocation levels was announced, ceteris paribus; and/or H_2) an increase in water allocation prices in the three or five day time-period before an unchanged allocation announcement was made, ceteris paribus. We were also interested in understanding if these effects were different in the two time-periods, namely before July 1st, 2014 and after when insider trading was officially regulated, with the expectation that if insider trading was significant enough to be detected, it may be more likely to be detected before rules enforcing knowledge and transfer came into place. In our total time-period model (2008-2017) and the time-period before regulation on July 1st, 2014, the results suggested a significant decrease in water prices[14] in the five days (and three-day time-period dummy) before an increase in water allocation level announcement was made. After the new trading rules are introduced, no price drop is detected by $IncreaseAnn_t$ whatever observation time-period window was used. There was therefore some support for Hypothesis 1 for the whole time-period, and particularly before July 1st, 2014, the introduction of the new trading rules.

In terms of evidence for Hypothesis 2, Table 1's results depict a significant price increase three days before an announcement on unchanged water allocations, but only very weak evidence in the time-period after June 2014. No significant price movement was detected for the five days observation window. However, note that the dummy $UnchangedAnn_t$ is harder to interpret than the dummy $IncreaseAnn_t$. The reason is that an increase in water allocations increases available water supply and hence induces a decrease in water prices, while

[14] Note that the dependent variable in the models is water price change, which implies that changes in water price are more negative in the five days (or three days) before an increase in water allocation level announcement is made. As a result, this is equal to a price fall.

an announcement that leaves water allocation unchanged is dependent on market agents' expectations. If irrigators' expected water allocations to increase before the announcement, then water prices may increase. Otherwise, it may remain unchanged. Thus, we find reasonable evidence to support Hypothesis 1 before the new trading rules are introduced, and some evidence to support Hypothesis 2 after the trading rules were enforced. It was expected that stronger insider trading evidence would be found primarily in the period before July 2014, with such price movements decreasing or disappearing after 2014, as insider trading practices become officially illegal. Our H2 results are therefore not totally confirming to *a prior* insider trading expectation.

We suggest that the reason that our findings regarding abnormal price movements are not completely confirming to insider trading expectations is that we believe that there has been a general increase in informed water market trading and rational speculation by water owners over this time-period. In July 2014, the new trading rules that entered into application in the Australian water market explicitly forbid the use of privileged information related to allocation announcements to trade on water markets in the MDB. However, we detected very weak statistical evidence of abnormal price movements after 2014 in situations where allocations remain unchanged (and were nowhere near fully allocated which represents a situation where there is more economic incentive to 'guess' the markets). It is therefore highly probable that these detected price movements are caused by rational and accurate speculation, as knowledge about water markets and information has increased considerably. Appendix II provides additional investigation.

5.2. Other price drivers

As all our variables are first differenced, there was a low level of significance of our price determinants. It appears that daily water allocation trade amount has a negative impact on water price before July 1st, 2014. This is consistent with the argument that larger trades imply a lower mean price for water because of water's declining marginal value (Colby *et al.* 1993), as a higher daily water allocation trade amount also implies a higher trade count. The total storage in major dams located within the area, such as Lake Eildon, has a significant negative impact on water prices, as they denote a higher water supply, i.e. a higher water allocation level. When more water is made available, water supply increases and prices tend to drop. The ABARES index of commodity prices received by irrigators has a significant, positive impact on water prices after 2014. As expected, higher commodity prices tend to increase irrigation water demand. This effect was not found before 2014. This result may reflect changing irrigation investment, especially the increase in permanent plantings (especially almonds) in the southern MDB in the last few years, which has been driven considerably by higher commodity prices.

Water market allocation prices progressively decrease and stabilise at the end of the water year. This is shown by the respective negative and positive impacts of our month index and squared month index. The alternative use of fixed monthly effects did not alter this result. This seasonal pattern has been previously found, because at the beginning of the water year, there is a high degree of uncertainty regarding the level of water allocations in the following months; higher prices at the beginning of the water year are perceived by farmers as an insurance premium (Wheeler *et al.* 2008; Loch *et al.* 2012).

5.3. Summary

Thus, our analysis of water allocation prices suggests that scarcity and seasonal factors are the most important influences of water market price movements. In recent years, movements in irrigation commodity prices have become more important, and this supports the general finding that water market traders are becoming more sophisticated and speculative. Our results suggest that insider trading may have been present before the introduction of insider rules in 2014, but only very weak evidence that it may have been present afterwards. Because most announcements can be predicted using public information, it is entirely possible that successful speculation is present in the water market. However, given that not all announcements can be predicted, we cannot rule out the possibility of insider trading still existing to some extent within Australian water markets, although it is clearly less than in earlier periods of time.

6. Conclusion

This study provides the first systematic, comprehensive analysis of the occurrence of insider trading in water markets. Australia provides a valuable case study to investigate the occurrence of insider trading as it has the most developed water markets in the world and high-quality water trade market information. There is also a natural experiment within the data that allowed the presence of insider trading to be explored in different time-periods, with water market rules introduced in 2014 that officially regulated insider trading. We analysed daily water allocation price and volume market data (2008-2017) and sought to detect abnormal price movements preceding water allocation announcements in the largest and most active trading zone in the MDB, namely the Greater Goulburn. Controlling for known water market influences, evidence was found of abnormal price movements (in the hypothesised direction) preceding water allocation announcements, especially before 2014. There is also some evidence that the new water trading rules introduced in 2014 may have decreased (or eliminated) the incidence of such abnormal price movements, although there is still some very weak evidence of abnormal price movements post 2014. However, it is entirely possible that detected abnormal price movements post 2014 are related to an increase in informed and rationally speculative trading behaviour in general in water markets, rather than insider trading per se.

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8. Appendix I: Summary statistics and times series tests

Table I.1: Summary statistics and data sources

Variable	*Description*	*Mean*	*Std. Dev.*	*Min*	*Max*
Water allocation price	Mean daily weighted water allocation price on the market (AUD$/ML), CPI adjusted to 2008 prices. The mean is weighted to reflect differences in the quantity of water exchanged by each trade.	114	112.2	0.8	1233.2
Allocation trade amount (ML)	Daily water allocation trade amount (ML/day)	1211.2	1251.9	1	20180
Trade count	Daily trade count (number of trades/day)	14.1	12.6	1	88
Total Storage in Northern Victorian Dams	Daily sum of water storage (Lake Buffalo, Nillahcootie, Eppalock, Eildon; Goulburn Weir; Laanecoorie, Cairn Curran, Tullaroop Reservoirs) (GL)	2359.5	1052.7	365.6	3848.0
Cheese price	Mean monthly output price of Cheese on the market (AUD$/kg)	4.3	0.5	3.6	6.5
Feed barley price	Mean monthly output price of Feed barley (AUD$/t)	217.3	35.7	143.7	360.8
Index of irrigator prices	Annual index of commodity prices received by Australian irrigators (ABARES† 2017)	144.6	12.8	124.3	163.9
Drought	Drought months=1, i.e. periods defined by BoM‡ as months of serious rainfall deficiency or when rainfall has been under average for three consecutive months.	0.3	0.5	0	1
Cumulative 30 days rainfall	Sum of the 30 previous days of daily precipitations at Kerang station (mm)	31.8	28	0	210.6
Water share allocation level (%)	Level of water allocations fortnightly, expressed as a percentage of the volume specified by the water entitlement.	80.2	29.3	0	100
Dummy 1 – IncreaseAnn_t§	Dummy equal to one when an announcement will increase water allocations in the next five days§.	0.1	0.3	0	1
Dummy 2 – UnchangedAnn_t§	Dummy equal to one when an announcement will be made regarding water allocations that will let them unchanged in the next five days¶ (excluding cases when the allocation level is 100% before the announcement).	0.1	0.3	0	1
Month index	Monthly index, July=1	7	3.3	1	12
Year index	Yearly index, 2008=1	5.8	2.6	1	10

Sources: Bureau of Meteorology (BoM) (Water market transactions, dam storage, drought and rainfall); ABARES (Commodity price data); Northern Victoria Resource Manager (Allocation announcements)

† ABARES : Australian Bureau of Agricultural and Resource and Economics and Sciences

‡ BoM : Australian Bureau of Meteorology

§ Reference group: days for which no announcement increasing water allocations or no announcement of unchanged water allocation will be made in the next five days

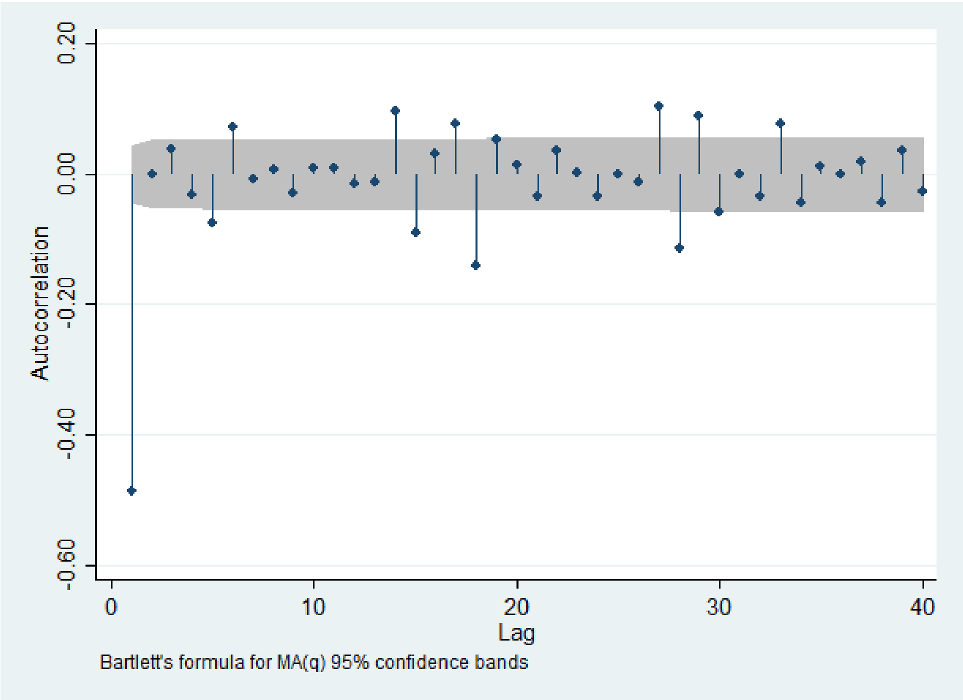
¶ Alternative time windows have been tested, including three days

Table I.2: Results from stationarity (KPSS†) tests

H_0: Variable is trend stationary		
Variable	***KPSS test statistic (lag_10)***	***Critical value (p=.05)***
Daily mean water price (AUD$/ML)	2.96	0.15
Daily total amount traded (ML)	0.65	0.15
Rainfall (mm)	0.34	0.15
Feed barley price (A$/t)	2.03	0.15
Lagged Cheese price (A$/kg)	1.51	0.15
Allocation level (%)	2.88	0.15

Note: H_0 can be rejected at the 0.1 significance level for each of the variables, suggesting they are not trend stationary.

Figure I.1: Autocorrelation (ACF) of the first differenced mean daily water allocation price (dependent variable)



† KPSS: Kwiatkowski-Philipps-Schmidt-Shin

Figure I.2: Partial Autocorrelation Functions (PACF) of the first differenced mean daily water allocation price (dependent variable)

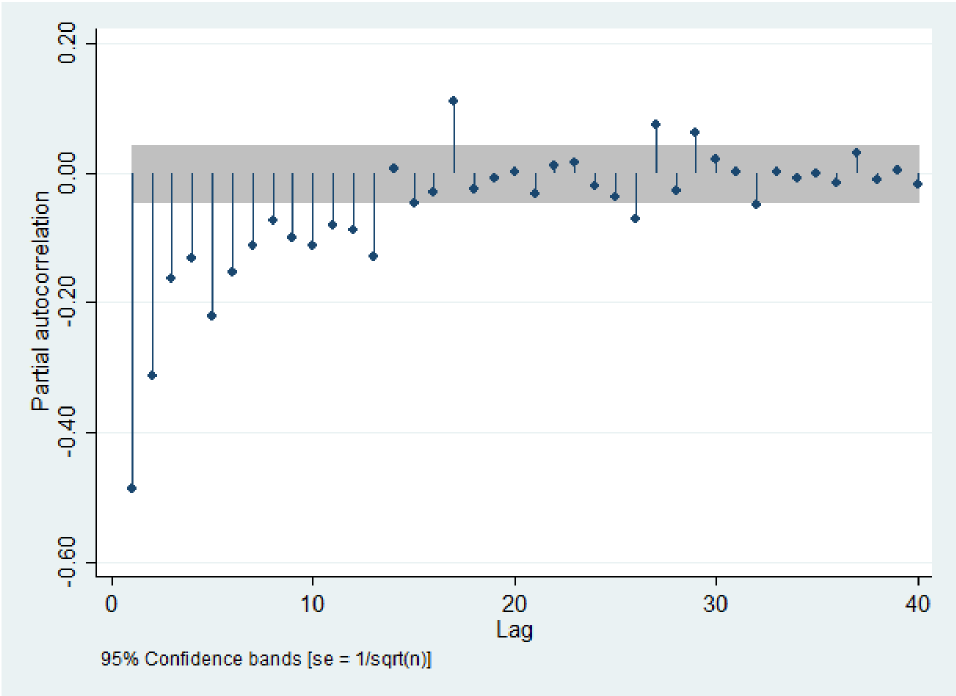
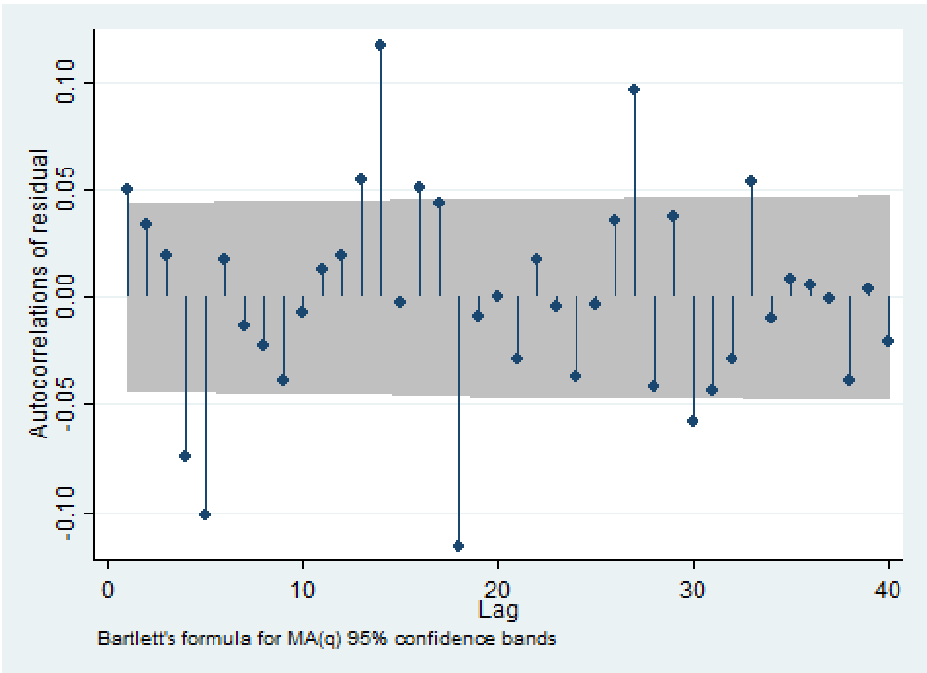


Figure I.3: Residual autocorrelations (regression for all years for the five-day observation window)



9. Appendix II: Insider trading or rational speculation? Additional investigation

To test whether the weak evidence of a price increase in the three days before an unchanged water allocation announcement could be related to either insider trading or rational speculations after 2014, an additional database was gathered with 158[15] water allocation announcements between 2001 and June 2017 in the Goulburn, along with additional information commonly available to irrigators, such as storage in major dams in the area and rainfall data. Using this information, a probit model was estimated with a dependent variable equal to one if an announcement increases water allocations and equal to zero otherwise. This model was run using different time-periods (2001-2007; 2007-2014; 2001-2014). The parameters of these models were then used to predict the content of announcements for future time-periods. In order to avoid bias, the time-period (e.g. 2014-2017) for which the content of announcement was predicted was not used to estimate the corresponding probit model. We sought to answer two questions: i) whether the models could predict the announcements before July 2014 that increased allocations, using publicly available information; and ii) whether the models could predict the announcements after July 2014 that left water allocations unchanged, using publicly available information. Tables II.1 and II.2 provides the prediction results.

