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► **To cite this version:**

Shan Roux Hu. The social value of information in the delegation of local public services. Economics and Finance. Université Bourgogne Franche-Comté, 2021. English. NNT : 2021UBFCB001 . tel-03359254

HAL Id: tel-03359254

<https://theses.hal.science/tel-03359254>

Submitted on 30 Sep 2021

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**THESE DE DOCTORAT DE L'ETABLISSEMENT UNIVERSITE BOURGOGNE FRANCHE-COMTE
PREPAREE A L'UNIVERSITE DE FRANCHE-COMTE**

Ecole doctorale n°593

Ecole Doctorale Droit, Gestion, Sciences Economiques et Politiques (DGEP)

Doctorat en Sciences Economiques

Par

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Sous la Direction de Monsieur J. C. El Naboulsi

The Social Value of Information in the Delegation of Local Public Services

Thèse présentée et soutenue publiquement le 28 janvier 2021 à Besançon.

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Titre : LA VALEUR SOCIALE DE LA DIVULGATION D'INFORMATION DANS LA DÉLÉGATION DES SERVICES PUBLICS D'EAU

Mots clés : Divulgence de l'information, délégation, précision des informations publiques et privées, La concurrence par comparaison

Résumé : Dans cette thèse, nous recherchons des solutions permettant à une collectivité locale d'améliorer la transparence et la gouvernance dans la gestion déléguée de ses services publics à caractère industriel et commercial, e.g., la distribution de l'eau et l'assainissement. Sur la base de la littérature théorique et expérimentale portant sur la valeur sociale de l'information, nous analysons le rôle que peut jouer l'information publique dans la définition des conventions de délégation des services. Nous soulignons qu'une autorité publique locale peut utiliser l'information disponible afin d'inciter les opérateurs à révéler certaines informations privées dont ils disposent. Par ailleurs, nous montrons que l'information publique peut aider les autorités locales à coordonner les décisions stratégiques des opérateurs en vue d'améliorer la qualité des infrastructures. Ensuite, nous analysons le rôle déterminant de la précision de l'information dans la définition des schémas contractuels.

En comparant la précision de l'information publique à celle de l'information privée au stade de la négociation, nous déterminons le seuil de l'information publique permettant à une collectivité de choisir le mode de gestion le plus approprié. En outre, comme la pression concurrentielle entre opérateurs potentiels souhaitant remporter le contrat de délégation génère des croyances trompeuses sur la qualité des infrastructures, nous montrons que toute augmentation de la précision limite ces croyances et réduit les rentes informationnelles cédées à un opérateur. Enfin, dans la phase de sélection, nous combinons l'information publique à la concurrence par comparaison. Nous montrons que, pour un niveau donné de précision de l'information privée, la diffusion de l'information améliore l'efficacité de ce schéma de régulation.

Title : THE SOCIAL VALUE OF INFORMATION DISCLOSURE IN THE DELEGATION OF PUBLIC WATER SERVICES

Keywords : Information Disclosure, Delegation, Precision of public and private information, Yardstick Competition

Abstract: In this thesis, we are looking for solutions enabling a local authority to improve transparency and governance in the delegated management of its services, e.g., water and sanitation services. Based on the theoretical and experimental literature on the social value of information, we analyze the role that public information can play in defining delegation agreements. We point out that a local authority can use the available information to induce operators to reveal privately-held information. Furthermore, we show that public information can help local authorities to coordinate operators' strategic decisions to improve infrastructure quality. Then, we analyze the decisive role of information precision in the definition of contractual schemes.

By comparing the precision of public information with that of private information at the negotiation stage, we determine the threshold of public information enabling a local authority to choose the most appropriate management contract. Furthermore, as competition between potential operators wishing to win the delegation contract generates misleading beliefs about the quality of the infrastructure, we show that any increase in information precision limits these beliefs and reduces the informational rents a local authority may concede to an operator. Finally, in the selection phase, we combine information disclosure with the well-known Yardstick Competition regulatory process. We show that, for a given level of precision of privately-held information, disclosure enhances the efficiency of this regulatory scheme.

ACKNOWLEDGEMENTS

The preparation of a Ph.D. dissertation is a hard experience for me. Without the help and encouragement of numerous people around me, I could not have accomplished this task. I take advantage of this page to express my considerable gratitude to all of them.

First and foremost, I am greatly indebted to my supervisor, Professor Yolande Hiriart. Before the start of the Ph.D. dissertation, she made me love the economic science, in particular, the new regulation and made me gain confidence in my ability