Depending on the time-period used for the probit model, we correctly predict 85-89% of the announcements between 2014 and 2017 while between 2007 and 2014, correct prediction is 57.5%. The result of more accurate predictions increasing with time is also related to the fact that after the drought, allocation announcements more frequently increased water allocation levels. Before July 2014, we correctly predicted 41/58 announcements that increased allocations. There were only four announcements after 2014 where the water allocation level

[15] Announcements made after allocations reached 100% were not modelled, as their outcomes were certain.

remained unchanged. Correct predictions for such announcements are 3/4 using the earliest trading model (A) while it was much poorer for the other models (0/4 using models B and C).

Table II.1: Prediction modelling: Probit estimation for various calibration time-periods†

	Model A: *July 2001-June 2007*	Model B: *July 2007-June 2014*	Model C: *July 2001-June 2014*
Previous allocation level	-0.022**	0.043**	-0.007
	(-2.10)	(3.1)	(-1.30)
Cumulative 30 days rainfall	-0.004	0.007	0.003
	(-0.45)	(0.5)	(0.49)
Storage in Lake Eildon (GL)	0.001***	0.002	0.001***
	(2.7)	(1.47)	(3.4)
Constant	-0.252	-2.084*	-0.468*
	(-0.62)	(-1.95)	(-1.74)
N	58	73	131
Pseudo R^2	0.106	0.403	0.144
BIC	85.86	61.43	168.5

Notes: t statistics in parentheses; * p<0.1, ** p<0.05, *** p<0.01. For each announcement in the database, the dependent variable equals one if the announcement increases water allocations. It equals zero if water allocations are unchanged.

Table II.2: Predictions of water allocation announcements in the GMID

Time-period: model	*Time-period: calibration*	*Number (Percentage) of announcements correctly predicted*	*Number of unchanged announcements correctly predicted*	*Number of announcements increasing allocations correctly predicted*
A: 2001–2007	2007–2014	42/73 (57.5%)	1/15	41/58
A: 2001–2007	2014–2017	24/27 (88.9%)	3/4	21/23
A: 2001–2007	2007–2017	66/100 (66%)	4/19	62/81
B: 2007–2014	2014–2017	23/27 (85.2%)	0/4	23/23
C: 2001–2014	2014–2017	23/27 (85.2%)	0/4	23/23

† For each probit model, the time-period for which the content of announcement is predicted (hold-out period) is excluded from the estimation in order to avoid bias. E.g., we only use announcements made from July 1st, 2001 to June 30th, 2014 to predict announcements made between July 1st, 2014 and June 30th, 2017.

Chapter 3[16]:

The Dynamics of Groundwater Markets: Price Leadership and Groundwater Demand Elasticity in the Murrumbidgee, Australia

Abstract

Groundwater over-extraction is a problem facing many countries around the world. Water pricing and developing property rights to enable groundwater trade are a potential demand-based method to address the over-extraction of groundwater resources. However, successful implementation of groundwater trading requires knowledge about the dynamics of groundwater demand and their interaction/substitutability with surface water markets; and, given the paucity of empirical data available, price elasticities of groundwater trade are rare in the literature. We analyse 10 years of surface and groundwater market data (2008-2018) in temporary markets within the Murrumbidgee catchment of the Murray-Darling Basin, Australia, to explore a) the lead-lag relationship between surface and groundwater markets; and b) the price elasticity of groundwater demand to changes in prices. Results illustrate that surface water markets show price leadership to groundwater markets, and that groundwater market demand is elastic, with a -1.04 price elasticity estimate in our time-period.

Keywords: Murray-Darling Basin; Price Leadership; Groundwater demand elasticity; Groundwater markets.

[16] This chapter refers to the article cowritten with Sarah Ann Wheeler and Alec Zuo.

1. Introduction

Water use has been increasing worldwide by about 1% per year, and global water demand is expected to increase at a similar rate until 2050 (WWAP, 2019). As a result, over-extraction of groundwater resources is a growing problem and a consequence of a common-pool resource dilemma (Ostrom, 1990). Groundwater overuse represents significant costs to society: it can increase withdrawal costs, as water has to be pumped from a greater depth; it generates cones of depression (Wheeler et al., 2016); and can lead to groundwater depletion and significant infrastructure costs (Asci et al., 2017). Given agriculture uses 69% of available freshwater resources in the world (WWAP, 2019), the increased use of irrigation water pricing and property rights have been suggested as a potential means to cope with water scarcity (Blanco-Gutiérrez et al., 2011). The literature has shown that increased water prices (usually through irrigation water charges) can favour the adoption of water conservation technologies (Caswell and Zilberman, 1985; Caswell et al., 1990) and decrease irrigation groundwater use (Smith et al., 2017).

Groundwater markets often emerge as formal or informal tools to put a price on water and reallocate scarce groundwater resources. Examples of formal groundwater markets are found in Australia (Wheeler et al., 2016), the western United States (Colby, 2000) and China (Zhang et al., 2008); while informal markets exist in India (Manjunatha et al., 2011) and Pakistan (Khair et al., 2012). Although groundwater markets remain limited in their extent, they have been shown to generate significant benefits in various contexts. Groundwater markets can involve significant gains from trading (Knapp et al., 2003; Gao et al., 2013; Palazzo and Brozovic, 2014), with participants more efficient in their use of water (i.e. generating more outputs with the same amount of water (Manjunatha et al., 2011; Razzaq et al., 2019)). In some situations, groundwater markets have allowed resource-poor farmers access to irrigation water (Mukherji, 2007).

Little empirical research on the demand elasticities and market dynamics of groundwater markets has been conducted worldwide, largely because operating examples of groundwater markets with sufficient data are rare. This is usually because the range of necessary conditions for water markets to be successful have not been established (conditions include: (i) well defined property rights; (ii) effective and adaptive governance and legislation regarding enabling resources (including a 'cap' on water rights issued); (iii) sufficient knowledge about hydrology and resource constraint, (iv) proper accounting and monitoring of water use; (v) a sufficiently diverse potential market for water, notably in terms of diversity of value-added uses; and (vi) the existence of institutional arrangements to address externalities (Wheeler et al., 2017)). Allowing trade in the absence of adequate administrative arrangements can endanger water security (Maestu and Gomez-Ramos, 2013; Young, 2014; Wheeler et al., 2017). Where water use rights cannot be enforced, the risk of overuse is heightened (Diwakara and Nagaraj, 2003; Zhang, 2007), as is the importance of understanding the connectivity and substitutability between surface and groundwater resources.

Australia provides a rare example of a mature dataset on groundwater markets because of its long-functioning history and development of markets over the past thirty years (Wheeler et al., 2017). In many instances, groundwater markets in Australia coexist with surface water markets. In cases where both type of water resources are available, the substitutability and connectivity between surface and groundwater is a major water policy issue. For example, understanding the actual impact of water use efficiency subsidies requires knowledge about the volume represented by return flows (irrigation surface water flowing to aquifers following its use) (Williams and Grafton, 2019). Furthermore, groundwater pumping in areas close to rivers can decrease available surface water in nearby streams; this situation led to inter-state conflict in the US (Kuwayama and Brozovic, 2013). There is also a well-known substitution phenomenon between surface and groundwater (Haensch et al., 2016). These interactions affect water markets when they coexist in the same area: as noted by Wheeler et al. (2016), farmers sold their water to the government and compensated by increasing groundwater pumping during the 1980 drought in California. Similar evidence has been found in Australia (Wheeler and Cheeseman, 2013) and China (Zhang, 2007). Therefore, improving the knowledge about the interconnections between surface and groundwater resource management is important (Ross, 2018; Williamson and Grafton, 2019).

Moreover, the appropriateness of property rights and pricing policies in general is conditioned by a sufficiently high elasticity of irrigation water demand. In cases where water demand is inelastic, a water pricing policy targeting a reduction in irrigation withdrawals would need to considerably increase the water price in order to reduce irrigation water consumption, thereby strongly affecting farm income (de Fraiture and Perry, 2007). With a perfectly inelastic groundwater demand, the lack of a rationing mechanism based on the productivity of water use can generate inefficiency (Wang and Seguarra, 2011).

Given this context, the interest of this research is twofold. First, this study adds to the literature by providing a rare estimate of groundwater temporary market demand price elasticities, using over a decade of exogenous water price variations from a key groundwater use area, the Murrumbidgee in Australia. Second, we examine the dynamics of groundwater temporary markets, by analysing drivers of prices and trade, along with the connectivity and substitutability between surface and groundwater markets. Our results provide insights that can be used to inform pricing and water market policies in the countries choosing to implement such tools.

2. Literature review: Groundwater markets, price leadership and groundwater demand elasticity

Studies on the price elasticity of irrigation surface water use (or irrigation water use in general) often use mathematical programming methodologies. Estimates vary between 0 and 2.81 in absolute value, depending on study characteristics (Shumway, 1973; Frank and Beatie, 1979; Howitt et al., 1980; Pagan et al., 1997; Hooker and Alexander, 1998; Scheierling et al., 2004). Other studies use econometrics and water market transactions to estimate surface water demand elasticity, assuming or holding other factors constant. Brooks and Harris (2008) examined gains from temporary surface water trade in Victoria, Australia. Using bid and ask offers, they found very high surface water demand elasticity estimates, ranging from 3.51-3.56. Wheeler et al. (2008) used 2SLS regression methodology to model actual prices and quantity traded on the Victorian temporary surface water market from 1997 to 2007 and found a demand elasticity of -0.52 in the short-term and -0.81 in the long-term.

Studies estimating groundwater demand elasticity focus mainly on groundwater irrigation charges only. Nieswiadomy (1985) used changes in pumping costs in Texas to report a -0.80 price elasticity. Ogg and Gollehon (1989) found that groundwater demand in 16 western states was relatively inelastic (-0.22 to -0.34). Moore et al. (1994) also found inelastic groundwater demand (-0.10) in the western United States, and Gonzalez-Alvarez et al. (2006) found a similar result in Georgia with a -0.27 elasticity of groundwater demand. Hendricks and Peterson (2012) used Kansas field-level data and found an overall groundwater demand elasticity of -0.10, most of which was due to changes in the intensive margin (changes in the amount of water applied per acre). Pfeiffer and Lin (2014) employed a 2SLS panel data approach, to study the effect of a public financing program targeting an overall increase in groundwater use efficiency. They noted that, following the program, the expected fall in groundwater use did not occur, partly due to shifting crop patterns. Badiani-Magnusson and Jessoe (2019) used variations in electricity subsidies across India and found that, overall, the groundwater demand price elasticity was -0.18 in the short-term. Mieno and Brozovic (2016) used extensive data on groundwater use and electricity consumption to estimate groundwater elasticity in Nebraska (-0.5). They found strong biases could arise from measurement errors in various components of the total irrigation costs, including marginal price of water, marginal cost of energy, and pumping efficiency.

Many factors can influence the estimation of groundwater demand elasticity. In a meta-analysis of 24 irrigation water price elasticity studies, Scheierling et al. (2006) noted that the price at which elasticity is estimated, method of econometrics, and temperature all tend to increase the absolute value of elasticity estimates. Their analysis involved both studies on surface and groundwater, however they did not find significant differences in estimates based on the type of resource considered. Conversely, the existence of high value crops in the area of study tends to decrease the price elasticity of irrigation water. Indeed, Frija et al. (2011) noted that farmers found to be less water efficient tended to have lower elastic water demand. Irrigation methods therefore impact elasticities in the sense that they affect the amount of water consumed per acre (Pfeiffer and Lin, 2014). Furthermore, measurement errors in irrigation water costs can also impact the elasticity estimate and generate biases (Mieno and Brozovic, 2016). However, the same authors noted that using exogenous water price variations could avoid this problem, although such cases are difficult to find.

Indeed, studies using exogeneous changes in water price to study irrigation groundwater demand elasticity are rare. Alamdarlo et al. (2019) employed mathematical programming to analyse the impact of supply and demand policies in an informal groundwater market framework in the Qazvin plain in Iran, finding groundwater demand elasticities from 0 to -0.17.

Apart from this, we found no study estimating groundwater demand elasticity using actual groundwater market transactions. However, there has been some discussion regarding the influences on groundwater markets. They are influenced by traditional surface-water market drivers including rainfall and temperature, allocations received, dam storages, output prices for commodities grown in the area, and seasonal factors (Wheeler et al., 2008). Evidence of price clustering has also been reported (Brooks et al., 2013). In the case of groundwater markets, salinity can also be of influence (Gill et al., 2017). Furthermore, Brooks and Harris (2014) found evidence of price leadership between two water trading zones in the Goulburn-Murray irrigation district. Price leadership is a lead-lag relationship between two indexes, whereby variations in one index can be explained by past variations of another market index. Such lead-lag relationships have been found in various contexts in financial markets, such as between futures and their underlying stocks (Min and Najand, 1999) or between different markets offering similar market products (Roope and Zurbruegg, 2002). However, no study to date has considered the potential lead-lag relationship between ground- and surface water markets. Nevertheless, as more liquid markets (such as surface water markets in Australia) react quickly to new information, the existence of such a lead-lag relationship in the Murrumbidgee is likely and needs to be examined.

Therefore, this study will first analyse dynamics of groundwater markets in a key groundwater usage area (the Murrumbidgee in Australia) and investigate the existence of a lead-lag relationship between surface and groundwater markets. It will also provide one of the first estimates of groundwater market demand price elasticities using exogenous variations in groundwater price, taking into account the various groundwater market dynamics identified.

3. Case Study

3.1. Overview

Water markets in Australia's Murray-Darling Basin (MDB) emerged in the 1980s and evolved through progressive waves of reform to become the most active water market area in the world (Grafton et al., 2011). Most water trades in the MDB are surface water transactions, especially in the southern connected system. However, groundwater markets have also been established in various part of Australia. The primary Australia-wide groundwater markets, as well as permanent and temporary trades, appear in Table 1:

Table 1: Groundwater trade count per groundwater system in Australia, 2008-2018

Groundwater system	State	Total trade count[17]	Temporary trades	Permanent trades	Prop. (%)
South East SA	SA	2,019	170	1,849	10.6
Murrumbidgee Alluvium	NSW	1,808	1,449	359	9.5
Adelaide & Mt Lofty	SA	1,646	220	1,426	8.7
Namoi Alluvium	NSW	1,531	894	637	8.1
Murray Alluvium	NSW	1,467	1,087	380	7.7
Condamine-Balonne	QLD	1,091	436	655	5.8
Burnett Basin	QLD	955	627	328	5.0
Goulburn-Murray	VIC	808	165	643	4.3
Lachlan Alluvium	NSW	673	446	227	3.5
Gwydir Alluvium	NSW	522	444	78	2.8
Others			1,005	5,447	34.1
TOTAL		18,972	6,943	12,029	100.0

Source: BoM water market data.

[17] Note: Many groundwater trades are recorded with a price value of 0. Excluding these transactions reduces the number of trades by 51.7% (temporary trades) and 75.3% (permanent trades), although this is most likely to occur in SA water registries. Murrumbidgee Alluvium has 33% zero priced trades. Reasons for not reporting prices can include (1) trades without a valid contract (within a single entity, with family or friends…); (2) not reporting prices during a transaction: price reporting is compulsory since 2014, but enforcement is sometimes lacking despite new trading rules in 2014 (MDBA, 2014).

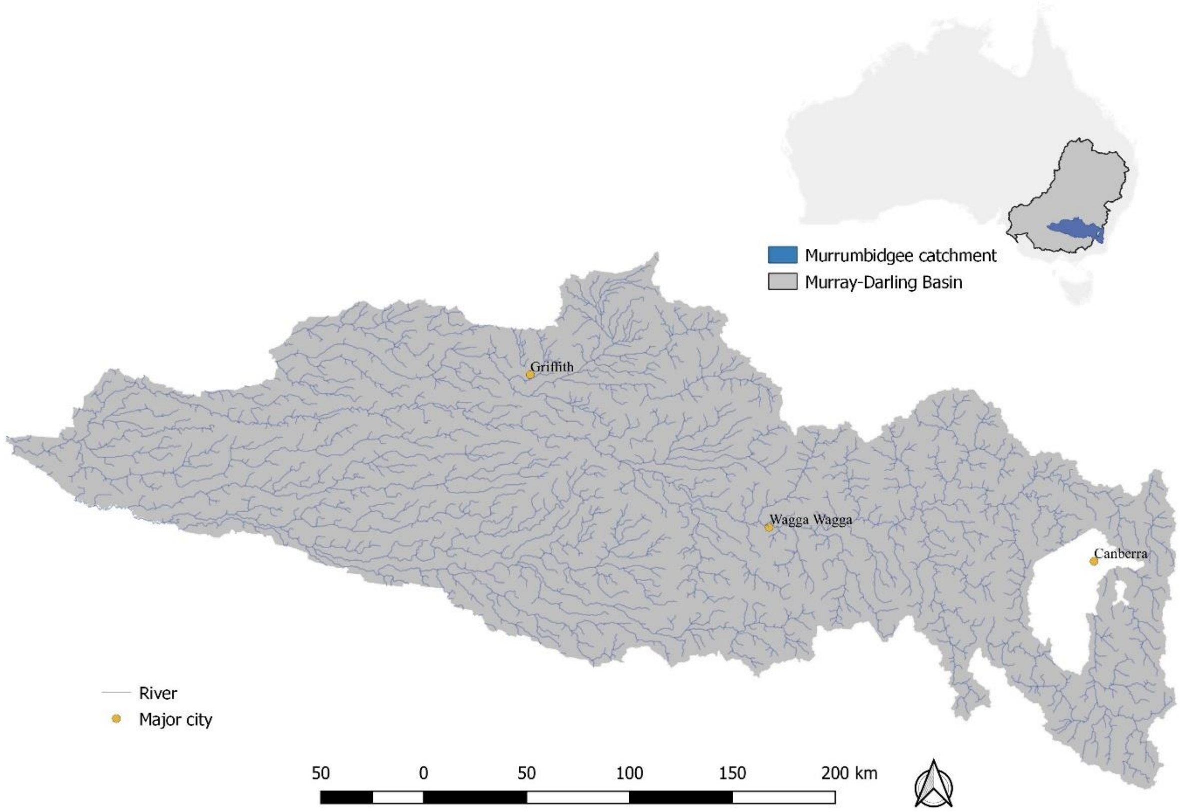
Between 2 July 2008 and 20 April 2018, 6,943 groundwater temporary trades were recorded Australia-wide in the BoM water market database, along with 12,029 permanent trades. While most groundwater trades occurred in New South Wales, Queensland and South Australia also had a significant number of transactions.

We focus on temporary groundwater markets in the Murrumbidgee region for several reasons. First, trading is generally not allowed between different groundwater systems (as in the Murrumbidgee), which argues for the analysis of a single water system. Second, permanent groundwater price transactions were found too rare to allow the creation of consistent time-series data. Third, the Murrumbidgee groundwater market represents 9.5% of all groundwater trades in Australia, but contained a considerably lower proportion of zero priced-trades (26%) than most other regions.

3.2. The Murrumbidgee

Groundwater extraction for irrigation purposes in the Murrumbidgee started in the early 1960s. Before 1982, groundwater access was unrestricted. Since 2006, the authorities stopped issuing new water extraction licences, and licenses became fully tradeable and separated from land titles (Green et al., 2011). The Murrumbidgee catchment (Figure 1) comprises 8% of the MDB and 16% of its water.

Figure 1: The Murrumbidgee region



Source: GIS data collected from the Murray-Darling Basin Authority (MDBA, 2013), the OpenStreetMap layer "Places and Boundaries", and the HydroSHEDS project (Lehner et al., 2008).
Note: Region represented as defined by the Murrumbidgee surface water resource management area.

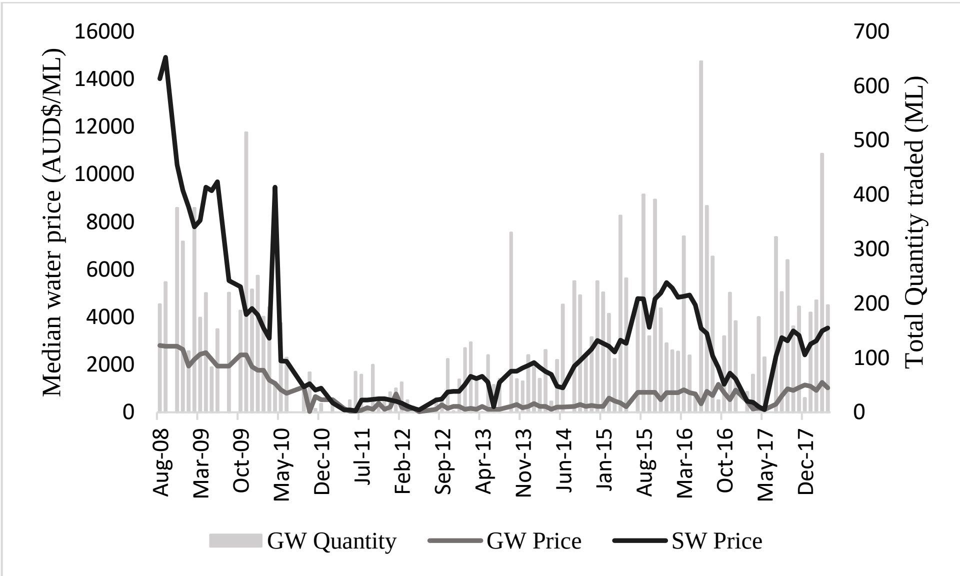
The catchment hosts one of the most active groundwater markets in Australia, coexisting with a significant surface water market. Irrigated agriculture in the Murrumbidgee mainly includes rice and cotton, representing around 65% of the total agricultural water use in 2016-17 (ABS, 2018). Other crops include cereals, pastures, fruits and nuts.

Water use in the Murrumbidgee is based on an annual accounting system. Along regulated water sources such as the Murrumbidgee river or the Murrumbidgee Alluvium, each water user must own a water license. An initial Available Water Determination is made at the beginning of the year[18], determining the amount of water delivered to each of the shares listed on a user's water license (Green et al., 2011). Water determinations may increase throughout the year, depending on climatic circumstances. Different categories of surface and groundwater licenses exist, defining access to surface or groundwater according to varying levels of priorities (i.e. risk) on the use of surface water resources. The most common and popular surface water license in the Murrumbidgee is the general security license, or aquifer access license in the case of groundwater.

Groundwater trading has been occurring since 1987, mainly in the Lower Murrumbidgee Deep Water Source. While early trades involved temporary transfers (called allocation transfers), permanent groundwater transfers (called groundwater license entitlement transfers) have been permitted since 2006. Groundwater markets are considerably less active than surface water markets and are limited to a shared groundwater source (trading between different groundwater sources is not permitted). Figure 2 illustrates water market prices and the groundwater volume traded in the Murrumbidgee temporary water markets.

[18] Water years in Australia begin on July 1st and end on June 30th.

Figure 2: Median surface and groundwater prices and total groundwater quantity traded in Murrumbidgee temporary water markets, 2008-2018



Source: BoM water market data
Note: 0-priced trades are excluded, and prices are adjusted to inflation and are expressed in constant 2018 prices.

Groundwater markets in the Murrumbidgee show higher prices and a higher level of market activity in times of scarcity: between 2008 and 2010, the height of the Millennium Drought caused a sharp increase in surface and groundwater prices and an increase in the quantity of water traded. In contrast, flooding in 2010-11 meant prices fell to under AUD$20/ML, while the total quantity of groundwater traded remained low.

Note that the price of surface water (median price of AUD$94.62/ML) is consistently higher than groundwater (AUD$22.93/ML), expressed in constant 2018 prices. This reflects the fact that in many areas, irrigators favour surface water use over groundwater use. Reasons for this preference include the energy costs of groundwater extraction (Mitchell et al., 2012); greater tradability of surface water; and frequent presence of malfunctioning bores with high salinity (Gill et al., 2017; Hooker and Alexander 1998).

4. Data

The study uses 10 years (2008-2018) of surface and groundwater temporary market trade data in the Murrumbidgee, Australia. Market data (price and quantity traded – our dependent variables) for this study was extracted from the Australian Bureau of Meteorology's (BoM) national water market database. Independent variables collected included climate variables (rainfall and mean temperature) using BOM's Hay Airport Automatic Weather Station (AWS), located in the Murrumbidgee. Diesel prices were collected from the Australian Institute for Petroleum. Output prices were collected from the Australian Bureau for Agricultural and Resources Economics and Sciences (ABARES). All prices were adjusted to the consumer price index using values from the Reserve bank of Australia (RBA)[19] and the base year 2018. Descriptive statistics can be found in Appendix A.

5. Methodology

The method follows two stages. First, we model the price of temporary groundwater, to question the existence of a price leadership phenomenon between the surface and groundwater markets. Second, we model the quantity of temporary groundwater traded, in order to investigate the influence of the groundwater price and infer the price elasticity of groundwater demand.

[19] Several other variables were tested but not included in the final analysis, including the Groundwater level and Electricity prices.

5.1. Price leadership method

In order to investigate the existence of a lead-lag relationship in various markets, Vector Auto-Regressive (VAR) frameworks have often been used in the literature (Brooks and Harris, 2014; Chordia and Swaminathan, 2000; Chevallier, 2010). Most VAR frameworks are parsimonious (Chevallier, 2010; Brooks and Harris, 2014) in the sense that they only use a few covariates. However, in the case of water markets, climatic variables have a clear influence on market price and quantities traded (Wheeler et al., 2008; Brooks and Harris, 2008; Loch et al., 2012). Therefore, we used a VAR-X model including four market variables (price and quantity traded for surface and groundwater trade) and two climatic variables: rainfall and mean temperature. VAR-X models include endogenous variables, used as dependent and independent variables successively, and exogenous variables that are only used as independent variables. We defined market variables to be endogenous due to the potential interconnections between surface and groundwater trade, while rainfall and the mean temperature were considered exogenous. Thus, we alternatively used each market variable (price and quantity traded, for surface (SW) and groundwater (GW)) as a dependent variable and regressed it on the past values of other market variables, while controlling for climatic factors.[20]

Augmented Dickey-Fuller and KPSS stationarity tests revealed that most market variables (prices and quantities) were not stationary, but became stationary once logged and first differenced. First differences *(D.)* of climatic variables were found stationary. Therefore, market variables have been logged *(log)* and then first differenced, while climatic variables were simply first differenced.

[20] Monthly rainfall and Mean monthly temperature were used in the final results, although the cumulative three months rainfall has also been teste in the analysis.

VAR-X frameworks can be applied using a various number of past values for each variable. Indicators such as FPE, Akaike's IC, HQIC or the Schwarz-Bayesian IC were used in order to determine the number of lags to include. Each regression was run using an alternative number of lags, and various information criteria were compared. The Australian water year begins in July and ends in June, where the early months in the season usually show lower trade intensities, as irrigators face higher uncertainty. Therefore, the maximum potential number of lags in these tests was set to be nine. Results show that the FPE and AIC indicate the use of nine lags, while the HQIC and SBIC suggest the use of one lag. In order to avoid overfitting, we chose to use one lagged value for each variable in our analysis.

The VARX(1) model using logs and first differences estimates the following:

$$D.logGWPrice_t = \alpha_0 + \alpha_1 L.D.logGWPrice_{t-1} + \alpha_2 L.D.logGWQuantity_{t-1} + \alpha_3 L.D.logSWPrice_{t-1} + \alpha_4 L.D.logSWQuantity_{t-1} + \alpha_5 L.D.MonthlyRainfall_{t-1} + \alpha_6 L.D.MeanTemperature_{t-1} + \varepsilon_t' \quad (1)$$

$$D.logGWQuantity_t = \beta_0 + \beta_1 L.D.logGWPrice_{t-1} + \beta_2 L.D.logGWQuantity_{t-1} + \beta_3 L.D.logSWPrice_{t-1} + \beta_4 L.D.logSWQuantity_{t-1} + \beta_5 L.D.MonthlyRainfall_{t-1} + \beta_6 L.D.MeanTemperature_{t-1} + \varepsilon_t'' \quad (2)$$

$$D.logSWPrice_t = \gamma_0 + \gamma_1 L.D.logGWPrice_{t-1} + \gamma_2 L.D.logGWQuantity_{t-1} + \gamma_3 L.D.logSWPrice_{t-1} + \gamma_4 L.D.logSWQuantity_{t-1} + \gamma_5 L.D.MonthlyRainfall_{t-1} + \gamma_6 L.D.MeanTemperature_{t-1} + \varepsilon_t''' \quad (3)$$

$$D.logSWQuantity = \delta_0 + \delta_1 L.D.logGWPrice_{t-1} + \delta_2 L.D.logGWQuantity_{t-1} + \delta_3 L.D.logSWPrice_{t-1} + \delta_4 L.D.logSWQuantity_{t-1} + \delta_5 L.D.MonthlyRainfall_{t-1} + \delta_6 L.D.MeanTemperature_{t-1} + \varepsilon_t'''' \quad (4)$$

Following the regression, Granger causality tests were used to identify potential causal relationships between our variables. We then applied Impulse-Response Functions (IRF) and forecast-error variance decomposition in order to understand the duration and extent of the interconnections between surface and groundwater temporary markets.

5.2. Price elasticity of groundwater demand method

The groundwater price and the groundwater volume are simultaneously determined; this raises the possibility of endogeneity. Thus, we use an instrumental variables approach. In order to identify the demand equation, a valid instrument must be found for the groundwater price: such a variable should impact water supply (e.g. influence water sellers) without affecting water demand (e.g. water buyers). In a water market context, the difficulty in finding a proper instrument is exacerbated by the fact that water sellers can also be water buyers. Several instruments were tested and variables such as the groundwater level, electricity prices, and various agricultural output prices were found to impact demand and hence were unsuitable. However, rice price was identified as an appropriate instrument for groundwater price. Rice growers tend to own large general security water licenses, grow rice in wet years, and often sell water in drought years when water prices are high. Notably, it has been reported that selling water allocations when water prices were superior to AUD$200/ML was perceived as a better and less risky strategy than growing rice (Loch et al., 2012; Zuo et al., 2015). Therefore, the price of rice can influence water supply on the market, as rice producers are frequent water sellers on the Murrumbidgee water markets, especially in times of water scarcity. Thus, we expect rice price to mainly influence the groundwater supply and to have very limited effect on groundwater demand, making it a valid instrument for groundwater price, and allowing price elasticity of groundwater demand to be properly estimated.

Following Wheeler et al. (2008), a linear log-log specification was used. The instrumental approach used two stage least squares (2SLS) estimation:

$$GWPrice_t = f(X_t, Z_t)$$

Where:

X is a vector of explanatory variables, and Z the instrument (rice price in month t). We then proceed to the estimation, using the predicted value of the groundwater price:

$$GWVol_t = f(X_t, \widehat{GWPrice}_t)$$

Several control variables were included. Given that groundwater markets may be potentially influenced by surface water markets in the Murrumbidgee, price of permanent and temporary surface water rights were included. As many irrigators use diesel pumps to extract groundwater, average annual diesel price[21] was included. Finally, climate variables (rainfall and mean temperature in month), and seasonal dummies were used to consider climatic circumstances and seasonal patterns. Several other control variables were tested[22] but not included in the final model. Descriptive statistics can be found in Appendix A and maximum likelihood estimation was used to estimate the model's parameters. The regression is:

Stage 1:

$$lnGWPrice_t = \alpha_0 + \alpha_1 Rice_t + \alpha_2 lnTempSurfacewaterprice + \alpha_3 lnPermSurfacewateprice + \alpha_4 lnDieselprice_t + \alpha_5 lnMeantemperature_t + \alpha_6 lnMonthlyrainfall_t + \alpha_7 Earlyseason + \alpha_8 Midseason + e_t \quad (5)$$

[21] Due to data availability constraints, we used diesel price in Sydney as a proxy for Murrumbidgee data.
[22] Red wine and cotton prices; rainfall in the last three months; electricity price; the mean groundwater level in six bores over the Murrumbidgee alluvium, the general security surface water allocation level, a month index.

Stage 2:

$$lnGWVol_t = \beta_0 + \beta_1 ln\widehat{GWPrice}_t + \beta_2 lnTempSurfacewaterprice + \beta_3 lnPermSurfacewaterprice + \beta_4 \ln Dieselprice_t + \beta_5 lnMeantemperature_t + \beta_6 lnMonthlyrainfall_t + \beta_7 Earlyseason + \beta_8 Midseason + e'_t \quad (6)$$

6. Results and analysis

6.1. Price Leadership

Table 2 illustrates the Granger causality tests and Table 3 the VARX(1) regression results:

Table 2: Results from the Granger causality tests using parameters from the VARX(1) model for key market variables in the Murrumbidgee temporary surface and groundwater markets, 2008-2018

Lags of	Groundwater		Surface water	
	Price	Quantity	Price	Quantity
GW Price		0.058 (0.810)	0.060 (0.806)	0.621 (0.431)
GW Quantity	1.775 (0.183)		0.329 (0.566)	0.664 (0.415)
SW Price	19.949 (0.000)	0.350 (0.554)		0.113 (0.737)
SW Quantity	0.163 (0.686)	7.163 (0.007)	2.522 (0.112)	

Note: chi-2 reported, p values in parenthesis

Table 3: Results from the VARX(1) estimation for a unit percent change in key market variables in the Murrumbidgee temporary surface and groundwater markets, 2008-2018

	Dependent variable			
	GW Price	GW Quantity	SW Price	SW Quantity
	1	2	3	4
GW Price	-0.474***	0.042	-0.020	0.109
	(-5.40)	(0.24)	(-0.25)	(0.79)
GW Quantity	0.061	-0.505***	-0.025	-0.059
	(1.33)	(-5.50)	(-0.57)	(-0.81)
SW Price	0.504***	-0.134	-0.144	0.060
	(4.47)	(-0.59)	(-1.36)	(0.34)
SW Quantity	-0.027	0.354***	0.099	-0.011
	(-0.40)	(2.68)	(1.59)	(-0.11)
Monthly rainfall	-0.003*	0.0002	-0.001	-0.001
	(-1.80)	(0.08)	(-0.60)	(-0.38)
Monthly mean temperature	0.027	-0.002	0.016	0.038
	(1.57)	(-0.07)	(1.02)	(1.41)
_cons	-0.009	-0.004	-0.019	-0.007
	(-0.14)	(-0.03)	(-0.33)	(-0.07)
N	100	100	100	100
R-sq	0.352	0.276	0.055	0.046
Chi-sq p.val	0.00	0.00	0.44	0.57

Note: * p<0.1, ** p<0.05, *** p<0.01; t statistics in parentheses. Market variables are logged and first differenced. Climate variables are first differenced.

Granger causality tests and the VARX results suggest the existence of a price leadership phenomenon from surface water markets to groundwater markets. The percent change in groundwater price is Granger-caused by the past change in the surface water price: the parameter of the surface water price in regression (1) is positive and highly significant. Similar evidence was found regarding groundwater quantity traded: the unit percent change in quantity of groundwater traded can be explained by the past change of surface water quantity traded. In order to analyse the duration and extent of the interaction between surface and groundwater temporary markets (Roca and Tularam, 2012), orthogonalized impulse-response functions and the forecast error variance decomposition were generated (see Appendix B). They suggest that a one-unit percent change in the surface water market generates a response in groundwater price that is positive and significantly different from zero at lag one (See figure B1). This response weakens in the second month and disappears four months later. Furthermore, the variance of the forecast error for the groundwater price is due 83.2% to its own innovations and 14.4% to innovations in the surface water price.

Note that Table B1 also shows that the variance of the forecast error for the surface water price is due 84% to its own innovations and 11.8% to innovations in the groundwater price, which could suggest that the opposite (groundwater market characteristics impact surface water markets) could be also true. However, Granger causality tests and regression estimates do not show any impact of the past percent change in groundwater market characteristics, on either surface water market prices or quantities traded. Impulse response functions also show no significant response in surface water price for lags one to eight, following a unit percent change in groundwater price.

Overall, these results suggest that market-sensitive information is first incorporated by the surface water market, and then transmitted to groundwater markets. Such a result is coherent with the financial literature, showing that more liquid markets tend to incorporate market information faster (Roope and Zurbruegg, 2002; Brooks and Harris, 2014).

6.2. *Price elasticity of groundwater demand*

Results from the 2SLS modelling are shown in Table 4. The Durbin-Wu Hausman test confirmed the endogeneity of the groundwater price. Under-identification and weak instrument tests (e.g. Kleibergen-Paap rk LM and Wald F statistics) suggest no under-identification or weak instrument, and our instrument has a significant, positive impact on the groundwater price.

Table 4: Results from the 2SLS estimation for the quantity of groundwater traded in the Murrumbidgee temporary groundwater market 2008-2018

	Dependent variable	
	GW Quantity (Second stage)	GW Price (First stage)
GW price (instrumented)	-1.046**	
	(0.455)	
Rice price (Instrument for GW Price)		1.076***
		(0.223)
Surface water price	1.174***	0.549***
	(0.305)	(0.061)
General security surface water entitlement price	2.179**	1.263***
	(0.985)	(0.341)
Diesel price	-1.229	-1.367**
	(1.002)	(0.680)
Mean temperature	0.376	0.587**
	(0.528)	(0.254)
Monthly rainfall	-0.010	0.037
	(0.108)	(0.052)
Early season	0.501	0.346*
	(0.383)	(0.175)
Mid-season	0.048	0.004
	(0.285)	(0.160)
_cons	-4.480	-9.906*
	(10.260)	(5.294)
N	102	102
Centered R^2	0.29	
Kleibergen-Paap rk Wald F stat.[23]		23.284 (p-value=0.00)
Weak identification test threshold[24]		16.38 (p-value <0.05)
Endogeneity test stat.[25]		5.221 (p-value=0.02)

Note: Standard errors in parentheses; * p < 0.1 ** p < 0.05 *** p < 0.01.

[23] Null hypothesis that our equation is under-identified. Rejection in this case, means our equation is not under-identified.
[24] The null hypothesis is that the instrument is weak. The critical value for 10% maximal IV size at the 0.05 significance level is 16.38 (Stock and Yogo, 2005). Therefore, the null is rejected, suggesting the instrument is not weak.
[25] Null hypothesis is that the groundwater price can be treated as exogenous. In this case, the rejection of the null hypothesis suggests that groundwater price is endogenous.

Second stage estimates reveal a groundwater temporary demand price elasticity close to the unit elasticity (-1.05): a one percent increase in the groundwater price leads to a 1.05 percent decrease in groundwater demand. This is a relatively high estimate compared to the literature dedicated to the price elasticity of groundwater use via irrigation charge. For example, Mieno and Brozovic's (2016) estimate was -0.5 for changes in groundwater use in reaction to changes in pumping costs in northern America. However, the surface water market price elasticity literature suggests even higher estimates (in absolute value): Wheeler et al. (2008) found a -1.51 temporary surface water demand elasticity from 1997-2007 in the Goulburn. Our result suggests that while the groundwater market demand seems generally more elastic than other irrigation charging estimates, it is less elastic than surface water market demand. This is most likely explained by the fact that surface water trade volume is much larger, price is generally higher, the market is more liquid, and covers a far greater tradeable area across the southern MDB than the Murrumbidgee groundwater market.

As expected, surface water market prices significantly affect groundwater prices in the Murrumbidgee. This confirms the existence of a substitution effect between surface and groundwater (Haensch et al., 2016). Diesel prices have a negative impact on groundwater price: similar to a decrease in farmers' income, an increase in diesel prices shifts the water demand curve to the left as it costs more to pump groundwater. As water demand is reduced, groundwater water prices fall. Mean temperature is positively associated with groundwater price, as evapotranspiration increases crop water demand while not affecting supply. Rainfall has no statistically significant impact. Finally, we find that groundwater prices are slightly higher at the beginning of the water season (i.e. between July and September). This confirms a seasonal trend already noted in the literature: as uncertainty related to water resources availability is higher, farmers buying water early in the season tend to pay more. This is perceived as an insurance premium, and in the case of groundwater in Murrumbidgee we find that this impact disappears after October.

7. Conclusion

This study used a ten-year dataset of groundwater, surface water market prices and quantity traded in the Murrumbidgee to identify two key results to inform water policy. First, there is a significant price leadership phenomenon from surface water markets to groundwater markets. Surface water markets are used the most by irrigators in the Murrumbidgee; hence they incorporate market sensitive information first, and this information is then transmitted to groundwater markets. The price of groundwater and its quantity traded are therefore dependent on the price and quantity of the surface water traded. This suggests the existence of a substitution effect between surface and groundwater, despite irrigator preference for surface water. Therefore, the need for an integration of water policy that applies to both surface and groundwater resources is imperative. Conjunctive management of water resources (Ross, 2018) could offer several benefits in this perspective. If water policies only target surface water resources, it is likely that irrigators will substitute groundwater for surface water: there is increasing evidence of such behaviour (Zhang, 2007; Wheeler et al., 2016). Furthermore, quantifying return flows is also important (Williams and Grafton, 2019).

Second, groundwater temporary market demand in the Murrumbidgee was unitary elastic (-1.05) in our period of study. Therefore, any policy targeting increasing the water price should reduce groundwater demand in the Murrumbidgee. However, any change in demand would vary depending on climatic circumstances and price levels on both surface and groundwater markets.

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10. References

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11. Appendix A: Descriptive statistics

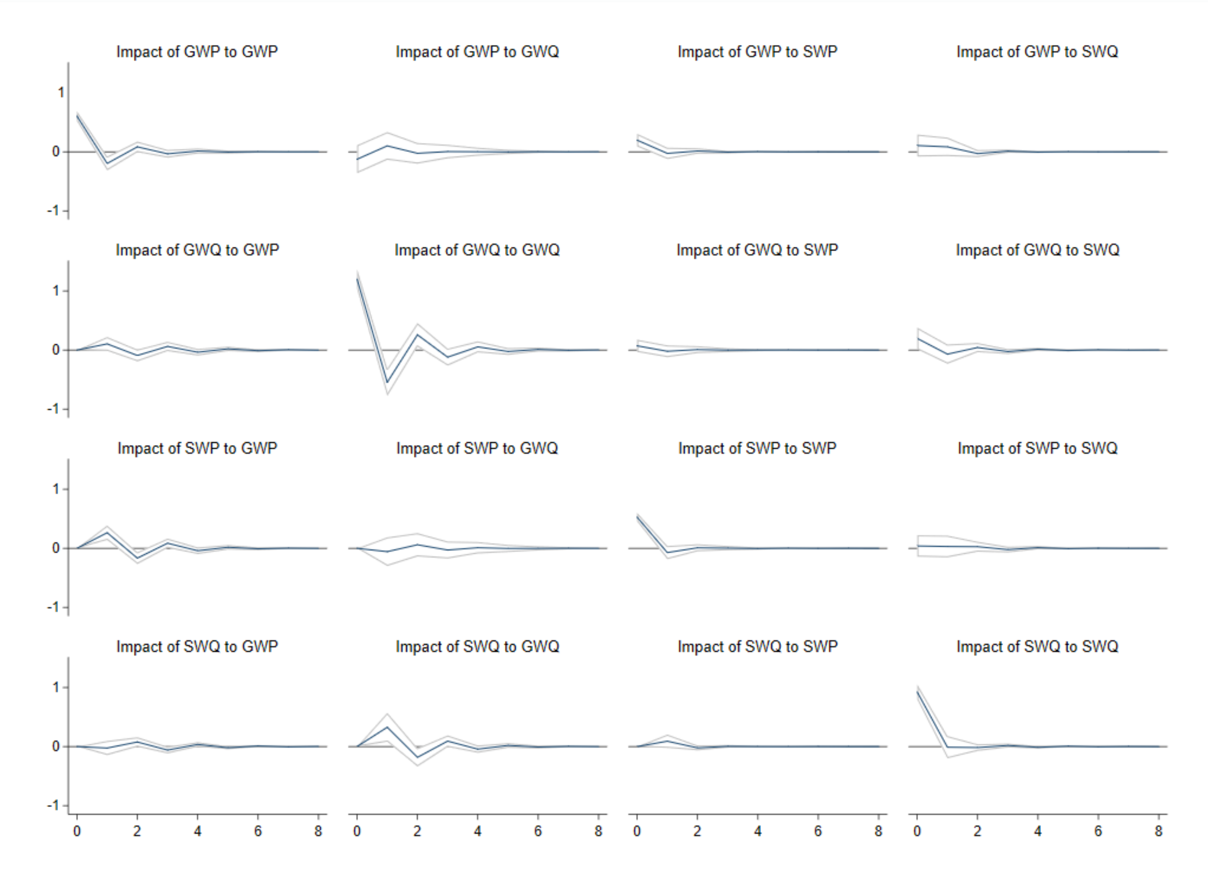
Table A1: Descriptive statistics

Variable	Description	Used in [26]	Source	Obs	Mean	Std. Dev.	Min	Max
Groundwater allocation price	Median monthly groundwater allocation price in the Murrumbidgee Alluvium, $/ML in constant 2018 prices	PL, E		102	33.78	32.74	1.13	122.96
Groundwater quantity traded	Total monthly quantity of groundwater allocations traded (ML) in the Murrumbidgee Alluvium	PL, E	Bureau of Meteorology water market data[27]	102	3430.35	2874.48	10	14749.60
Surface water allocation price	Median monthly surface water allocation price $/ML, expressed in constant 2018 prices, in the Murrumbidgee regulated river trading zone	PL, E		102	132.44	129.95	2.84	652.89
General security entitlement price	Median price of the general security entitlement ($/ML, constant 2018 prices) in the Murrumbidgee regulated river trading zone	E		102	1056.10	246.49	667.88	1657.66
Rainfall in the last month	Monthly rainfall (mm) at Hay Airport AWS Station, NSW	PL, E	BoM Weather and Climate data[28]	102	30.64	32.96	0	184.80
Mean temperature	Mean temperature (°C) at Hay Airport AWS station, NSW	PL, E		102	18.55	5.77	8.40	27.80
Rice price	Monthly rice price (USD/t, constant 2018 prices)	E	ABARES	102	540.16	130.59	377.74	871.54
General security allocation level	General security allocation announced for the Murrumbidgee regulated river trading zone water (%)	E	NSW Government, DPI water	102	47.05	30.05	0	100
Diesel price	Mean monthly diesel price (AUD$ cents/litre constant 2018 prices) in Sydney, NSW	E	Australian Institute for Petroleum	102	137.86	20.26	95.75	197.56
Month index	Month index with July=1 and June=12	E	-	102	6.57	3.21	1	12
Early water season dummy	Dummy equal to 1 for July, August and September	E	-	102	0.22	0.41	0	1
Mid water season dummy	Dummy equal to 1 for October to January	E	-	102	0.36	0.48	0	1

[26] PL= Price Leadership analysis; E= Elasticity analysis.
[27] Available online: http://www.bom.gov.au/water/dashboards/#/water-markets/national/state/at, accessed on 15th May 2018, data from 01/07/2008 to 30/04/2018.
[28] Available online: http://www.bom.gov.au/climate/data/index.shtml?bookmark=136, accessed on 15th May 2018.

12. Appendix B: Orthogonal Impulse Response Functions and Forecast Error Variance Decomposition Results following the VARX(1) estimation

Figure B1: Orthogonalized Impulse-Response Functions and 5% confidence interval following the VARX(1) estimation in the Murrumbidgee temporary surface and groundwater markets, 2008-2018



Note: Impulse response functions trace the effect of an exogenous shock on one of the endogenous variables in the VARX model to the other endogenous variables. A more detailed explanation on Impulse Response Functions and Variance Decomposition can be found in Roca and Tularam (2012). The duration of the shock is described in the next 8 months (shocks rarely last more than 1 month). The result and the related 5% confidence interval are shown. Abbreviations can be interpreted the following way: GW is Groundwater, SW is Surface water, P is price, and Q is Quantity traded.

Table B1: Cholesky forecast error variance decomposition after two lags based on VARX(1) estimation for unit percent change in four market variables in the Murrumbidgee temporary surface and groundwater markets 2008-2018

Share of Variance (%)	Groundwater		Surface Water	
	Price	Quantity traded	Price	Quantity traded
Groundwater price (lag)	83.18	1.38	11.80	1.99
Groundwater quantity (lag)	2.25	92.75	1.66	4.76
Surface water price (lag)	14.44	0.17	84.07	0.28
Surface water quantity (lag)	0.13	5.70	2.47	92.97

Note: The Variance decomposition decomposes variations in one of the endogenous variables (first column) in the VARX(1) model into the component shocks to the other endogenous variables (Roca and Tularam, 2012; Reza et al., 2017) in columns 2 to 5. Variations are expressed in percent of the total variations and indicate the percent valuation that can be attributed to a given variable.

Chapter 4[29]:

Water markets in France: appropriate water scarcity management mechanisms? Case studies in the Poitevin Marsh Basin and the Neste system

Abstract

Water resources in France are relatively abundant in comparison to Australia's Murray-Darling Basin. However, water scarcity episodes can occur in summer (June to September), when most irrigation-withdrawals occur. In the last years, the French water management framework has evolved towards a reduction in water quotas and a more collective approach towards water resources allocation, under the influence of environmental issues and climate change. This study applies the WMRA framework to two French case studies: the Poitevin Marsh Basin and the Neste system. 11 semi-structured interviews with key local stakeholders were held in order to inform these case studies applications. Overall, the French water management framework is currently not designed for market instruments: buying, selling or transferring water extraction authorizations is currently not allowed in France. Water markets could be considered to mitigate losses associated to the planned reductions in water quotas (Poitevin Marsh) and to improve water demand management (Neste system). However, significant impediments have been identified, including a low social acceptability from local stakeholders. Establishing water markets in France seems to imply major changes in the social attitudes towards the use of market mechanisms applied to water management.

Keywords: Poitevin Marsh; Neste system; Water management; Water markets.

[29] This chapter refers to the article cowritten with Arnaud de Bonviller. An adapted version of this chapter is forthcoming in the Book: *Water Markets: A Global Assessment*. Edward Elgar, UK.

1. Introduction

In France, available renewable water resources per person exceed 2600 m^3, while the overall withdrawal rate is around 19% (Barthélémy and Verdier, 2008). France is therefore not a water scarce country according to the Water Resources Vulnerability Index (Raskin et al., 1997; FAO-AQUASTAT, 2014) and water stress is local or occasional only (Falkenmark, 1989). However, in the regions with the most irrigation-related withdrawals, water extractions often exceed the available renewable resource during low-flows months (Barthélémy and Verdier, 2008). In many areas, excessive water use in times of scarcity (mainly the French summer, between June and September) frequently necessitate administrative bans on certain water uses. Such areas, mainly located in central and south-western France, have been categorized Areas of Water Resources Management (ZRE). ZREs cover a significant part of the French metropolitan territory (see Appendix 2).

Water management in France is mainly defined at the basin level. France is divided in 7 river basins, each under the authority of an administrative Water Authority ("Agences de l'Eau") established by the 1964 water law. Each basin undertakes a Master Plan for Water Resource Management (SDAGE) defined by Basin Committees and the establishment of Local Water Commissions (CLE). Additional Local Plans for Water Resource Management plans (SAGE) can be established at the local level. The characteristics of each basin can vary widely (summary characteristics for different basins can be found in Appendix 3). The 7 French basins are relatively small (8700 to 155 000 km^2) and highly populated (32 to 238 inhabitants per km^2) in comparison to Australia's Murray-Darling Basin (1 059 000 km^2 and an average 1.9 population density (ABS, 2008)).

Water has been defined as a common patrimony of the nation by the 1992 water law. Therefore, water use rights in France are materialized by authorizations to extract water and cannot be owned individually and buying or selling water rights is currently illegal. Such authorizations are renewed on an annual basis and can vary depending on the type of water use considered (mainly irrigation, industry, and drinking water use). They are commonly designated as water withdrawals authorizations or water extractions authorizations.

In 2004, the European Water Framework Directive defined a good ecological state to be reached for all water bodies in the EU member States. In order to reach this objective, the 2006 French Water Law defined a new approach to quantitative water management. First, it required the definition of a maximum volume of water to be extracted (Cap) in each basin. This volume (*volume prélevable*) was defined as the volume that can be fully extracted from the environment, on average 8 years out of 10, all uses included, while ensuring the good functioning of the aquatic environment. Second, it required the revision of the existing water extraction authorizations in each basin, in order to comply with the cap. Third, it created Unique Organisms for Collective Management (OUGC[30]) in areas where imbalance between water demand and supply occur frequently (ZRE). OUGCs are responsible for irrigation water management and the delivery of irrigation water rights in particular. The cap defined by the state authorities (Prefects) in each basin often implies a diminution in water consumption, particularly for irrigation water purposes. This and other reasons led to important delays in the implementation of the 2006 water law (Martin, 2013). In this context, considering the adoption of water demand and scarcity management mechanisms – such as water markets – in France seems of interest.

Few studies have debated the use of water markets in France. Strosser and Montginoul (2001) provided a review of the economic principles underlying water markets and suggested two French contexts where the debate on water markets could be of interest: the Beauce aquifer

[30] A list of all acronyms and related definitions can be found in Appendix 1.

and the Neste basin. Barraqué (2002; 2004) reacted to this article by studying the history of water law related to Californian water markets. He stressed the important influence of common patrimony management in the Californian water law, the existence of high transaction (especially infrastructure-related) costs, and externalities. He argued for common patrimony water management instead of the use of water markets in France. Rinaudo et al. (2015) suggested the use of tradeable water savings certificates to improve urban water use efficiency. Besides, different studies focused the perception of water markets and economic incentives in general by stakeholders in France. Figureau et al. (2015) conducted a qualitative analysis of water markets in France using focus groups and different policy scenarios. They found a strong opposition to the use of markets applied to water, seen is a 'common good'. Rinaudo et al. (2012) conducted scenario workshops in France and Portugal and included a market related scenario. They found strong objections to consider water as a commodity and a fear of market power, especially from small farmers who consider markets as threatening their farm subsistence. Once these initial objections were stated, debates revealed potential benefits in orchard production, as farmers could lease their rights in the years preceding production, but farmers also worried about high transaction costs, third party-impacts, and an increase in the financial resources needed to enter the sector. Strong opposition to the use of water markets on ethical grounds was also found by Rinaudo et al. (2014; 2016), although the authors find an acknowledgement of informal remunerated water transfers in practice. Therefore, qualitative analysis shows that French farmers tend to show a preference for policies strengthening social incentives in relation to water over market mechanisms, although a contradiction with individualistic behaviours can be noted in practice (Rinaudo et al., 2012; 2016).

Some studies have attempted to models gains from trade arising from the potential use of water markets in France. Graveline and Mérel (2014) modelled potential market mechanisms in the Beauce aquifer, considered as 'France's cereal belt'. Considering a 30% reduction in water availability, they found that water markets would compensate 2% of the economic losses generated by the reduction in water availability, equivalent to 3 cents per cubic meter. Potential explanations for this result include the fact that only 23% of production was irrigated, and the possibility of using deficit irrigation without much yield loss on certain crops. These modest gains of economic benefits are consistent with the findings of other French (Bouscasse and Duponteil, 2014), Spanish (e.g. Kahil et al., 2015) or Italian (Zavalloni et al., 2014) case studies integrated in the Water Cap and Trade European project (Rinaudo et al., 2014b).

Given the fact that different local authorities have been devolved responsibilities in terms of water management at the local level, water management in France is highly context dependent. Therefore, this analysis will apply the Water Market Readiness Framework (Wheeler et al., 2017) to two case studies at the local level: The Poitevin Marsh Basin and the Neste river system. These two cases are representative of the two different irrigation development patterns commonly found in France (Martin, 2013). The Poitevin Marsh Basin (Section 1) is located in western France along the Atlantic Ocean. Agriculture is the main source of income in this Basin, in a context of varying water availability and rich environmental values. Irrigation in the Poitevin Marsh Basin has developed in 1970s and 1980s, often on an individual basis, without prior rules of water allocations. The Neste system (Section 2), located in south-western France, is a river system artificially replenished by the Neste canal, diverting water from the Neste river to the Neste system. It is supplying water to irrigation and to multiple other water uses in a context of frequent water scarcity episodes. In the Neste system, irrigation development at the end of the 20th century has been accompanied by Compagnie d'Aménagement des Coteaux de Gascogne (CACG), a company originally created in 1959 by the State, and a set of water allocations rules elaborated by decree in the early 20th century. These areas are both categorized as zones of water allocations (ZRE), as they experience recurrent episodes of water scarcity. In order to document these WMRA case study applications, 11 semi-structured interviews were realized within the areas of study with key public, private and civil society stakeholders[31], along with an extended literature review. In both cases, we first provide an overall presentation of the hydrological context (A). We then discuss the current water management needs (B), the current water management framework (C) and the potential benefits and impediments identified to the use of water markets (D).

2. The Poitevin Marsh Basin

2.1. Context: geography, water resources and hydrology

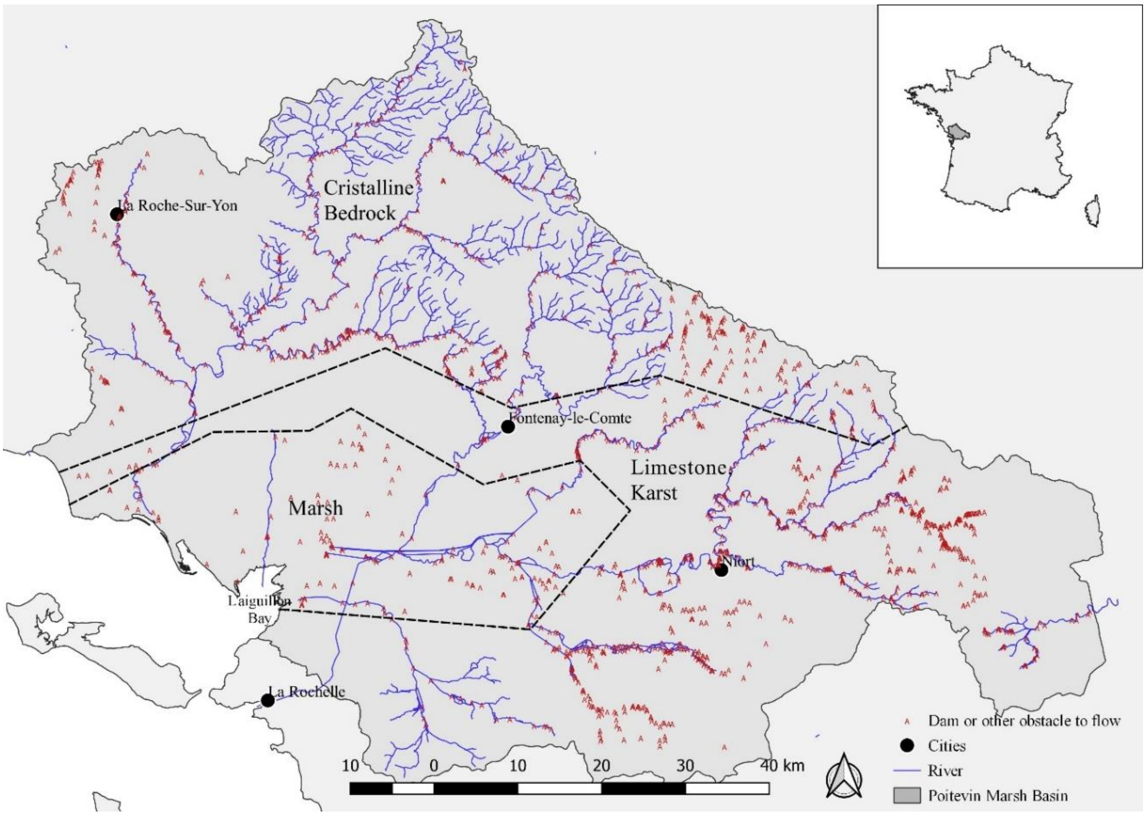
The Poitevin Marsh Basin (PMB) is a 6500 km² area located in western France, along the Atlantic Ocean. The Poitevin Marsh itself (*Marais Poitevin*) represents 1000 km². Its land has been progressively recovered from the sea, from the 13th to the 20th century.

The Basin has a semi-circular shape and its external part supplies water to the Marsh. Altitude remains stable across the basin: the highest elevation point is 300m high, with an average elevation of 2 to 3m NGF within the Marsh. The Poitevin Marsh is located in Western France and subject to an oceanic climate. Mean Temperatures are moderated (11°C) and rainfall is relatively high: 850 mm/year on average, 1000mm on the heights, and 800mm next to the sea. Effective rainfall (about 280 mm) occurs between October and May. In particularly dry years, such as 2005, effective rainfall can be as limited as 50mm with a total summer rainfall amounting to 100 mm (Douez et al., 2015).

[31] 10 interviews were organized face to face and 1 by telephone, involving 13 persons in total. 5 interviews were dedicated to the Neste system, and 6 to the Poitevin Marsh Basin. Interviews lasted between 1 and 2 hours, and mainly focused on questions guiding the assessment described in Wheeler et al. (2017), while some also mentioned topics deemed important and/or interesting by the interviewee(s). A descriptive summary of all realized interviews can be found in Appendix 4.

Three main geological structures coexist from the heights to the shoreline, as shown by Figure 1. The primary bedrock is located in the Basin's northern part and gives birth to a dense hydrographic network. These rivers trickle down until they reach the second structure, formed by limestone and karst layers. These layers are porous, and the hydrographic network shows a lower density. Many sources flow out of the karstic groundwater body, defining a part of the marsh said 'wet'. The wet marsh receives the water trickling down from the bedrock and the water from near groundwater bodies. This ring-shaped area is 10 to 15 kilometers wide in the north and becomes wider and with a higher proportion of clay in the eastern part of the Basin. It englobes and supplies water to the non-porous and more recent land of the Marsh through 4 main rivers. These rivers join in two estuaries downstream: the Lay estuary and L'Aiguillon Bay. The land in the Marsh has a large proportion of clay ("bri"), formed by the Flandrian Progression.

Figure 1: The Poitevin Marsh Basin

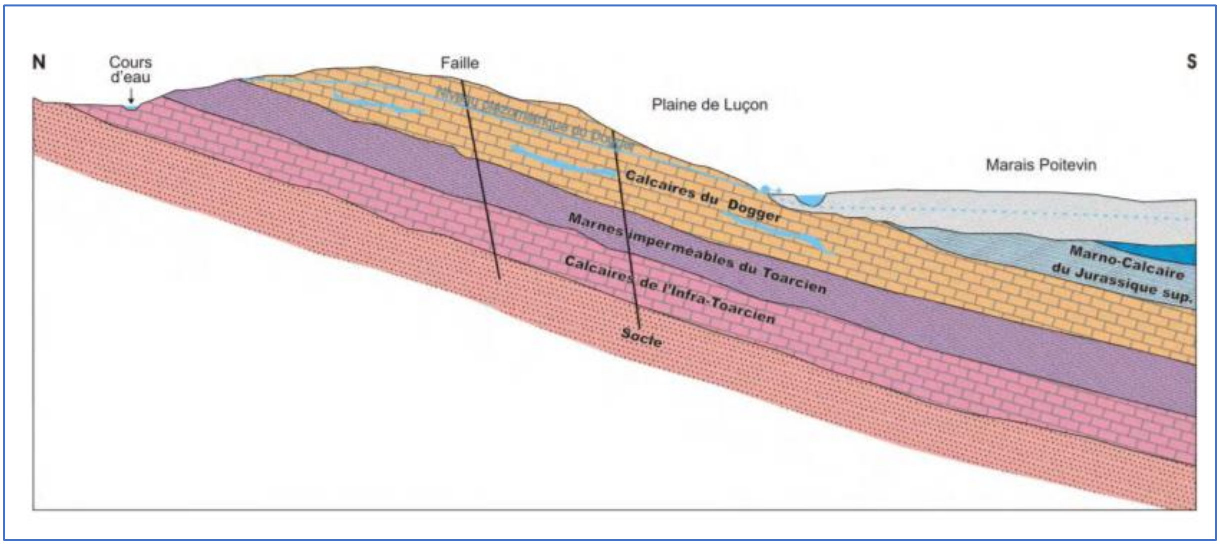


Source: GIS data layers from the SANDRE database (SAGE and Poitevin Marsh perimeter, Dams), and the CARTHAGE database (rivers).

Together, relief, hydrographic network and climate shaped this vast wetland. The basin's hydrology has been evolving throughout centuries, since the Middle Age when agriculture began in the basin.

The water trickling down from the north is regulated by dams designed for drinking water purposes and the compensation of irrigation water extractions. The specific natural flows of river bodies on the bedrock vary around 8 liter/s/km². In the eastern part of the basin, this natural flow reaches 10 l/s/km². The highest flows occur in January (25 to 30 l/s/km²) while minimum flows occur in August (1.5 to 3 l/s/km²). The hydrologic functioning of the Poitevin Marsh basin is uncommon, due to the existence of sources flowing out of the karstic aquifers, around the clay soils of the Marsh:

Figure 2: Schematic view of the hydrogeologic context in the northern part of the Poitevin Marsh Basin



Source: Douez et al., (2015)

The water supply of the Marsh can be deeply affected by a significant drop in the Dogger aquifer water level. Water entering the Marsh flows through 8000km of canals and ditches, whose water levels are monitored and supported by 200 dams spread throughout the territory. The canals are used to drain water from the Marsh during the winter and to store water in summer. Nowadays, ditches are often replaced by French drains and pumping systems directed towards the canals.

The three main surface river bodies coming from the northern and eastern part of the Basin are contained by embankments as they cross the 'wet' marshes towards the 'dry' marshes. These embankments protect the 'dry' marshes from the main rivers' floods by redirecting this water directly at sea. A complex hydraulic system monitors this evacuation according to the tides.

The Loire-Bretagne Master Plan for Water Resource Management (Comité de Bassin Loire-Bretagne, 2009) divided the Marsh in 28 sectors. Within each sector, the local water commissions (*Commissions locales de l'Eau, CLE*) defined minimal water levels to be respected throughout the season.

2.2. Current needs: Water management issues and users

2.2.1. The Poitevin Marsh, a wetland hosting significant environmental values

The Poitevin Wetland is located downstream of the Basin, near its estuary in L'Aiguillon Bay. It hosts important ecological values linked to the Basin's different habitats: the 'wet' marsh, the 'dry' marsh and intermediary marshes are home to about 250 registered bird species, as well as a significant number of fish and vegetal species related to the marshes' physical, chemical and climatic characteristics (Ayphassorho et al., 2016). Water is vital to the environmental values in the Poitevin wetland: environmental water needs in the Basin are thus significant.

However, ecological values in the wetlands have been threatened in the last decade by excessive water withdrawals, demographic pressure, water quality issues, the establishment of invasive species, and artificialization. The occurrence of climate change and the related increase in mean temperature and sea level are also sources of concern. In addition to this, within the wetland, permanent pastures are vital to the local biodiversity. However, such pastures, traditionally used by livestock and mixed crops farmers, have been progressively replaced by cereal crops (maize and corn in particular) throughout the 20th century. As a result, France was condemned in 2000 by the European Court of Justice for failure to comply with the legislation on the protection of wild birds in the Poitevin Marsh (EC, 1999[32]).

2.2.2. Quantitative issues: irrigation-related withdrawals in the summer

Agriculture represents the most part (54.6%) of total water extractions within the Poitevin Marsh basin, along with drinking water (42.7%) and industrial water use (2.7%) (EPMP, 2015). Irrigation water use in the Poitevin Marsh Basin occurs during the French summer, between June and September, and spring (March to May) to a lesser extent. Irrigation withdrawals are concentrated within groundwater bodies in the dried marsh, located around (and upstream of) the wetland. As the ground- and surface water bodies are largely interconnected throughout the basin, excessive withdrawals in irrigation areas can lower the water level in the marsh in summer, endangering environmental values and competing with other water uses (drinking water, tourism, wastewater treatment…).

2.2.3. Qualitative issues: nitrates in the Basin and water quality in L'Aiguillon Bay

In 2013, only 27% of water bodies in the Loire Bretagne Basin[33] were considered in a 'good ecological state' according to the European Water Directive. Previous attempts to reach a 61% proportion of water bodies in 'good ecological status' were unsuccessful and have been postponed to 2021 (Comité de Bassin Loire Bretagne, 2015, p.30). Problematic concentrations in nitrates and bacteriological pollutions were specifically mentioned during the interview. Salinity issues in the western part of the Basin (in the Lay sub-basin, along the Atlantic Ocean)

[32] https://curia.europa.eu/en/actu/communiques/cp99/aff/cp9993en.htm, accessed 29/04/2019.
[33] The Poitevin Marsh Basin is located within the Loire-Bretagne Basin.

have also been occasionally occurring due to excessive extractions in water bodies located next to the coastline, similar to what has been described by Ostrom (1990) in the western United States. Finally, water quality issues related to wastewater treatment are frequently affecting the mussels and oyster farming downstream the estuary in L'Aiguillon Bay, generating additional treatment costs for the local farmers.

2.2.4. Water management in the Poitevin Marsh Basin: stakeholders and governance

Three different instruments are currently used to manage water within the Basin. First, planification involves the definition of a Master Plan for Water Resource Management (SDAGE) at the Loire-Bretagne Basin (upper) level, and 3 Local Plans for Water Resource Management (SAGE) at the local level. Second, state regulations have been designed to announce bans on irrigation water extractions in times of scarcity, and to enforce water rights. Third, different contracts have been established between various institutions (including Water Agencies) and local water users in order to reach the various goals defined by water management schemes (Ayphassorho et al., 2016).

Many different actors are involved in water management of the Poitevin Marsh Basin. Following the European Court's ruling on France's failure to comply with the Wild Birds Directive in 2000, a State agency has been established with the aim of coordinating water management at the Basin level: Etablissement public du Marais Poitevin (EPMP). The Basin is crossing boundaries of various local administrative authorities, including 2 *régions* and 4 *départements*, and implies different State representatives, including the local *Préfet*. Other significant actors involve the private Marsh syndicates, maintaining the infrastructure within the Marsh, mixed syndicates in charge of the infrastructures around the Marsh, the Poitevin Marsh Regional Natural Park (PNRMP) monitoring biodiversity issues, The Gironde Estuary and Pertuis Charentais Sea Marine Natural Park (PNMGP) and the Sèvre Niortaise River sub-basin institution (IIBSN). Environmental NGOs (ENGOs) are also playing an important role within the local SAGEs Local Water Commissions (CLE). CLEs are 'local parliaments' gathering all local stakeholders (State actors, water users, and local authorities), in order to define the local water management plan (SAGE) according to what can be considered as a common patrimony management approach (Calvo-Mendieta et al., 2017). Water governance in the Poitevin Marsh Basin is therefore characterized by a plurality of actors, and sometimes a lack of coordination (Ayphassorho et al., 2016).

2.2.5. Other water management related issues: floods in the coastal area

As the Poitevin Marsh Basin's average elevation is around 3 meters NGF, flooding events during winter storms represent an important issue within and around the Marsh, exacerbated by the general elevation of the sea level associated with climate change. During the night between the 27th and 28th February 2010, the Xynthia storm flooded 16 000 ha and killed 33 inhabitants. Considerable attention is therefore paid to the existing protections against floods, and important modernization programs are currently being held along the Atlantic Ocean.

2.3. Current framework: Legal responses, Legal framework, Local stakeholders involved (esp. irrigators) and current water management.

2.3.1. Irrigation water rights in the Poitevin Marsh Basin

As the Poitevin has been defined as a Water allocation area (ZRE), irrigation water rights in the Basin are gathered and jointly requested by EPMP acting as a unique collective management organism (OUGC). EPMP requests a common withdrawal authorization (AUP), and then allocates water rights each year depending on the needs expressed by irrigators, in coordination with the local Agricultural Chambers. Therefore, water rights (*authorisations de prélèvements*) are granted on an annual basis and cannot be bought or sold.

In spite of the 2006 Water law requirements, no cap on total extraction has been defined and enforced as of 2019 in the Poitevin Marsh Basin. Besides, some water extractions occurring in the northern part of the basin (bedrock) are not monitored and considered disconnected from the remaining hydrological system.

2.3.2. Environmental flows and crisis management

As the Poitevin Marsh is affected by irrigation and other water withdrawals (concentrated between June and September), reference levels have been defined for groundwater (piezometric levels) and surface water (flow values) throughout the summer irrigation season. Three quantitative thresholds have been defined for groundwater bodies in the basin. Drinking water has been granted priority of use and remain unaffected by scarcity management measures. If the water level in a groundwater body decreases under the first threshold (the alert threshold or *seuil d'alerte*), EPMP has established a collective water scarcity management program with irrigators: in case of water scarcity episode, management measures implying the temporary limitation of water quotas (10 to 40% volume reductions) can be collectively applied. If the groundwater level decreases further down the second threshold (*seuil d'alerte renforcée*), the French State is taking over and a 50% cut of water quotas volumes is applied (*arrêté-cadre sécheresse*). Finally, the last threshold is defined as the groundwater level under which a ban of irrigation water use is declared, although some exceptions exist for particular high-valued crops. As surface and groundwater are largely interconnected within the Basin, similar thresholds have been defined for surface water bodies.

2.3.3. MAE, CAP, and other environmental policies

Following the European Court ruling, different policies have been applied to maintain pastures within the Poitevin Marsh Basin. Agro-environmental policies (MAE) providing financial livestock farming activity, agricultural practices requirements associated with Common Agricultural Policies (CAP) subsidies since 2015 and various similar policies have been established to stabilize the proportion of permanent pastures in the Basin. As a result, the area under pasture slightly increased between 2003 and 2013 (Ayphassorho et al., 2016).

2.3.4. The substitution reservoirs: a debated supply augmentation policy

The 2010 Leading Water management Scheme (Comité de Bassin Loire-Bretagne, 2009) defined a necessary reduction in water quotas by 55%, to be reached by 2015 in order to ensure that water extractions were compatible with all existing uses and a good ecological state in the Marsh. To compensate the potential economic losses while limiting water withdrawals during the summer, the local authorities suggested the use of a supply augmentation policy: the construction of substitution reservoirs. Such reservoirs are filled during the winter, when the surface river flows and groundwater levels are high, and the stored water is used as a substitute to irrigation water withdrawals between June and September. Although different substitution reservoirs have been built and are now functional in the northern part of the Basin, in its southern part they generated significant political controversy. In 2019, most of the substitution reservoirs were built or approved in the Northern part of the Basin and their operation was conceded to a private operator (Compagnie d'Aménagement des Coteaux de Gascogne, CACG) also present in the Neste system. This enabled a 30% diminution of the annual volume of granted water rights in practice, although a significant part of it was related to reductions in unused water rights (Ayphassorho et al., 2016). In the southern part of the Basin, significant political controversies led to several mediations supervised by the State authorities. This led to a public management protocol specifying different agricultural practices to be adopted in exchange for the reservoir's construction. Many projects and negotiations were still ongoing at the time of the study, and the associated reduction in water quotas was not finalized at the time of our study.

2.3.5. Compliance and enforcement

About 99% of drills are metered within the Basin. Irrigators must provide meters' indexes several times a year, and penalties are imposed for each missing index. The local Water Police is in charge of the compliance and enforcement of water rights in the Marais Poitevin Basin. If irrigators are connected to a substitution reservoir, CACG is also conducting verification on the basis of the contract established with the irrigator. In addition to this, Agricultural Chambers can occasionally make sure that the water use remains within the volume specified by the irrigator's water right. However, given the limited budget of the water police and the diversity of actors involved, unauthorized water use and water use in excess of a water right can still happen at the margin.

2.4. *Water markets in the Marais Poitevin: Potential benefits, impediments and implementation*

2.4.1. *Water demand and diversity of value-added uses*

Irrigation represents most of the water demand in the Basin. Permanent and temporary pastures cover about 31% of the total agricultural area, while the most important crops cultivated include corn (29% of the total agricultural area) and maize (19%). Other crops representing smaller agricultural areas include various other cereals, tobacco and seeds, and a diversity of higher valued crops related to smaller water uses. Organic farming has been developing in the last years, under what is generally perceived as favourable market circumstances (high output prices in particular). Drinking water is also responsible for a significant demand. Besides, tourism (the 2nd local economic activity, after agriculture) is deeply related to the Marsh's ecological values; its preservation and the associated environmental flows are therefore representing a significant demand for water as well. Specifically, navigation in the emblematic part of the Marsh represents an important water demand from the tourism sector. Thus, the demand for irrigation water is dominated by a few low value crops (maize, corn…), while the demand for other water uses diverse (tourism, domestic water use) and involves a significant environmental water demand (EPMP, 2015).

2.4.2. *Informal transactions: water markets in practice?*

Anecdotal evidence suggests that a limited amount of informal transactions might be occurring in the Poitevin Marsh Basin (Kervarec, 2014). Limited evidence of irrigators growing higher-valued crops leasing land to benefit from the associated water rights has also been reported in the interviews.

2.4.3. *Potential benefits*

70% the water extracted for irrigation purposes in the Poitevin Marsh Basin is groundwater (EPMP, 2015). Transportation costs would therefore be low in the context of a groundwater market, as most of the aquifers in the 'dry' marsh are connected. Besides, irrigation and drinking water use in the Basin can be compensated by the existing dams and (for the northern part) substitution reservoirs. Furthermore, EPMP has establishing a public information system (SIEMP, available online) monitoring the water flows (fur surface water) and levels (for groundwater or in the marsh) for 204 stations across the basin. Thus, environmental externalities related to water transfers could be adequately managed, provided that a cap is defined in compatibility with the environmental needs of the marsh.

In order to comply with the 2016-2021 Master Plan for Water Resource Management (SDAGE), significant cuts will be required to the annual volume of water rights granted (Comité de Bassin Loire-Bretagne, 2015). In addition to this, the necessary diminution in water extractions might be greater than what is described in the SDAGE: a study from an expert panel (Groupe d'experts, 2007) preconized a smaller volume of annual extraction than the SDAGE. Redirecting water from lower to higher value crops and less water-intensive crops, in this perspective, would facilitate the transition while benefiting employment (Martin, 2013).

In this context, the use of water markets could be considered in order to mitigate the economic losses related to a reduction in water extractions. Bouscasse and Duponteil (2014) modelled water markets within the irrigation sector in the Poitevin wetlands, in the context of a projected 55% decrease in water quotas. They find that groundwater markets could mitigate 0.5% of the 18% consecutive loss in gross margin. This limited impact is explained by the relative homogeneity of farming systems, the hypothesized ability of farmers to adapt their cropping patterns, but also by the modelling approach (monthly demand and the use of a mean farming profile that leads to a lower modelled heterogeneity among farmers' profiles, as compared to what could be witnessed in practice). They note, however, that achieving the same reduction in quotas using a pricing policy only (i.e. increasing the water price in order to decrease water consumption without allowing water transfers) would cause a higher loss in farm gross margin.

Another benefit from the use of water markets, raised during our interviews, would be that it could create an 'incited solidarity' between irrigators. In times of scarcity, irrigators might be incited to lend or transfer their water to others in need by the monetary compensation involved.

2.4.4. Impediments

Impediments identified to the use of water markets in the Poitevin Marsh Basin are first related to the French legislative framework. Currently, the annual water withdrawals authorizations granted by OUGCs are not transferrable, and it is illegal to sell them.

Another impediment is the absence of a permanent cap in the current water management plans. Allowing trade in absence of such a cap would expose the wetland to additional pressures related to water withdrawals, in a context where the reduction in water extractions planned by the previous water management plan (SDAGE) have not fully been realized, although our interviews suggest that 'sleeping' water rights are rare in the Basin. Besides, ground- and surface water resources are largely interconnected with and around the Poitevin Marsh: most water extractions occur in the Dogger groundwater aquifer, directly connected to the Marsh. Environmental externalities must thus be monitored closely.

A third category of impediments resides in the low social acceptability of water markets in the Poitevin Marsh Basin, identified both in the literature (Kervarec, 2014) and the semi-structured interviews conducted. The important difference between management principles applied to water markets and those applied to current water management in the Poitevin Marsh Basin, objections on ethical grounds, fear of monopoly and market power, the use of water policy as a more general management tool, concerns related to the concentration of water withdrawals near the Marsh and about a deteriorated image of irrigators that would result have been expressed by our interviewees. Thus, establishing water markets in the Poitevin Marsh Basin would require a deep change in paradigm associated to local attitudes towards water management.

3. The Neste system

3.1. Context: geography, water resources and hydrology

The Neste river Basin covers about 9000 km². It includes the Garonne left-bank tributaries (*Rivières de Gascogne*) as well as an upstream alpine sector (the natural Neste river). The natural Neste spreads into 2 deep valleys, through summits culminating at a 3000m elevation. The Neste river proceeds eastwards and flows into the Garonne river after a short distance.

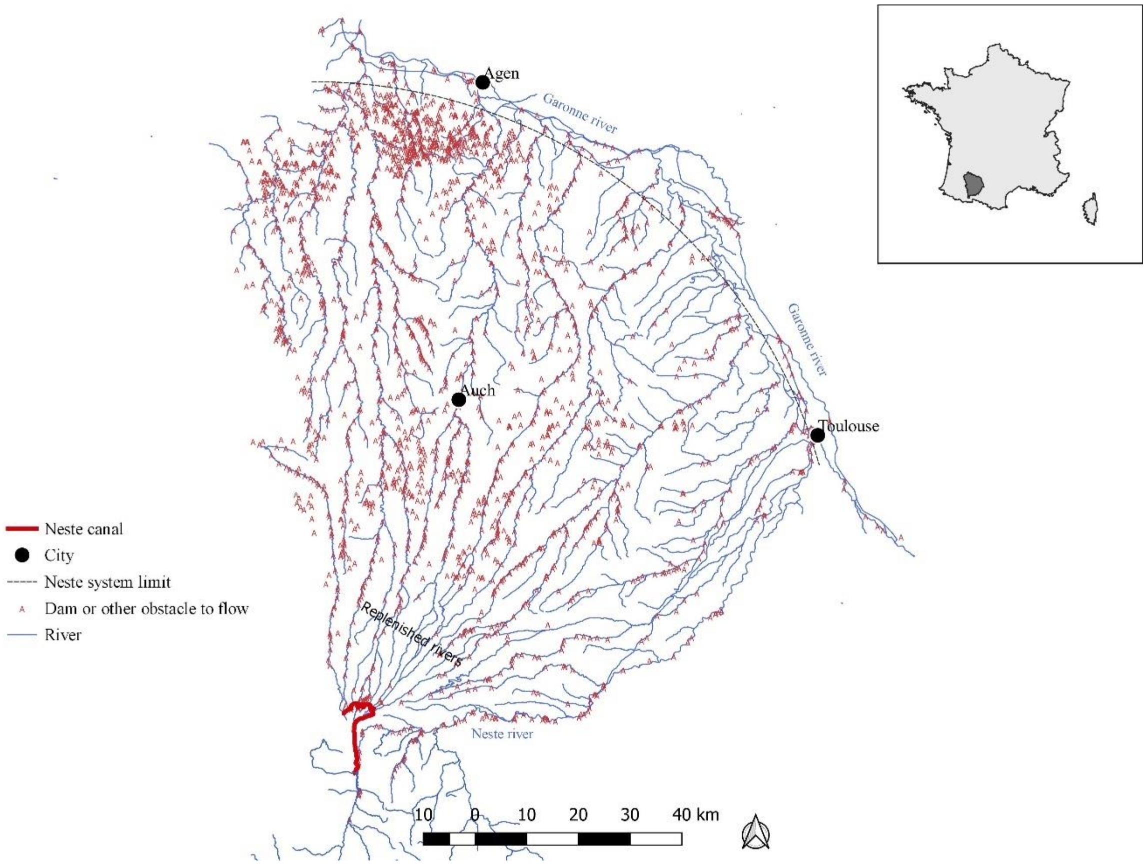
The Gascony rivers originate in the Piedmont plateaux. These plateaux are not supplied water from the Pyrenees mountains. These rivers are tributaries of the Garonne river, and previously follow a parallel route upstream of the confluence. Their catchments have very long shapes (50 to 150 km, for 500 to 1000 km² catchments' surface areas). The intense erosion of the Pyrenees mountains that ended in the early Quaternary period cut these rivers from their initial water supply.

The territory is located in South-Western France with a semi-oceanic climate. The average temperature is 13°C, and the winter is mild, although colder in the mountains (close to 0°C in the Pyrenean valleys in December and January). Annual rainfall is around 750mm and increases with altitude (more than 1000 mm in the Pyrenees). Rainfall is quite stable, ranging from 75mm (maximal, in December) to 50mm (minimal, in July). Beyond a 1500 m altitude, the snow cover is persisting during winter months (High Neste). Effective rainfall occurs between October and May and is close to 400mm in the south alpine sector, and 200mm in the north. In the last years, drought episodes have been common in the territory, with dry and hot summers.

The land around the Gascony rivers is mainly non-porous, including marl, clay (molasses) and sand and clay colluviums created by alteration of the molasses. The structure of this land, non-porous at its surface, explain the high density of the hydrographic network. It also explains the high variation in flows for the tributaries that are not supplied water by the Pyrenees mountains. These rivers show average specific flows (5 to 10 $l/s/km^2$) et minimum flows between 1 and 1.5 $l/s/km^2$. The natural Neste has a 30$l/s/km^2$ average flow regulated by snowmelt. The minimum annual flow occurs in January and is around 20$l/s/km^2$.

About 20 lakes have been established in the mountains, originally for hydroelectric purposes. They supply 48 Mm3 to irrigation water supply annually.

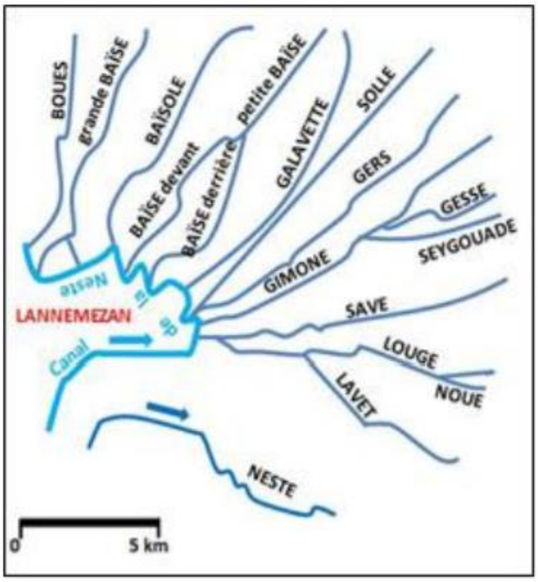
Figure 3: The Neste system and the Garonne river



Sources: GIS data layers from the CARTHAGE and SANDRE databases

The eastern proximity of a basin supplied water from the Pyrenees, the western existence of rivers with a very low water supply (especially in summer) and the absence of any significant groundwater aquifer explain the construction of the Neste canal in 1862, in order to develop irrigated agriculture in the region. Later, different dams were built in the piedmont sector, across the artificially replenished rivers, to guarantee a 73Mm3 annual water volume. In its upstream part, the canal is following the natural Neste. It then replenishes 17 rivers, through the use of channels cumulating 90km in length.

Figure 4: Schematic view of the Neste system



Source: Beaucoueste et al., 2001

Today, about 250 Mm^3 transit through the Neste canal annually (Ricart and Clarimont, 2017). The water is shared between environmental needs, drinking water uses for about 300 000 inhabitant (11Mm^3), the compensation of irrigation withdrawals (60 Mm^3) an industrial water use (6Mm^3). This water is also used to fill the piedmont dams during the spring.

A 4 m^3/s minimum flow requirement (MFR) has been defined downstream of the canal intake in the natural Neste river. Additional minimum flows are required downstream of the system, before the Garonne confluence. The Neste system is monitored in real time, through the use of performance indicators and regulatory requirements. A hydrological monitoring system has been established to these ends.

3.2. Current needs: Water management issues and users

3.2.1. Water use in the Neste system

Multiple water uses coexist in the system. These uses involve drinking water, irrigation, hydropower (mills and dams), industrial uses (including cooling of the Golfech nuclear power plant downstream of the system), navigation, and environmental uses (including dilution for water quality purposes). Other non-consumptive uses include fishing, hunting, and diverse recreational uses as kayaking. Irrigation represents the vast majority of water withdrawals from the Neste system. In 2009, annual irrigation water needs were estimated between 75 and 100 million cubic meters depending on climatic circumstances (Mm^3). Such needs are concentrated within the low-flow period, between June and September. Drinking water and other domestic uses, in comparison, represented about 6 Mm^3 of water withdrawals per year (Villocel et al., 2009), while industrial uses were relatively low (about 2 Mm^3).

3.2.2. Environmental water

About 70% of the annual 220 Mm3 transiting from the Neste canal and through the Neste system is environmental water, meant to ensure that flows in the system remain over the defined minimum flow requirements (MFR). MFRs have been included in water management plans since the 1996 Adour-Garonne Directing Scheme for Water Management (SDAGE). Originally, MFRs were designed for water quality purposes and have evolved towards “Flows above which the normal coexistence of all uses and the good functioning of the aquatic environment are guaranteed, and which must thus be secured every year during the low water period with defined tolerances” (Comité de Bassin Adour-Garonne, 1996). MFRs have played an important role in the local water politics. Notably, they have been associated with actors and discourses legitimizing the construction of new reservoirs in order to guarantee minimum flows, while ensuring other uses (including irrigation) were not impacted (Fernandez et al., 2014).

3.2.3. Quantitative issues: withdrawals in low-flow months

Water scarcity in the Neste system is generally occurring in two time periods. First, although the Neste canal delivers about 250 Mm^3 a year to the Neste system (Ricart and Clarimont, 2017), irrigation water use is concentrated on the French summer (June to September), where temperature and potential evapotranspiration are higher while rainfall is variable. Second, water in the Neste system depends on the amount of snow melting from the Pyrenees. Therefore, scarcity episodes can be experienced outside of irrigation withdrawal peaks in Winter (December, January, February) when lower amounts of water flow from the Pyrenees. These water scarcity episodes endanger the ability of the system's operator to satisfy the different consumptive uses in the system while respecting the Minimum Flow Requirements (MFR) as defined by the law, and therefore cause important management issues.

3.2.4. Water management in the Neste system: Stakeholders and governance

The applicable Master Plan for Water Resource Management (SDAGE) in the Neste system is the 2015 Adour-Garonne SDAGE. No local management plan (SAGE) has been defined as of 2019. Water management in the Neste system involves various actors and stakeholders. The Compagnie d'Aménagement des Coteaux de Gascogne (CACG) is in charge of managing river flows in the Neste System, by monitoring water diversions from the Neste river and operating the associated dams and reservoirs. The local OUGC is the Gers Agricultural Chamber, granting water extraction authorization (water rights) on an annual basis in collaboration with CACG. Electricité de France (EDF) oversees hydropower generation using the 48hm3 of water stored in dams upstream; in concertation with CACG, EDF can release water in summer in order to keep flow levels over the minimum flows (MFRs) during low-flow months based on a contractual relationship. Other stakeholders from the Neste system involve state representatives, rural community (irrigators) and civil society representatives. This latter category includes the local Fishing federation and environmental NGOs (ENGOs). A recent analysis of stakeholders' attitudes has been done by Ricard and Clarimont (2017). It reveals multiple references to a latent conflict between rural community and ENGOs. While rural community concerns focus on the future agricultural model in the Lannemezan plain, civil society attitudes reveal concerns about privatizing the water management model and critics of maize monoculture in the area. Public and private services tend to focus on the social recognition of irrigation as a tool to develop the territory, the effect of irrigation on environmental flows, and concerns about the aforementioned conflict.

3.3. Current framework: Legal responses, Legal framework, Local stakeholders involved (esp. irrigators) and current water management.

3.3.1. Irrigation water rights in the Neste system

Irrigation Water rights in the system are granted on an annual basis. A cap (*volume prélevable*) has been defined by the State authorities (*Préfet)* in 2012, as required by the 2006 water law. Water withdrawals in the Neste system are first defined by a pluriannual withdrawal authorization (AUP) defining the total volume of water rights allowed for several years, in accordance with the cap. The current AUP covers the years 2016 to 2021. Water rights are granted for two separate time periods within the year: the low-flow period (June 1st to October 31st), and the remaining water season (November 1st to May 31st). The current AUP defined a global irrigation water right of 126 Mm3 in the low flow period, and 16.4 Mm3 for the remaining season. An annual allocation plan (PAR) is then formulated in concertation with the various actors involved in the Neste system. This plan is then approved by the State representative (*Préfet*) and specifies all the granted irrigation water rights on an annual basis. An important principle in this perspective is the *droit acquis* principle: once a water right is granted, a water user cannot be denied this right (in the same conditions) in the following years, as long as the user pays the related fee. Water rights in the Neste system are bundled to land, and the land value generally doubles if a water right is attached to it.

Water rights and prices vary depending on the use considered. In all of France's ZREs, irrigation water rights are granted by a common management organism (OUGC). In the Neste system, this role is shared between CACG, in charge of the infrastructure, the operational monitoring and the delivery of the granted water rights, and the local agricultural representatives (Chambre d'agriculture du Gers). Each irrigator must apply for a water right each year. An irrigator is then granted a water right based on resource availability and the respect of prior water rights. Water demand in the Neste system is currently exceeding water supply. A waiting list has therefore been created and is updated each year. Each year, priority is granted first to irrigators who request a right allocated to them in the previous year (*droit acquis*), second to newcomers, and third to irrigators wishing the increase their allocated volume. Each irrigator then establishes a contract with CACG in order to have the water delivered.

3.3.2. Compliance and enforcement

CACG is monitoring water flows in the system on a permanent basis, in order to ensure the availability of water to match individual water rights based on irrigators' declared water needs. Withdrawals from the Neste river and dam releases upstream of the system are used in order to manage flows in the system and match the allocated water rights. In this perspective, water use in the Neste system is fully metered. In order to control for unauthorized uses, CACG is conducting controls every year during summer months. Irrigators have strong incentives to use water as defined by their water right: in case water extractions exceeding the water right, CACG applies a tariff 4 to 11 times higher for the additional water used. Fines related to unauthorized water use can also be applied.

3.3.3. Functional arrangements allocating water between different uses

As described in section 2A/, irrigation is the main consumptive water use in the Neste system (75 to 100 Mm3), whereas drinking water (6Mm3) and industry (2Mm3) are limited. Irrigation water rights are jointly requested by the unique collective management organism (OUGC) in the name of all irrigators, in conformity with the pluriannual withdrawal authorization (AUP) and the cap. It is validated each year by the State representative (*Préfet*). A convention has been established between hydropower use for the dams and reservoirs located upstream of the Neste system, where the hydropower operator can release water during low-flow periods but outside demand peaks for electricity, including a financial compensation for the loss incurred by the company (Fernandez, 2014). Irrigation water rights costs remain the same throughout the system. However, access to water for other uses (such as industrial water use) have different prices as defined by the law. Specific minimum flows have been designed within the Neste system in this perspective.

3.3.4. Crisis management in the low flow months and Risk assignment

Scarcity episodes in the Neste system mainly occur between June and September, when most irrigation withdrawals occur. When flows decrease beyond a specific threshold in the system, the Neste Commission is required to meet. This Commission, originally created by CACG in the 1990s, gathers representatives from the different stakeholders in the System: State representatives, elected officials, and civil society stakeholders. Typical water management measures taken by the Neste Commission can include volumetric restrictions (decrease in water quotas) or additional time constraints on irrigation practices. The risk assignment varies according to the type of water used considered. As a higher priority is granted to drinking water use and some industrial water uses, they remain unaffected by scarcity management. Management measures thus adjust irrigation water rights and environmental flows objectives (MFRs or their respective tolerances) in order to cope with scarcity conditions. Decisions at the Neste Commission are taken based on a consensus between all participants. If, in spite of the management measures decided at the Neste Commission, flows decrease further down past a defined Crisis Flow (*Débit de crise, DCR*) then the State is taking over and a ban on all irrigation withdrawals can be decided and announced by a specific legislation (*arrêté-cadre sécheresse*).

3.4. Water markets in the Neste system: Potential benefits, impediments and implementation

3.4.1. Water demand and diverse value-added uses

Water demand in the system is higher than the available water supply: unfulfilled requests for irrigation water are gathered in a waiting list associated to irrigation water rights. In our opinion, the main potential benefit of establishing water markets in the Neste system would be to fluidify the waiting list, allowing irrigators to buy water rights. It has to be noted that the number of irrigators figuring in this list has been decreasing in the recent years; additional research is needed to understand this evolution.

No study has been published on the potential economic benefits arising from the use of water markets and their related gains from trade in the Neste system. Additional research on functioning water markets would be required in this perspective.

Besides, as extractions within the Neste system are compensated by water releases upstream and monitored in real time by CACG, the potential environmental externalities arising from water transfers are limited. Although significant environmental flows are needed upstream in order to maintain the existing ecosystem, such externalities could be compensated by the flow control operated by CACG as long as the cap on total water extractions is enforced. The significant amount of infrastructure in place would facilitate water transfer in the context of a water market, considerably limiting transaction costs.

3.4.2. Impediments

However, significant impediments exist to the establishment of water markets in the Neste system. First, as already mentioned, it is illegal in France to sell or transfer water rights (annual withdrawals authorizations) on an individual basis. Second, water rights in the Neste system are bundled to land: when agricultural land is sold, the corresponding water right is sold with it. This is closely related to the *droit acquis* principle: an irrigator owning a water right cannot currently be denied the same right in the next year. Abandoning this principle would expose farmers to a loss of prior investments, as the price of land doubles when associated with an irrigation water right. Third, the main impediment to the establishment of water markets in the Neste river system is the strong cultural and political opposition to the use of markets to manage water resources. Already shown by the scarce literature dedicated to water markets in France (Rinaudo et al., 2012; 2014; 2016; Figureau et al., 2015), this trend also appears in the semi-structured interviews realized. While some interviewees consider that potential gains from trade do exist, they are also worrying about the redistributive effects of such policies and do not support the idea of establishing water markets in the Neste system. Water markets are alternatively perceived as endangering the ability to use water policy as a tool for climate change adaptation, favouring farmers that are financially at ease while hurting irrigators that are already in a worrying financial situation, and representing a political choice hurting interviewees on ethical grounds.

4. Conclusion

This study applied the WMRA framework (Wheeler et al., 2017) to two case studies in France: the Poitevin Marsh Basin and the Neste system. An overview of the assessment provided in both cases can be found in Appendix 5.

Water management in France is currently not designed for water markets. It is illegal to buy, sell, and (in most cases) transfer water extraction authorisations and no significant interest has been expressed by the French authorities towards the use of market mechanisms applied to water rights. In practice, water rights are still bundled to land, and the value of water rights is partly reflected in the increased value of land when a water right has been attached to it. A cap has been defined in most basins, but in some cases (including the Poitevin Marsh Basin) it has not been implemented as of 2019.

The 2006 Water law recently established the basis of a water demand management through the establishment of a cap and the use of common organisms (OUGC) to allocate irrigation water rights. Granting OUGCs with more flexibility to allocate water rights and facilitate water transfers based on collectively established rules and considering the use of markets might be of interest.

Within the Poitevin Marsh Basin, important reductions in the volume of water quotas granted annually will necessarily be implemented in the coming years. Such a reduction, required by the cap recommended by the 2006 water law, has been occurring in some parts of the basin in association with the construction of substitution reservoirs. This policy, however, has generated significant political backlash in the southern part of the basin, showing a low social acceptability. In the perspective of additional reductions in water use due to climate change or future SDAGE requirements, markets could be considered as a tool to limit the resulting economic losses. In this perspective, additional research quantifying the potential related economic benefits in the context of existing water markets would be highly relevant to inform the debate.

In the Neste system, a cap is already in place and enforced. However, as the demand is currently greater than supply in water rights, a waiting list has been created. Due to the *droit acquis* principle, once an irrigator is granted an annual water right, he cannot be denied water rights in the following years as long as he fulfils the corresponding contractual obligations. As a result, some actors are currently excluded from access to water. As climate change is expected to further reduce average and minimum flows in the area (CBAG, 2017), additional means of demand management and flexibility would be of interest. Water markets could be considered in this perspective.

However, significant impediments have been identified to the use of water markets in our case studies. The Poitevin wetland is highly sensitive to water extractions and the most part of the basin is hydrologically connected. Therefore, externalities arising from water transfers would need to be closely monitored. In the Neste system, implementing water markets would require abandoning the *droit acquis* principle, thereby exposing irrigators to important losses in capital investment as the value of their land would drop. Finally, the most important impediment is the very low social acceptability of water markets in France. Concerns and opposition to the use of water market mechanisms applied to water resources (redistributive effects, ethics and water as a common good, fear of monopoly power…) have been expressed across our interviews and clearly described by the literature. The French water management is defined in a common patrimony perspective (Calvo-Mendieta et al., 2017) that seems hardly compatible with the institutional changes required to establish water markets. In this perspective, it seems to us that implementing water markets in France would require considerable change in the local paradigms of water management, in a context where the existing frameworks are already subjected to significant political debate.

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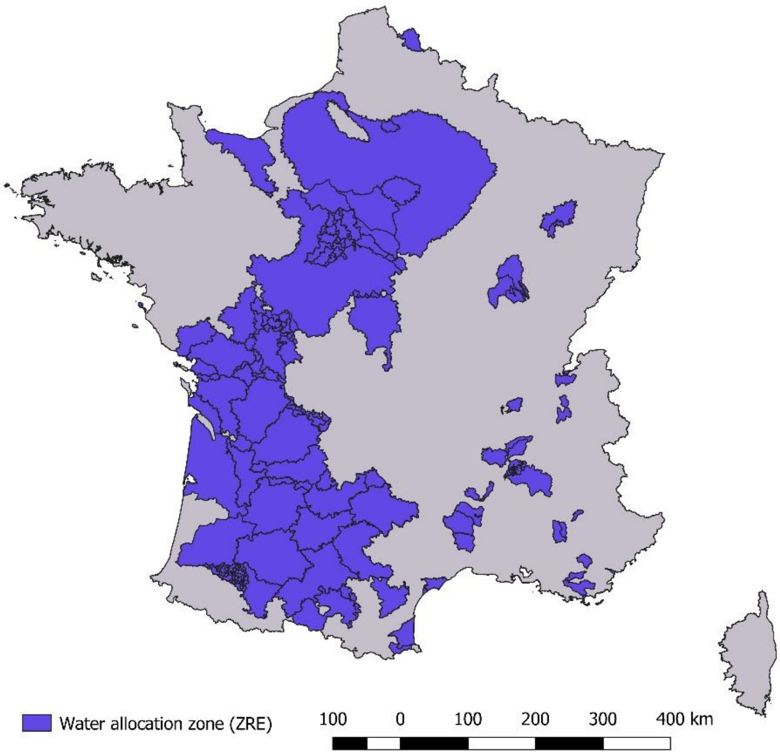
6. Appendix 1: Acronyms and definitions

Acronym	French initial component	Definition
AUP:	Autorisation Unique de Prélèvement	Pluriannual water withdrawal authorization granted by the local State authority (*Préfet*) to an OUGC, defining the volume of irrigation water to be extracted each year for a specific time period
CACG:	Compagnie d'Aménagement des Coteaux de Gascogne	Company in charge of monitoring water flows in the Neste system. CACG is also managing water stored in the Poitevin Marsh Basin's Substitution reservoirs.
CLE:	Commission Locale de l'Eau	Local Water Commission. It gathers local water stakeholders (State representatives, local government representatives, and civil society stakeholders). In charge of the SAGE elaboration, it acts as a local water parliament.
EPMP:	Etablissement Public du Marais Poitevin	State institution coordinating the various actors and stakeholders in the Poitevin Marsh Basin. It is also collaborating with local Agricultural Chambers to attribute water extraction authorizations each year.
OUGC:	Organisme Unique de Gestion Collective	Institution in charge of allocating annual irrigation water rights according to the 2006 Water Law.
SAGE:	Schéma d'Aménagement et de Gestion des Eaux	Local Plan for Water Resource Management establishing water management objectives at the local level, in accordance with the Basin's SDAGE. It is elaborated by the local CLEs.
SDAGE:	Schéma Directeur d'Aménagement et de Gestion des Eaux	Master Plan for Water Resource Management establishing water management objectives at the 7 French Basins level. I
ZRE:	Zone de Répartition des Eaux	Zone of Water Allocation. Defined as an area where the imbalance between water demand and supply occurs frequently by the 2006 Water Law.

7. Appendix 2: French Zones of Water Allocation (ZRE)



Source: SANDRE GIS database

8. Appendix 3: The 7 French Basins

Basin	Size (km²)	Main river	Mean Population density (hab/km²)
Loire-Bretagne	155 000	Loire	83
Seine-Normandie	95 000	Seine	192.6
Rhin-Meuse	31 400	Rhin	136.9
Artois-Picardie	20 000	Escaut	238
Adour-Garonne	117 650	Garonne	59.5
Rhône Méditerranée	130 000	Rhône	116
Corse	8700	-	32

Sources: French basin authorities

9. Appendix 4: Semi-structured interviews

Type of actor	**Institution or Company**	**Interviews**	**Interviewees involved**
State representatives	Etablissement public du Marais Poitevin (EPMP)	1	2
Local Government institutions	Syndicat mixte du Lay	1	1
	Syndicat mixte Vendée Sèvre Autizes	1	1
	Institution Interdépartementale du Bassin de la Sèvre Niortaise (IIBSN)	1	1
Civil society representatives	Chambre d'Agriculture des Deux-Sèvres	1	2
	Chambre d'Agriculture du Gers	1	1
	France Nature Environnement (FNE) Deux-Sèvres	1	1
	Fédération de pêche Midi-Pyrénées	1	1
Private sector	Compagnie d'Aménagement des Coteaux de Gascogne (CACG)	3	3

10. Appendix 5: Overview of the WMRA assessment in our case studies

Key fundamental market assessors	**Poitevin Marsh Basin**	**Neste System**
Property rights/Institution		
1. Water legislation	V	V
2. Unbundled rights	X	X
3. Rights transferrable	X	X
4. Rights enforceable	v	V
5. Constraints between connected systems	V	X
Hydrology		
1. Documented Hydrology System	V	V
2. Understanding of connected systems	v	V
3. Future impacts modelled	v	V
4. Trade impacts understood	X	X
5. Resource constraints enforced (cap)	X	V
Externalities /Governance		
1. Strong governance impartiality	?	?
2. Existence of externalities understood	V	V
3. Water-use monitored	v	V
4. Water-use enforced	v	V
System type		
1. Suitability of water sources for trade	V	V
2. Transfer infrastructure availability/suitability	V	V
3. Regulation requirements for trade	X	V
Adjustments		
1. Gains from trade (No of users, TC, diversity of use)	X	V
2. Political acceptability of trade	X	X
Entitlement registers and accounting		
1. Trustworthy systems	V	V
2. Trade and market information availability	X	X
TRADE STEP REACHED	Step One	Step One

Note: V suggests there is good evidence to support that part of the assessment; a smaller v indicates a positive but still limited evidence, and thus room for improvement; X indicates that the condition is not fulfilled.

General Conclusion

Water markets have emerged as economic tools to deal with water scarcity in various economic and cultural contexts. By reallocating water resources towards more productive activities, they can foster an increased efficiency of water use.

The first chapter of this thesis attempts to measure this potential impact at the aggregated regional level in Australia, where water markets have been in place for more than 20 years. We compare areas with and without water markets, with various degrees of water trade intensity. Results from our stochastic frontier modelling suggest that water markets are associated with a higher efficiency of agricultural production, although the size of this impact does not increase with water trade intensity.

Chapter two and three focus on two potential problems associated with the use of water markets in practice. Chapter two questions the existence of insider trading practices, a well-known market manipulation in the financial markets literature. We investigate the occurrence of insider trading behaviour by analysing price movements around important market announcements within the Murray-Darling Basin water markets, in Australia. We find evidence of informed price movements (i.e. consistent with the content of the announcement to be made) in the 5 to 10 days before announcements before 2014, when insider trading regulations were put in place. After 2014, we detect weak evidence of informed price movements. Such movements could be attributed to insider trading practices, or to an increased sophistication of water trade leading to rational speculation behaviour.

Chapter three questions the dynamics of groundwater trade in the Murrumbidgee, where surface water is also available and tradeable. We find that surface water trade significantly influenced groundwater trade, with evidence of a lead-lag relationship. In other words, market sensitive information is first reflected in the surface water price, and then transmitted to the groundwater price. In this context, groundwater temporary market demand in the Murrumbidgee is found unitary elastic: in our period of study, a 1% increase in the water price is associated with a 1.05% decrease in groundwater demand, a relatively high estimate compared to the literature. Therefore, any policy increasing the water price should reduce groundwater demand in the Murrumbidgee.

Chapter four questions the transferability of water markets systems to the Poitevin Marsh Basin and the Neste system, in France. In each case, we present the geographic and hydrological context, the current water management needs, the framework currently in place to address those needs and the benefits and impediments identified to the use of water markets. Overall, the current French water management system is not designed for the use of water markets. Nevertheless, important potential benefits are identified in both cases, in relation to the necessary transition towards higher-valued irrigation uses in a context of summer overconsumption and environmental flow requirements. However, significant barriers remain to the use of water markets in France, including legal barriers and a very low social acceptability of markets applied to water management in France.

Four years of research dedicated to water markets highlight five important remarks. First, there are important prerequisites in order for water markets to provide economic benefits. Examples include (but are not limited to): a clearly defined and enforced cap (i.e. a maximal defined amount of water rights); strong supporting institutions providing market information and ensuring the enforcement and monitoring of water use rights; and a large, hydrologically interconnected area implying a sufficiently diverse demand for water. Failure to comply with these prerequisites can generate important damage to the environment through water overuse or prevent markets to generate efficiency gains.

Second, water markets are no self-sufficient tools. When water markets are chosen as potential water management mechanisms, they should be used alongside other tools in order to deal with the diverse challenges raised by water resources management. In an environmental perspective, for example, restoring environmental flows has been attempted through a federal program aiming to buy water rights from irrigators in the Australian case. Environmental regulations are additional tools that might be required to manage challenges as salinity, water quality or environmental flows.

Third, one consequence of our previous point is that water markets do not imply no intervention from the regulator. The water authorities have a crucial role to play within water markets. Enforcing water rights, continuously looking for and monitoring the potential externalities, providing market information, avoiding asymmetrical information, and ensuring that no market power emerges represent as many important tasks fulfilled by the regulator.

Fourth, water markets are embedded in a social, political, and cultural framework. Therefore, they have been designed in practice in many different ways, reflecting different contexts. Cultural preferences such as values and ethical positioning can affect water markets when they are established or considered. This is supported by the recent evidence of an important social pressure among Australian irrigators not to sell permanent water rights of an area, or by the very low social acceptability of water markets in the French context.

Fifth and finally, in a policy perspective, analysing the costs and benefits of water markets should be done in comparison to other feasible alternatives in terms of water resource management. Where water markets might be deemed unsuitable to manage water resources and scarcity, the identified benefits to their use – their ability to reallocate water towards higher-valued agricultural uses, for example – might nevertheless inspire the design of policies based on a different framework. In this sense, empirical studies detailing the benefits obtained through the use of different water management mechanisms and attempting to compare provides an interesting research perspective in relation to water markets.

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Simon de Bonviller

Empirical Essays on Water markets

École Doctorale Augustin Cournot

Résumé

Cette thèse porte sur les marchés de droits d'eau, des systèmes permettant l'achat, la vente ou le prêt de droits d'eau selon diverses modalités. L'objectif de la thèse est de contribuer à la connaissance empirique de ces systèmes, présentés par la littérature comme des outils de gestion de la rareté de l'eau permettant une réallocation des ressources en eau vers des usages plus créateurs de valeur.

Les chapitres 1 questionne l'impact de l'existence d'un marché de droit d'eau et de l'intensité des transactions sur l'efficience technique dans l'agriculture Australienne.

Les chapitres 2 et 3 sont consacrés à deux sources de dysfonctionnements potentiels liés à l'usage de marchés de droits d'eau en pratique : les délits d'initiés, et les interactions entre eaux de surface et eau souterraine en présence du marché.

Le Chapitre 4, finalement, questionne la transférabilité des marchés de droits d'eau à deux cas d'étude en France : le bassin du Marais Poitevin, et le système Neste.

English Summary

This PhD focuses on water markets. Such systems involve the ability to buy, sell or lease water use rights under different modalities. The main objective of this thesis is to contribute to the empirical knowledge on water markets, described in the literature as tools to manage water scarcity by reallocating water resources towards higher valued uses.

Chapter 1 is dedicated to the economic impacts of water markets and questions the link between the existence of a water market, the intensity of water trade and technical efficiency in the agricultural sector.

Chapters 2 and 3 focus on two potential problems arising with the use of water markets: insider trading, et interactions between surface water and groundwater in presence of a market.

Finally, Chapter 4 questions the transposability of water markets to two case studies in France: the Poitevin Wetlands Basin and the Neste system.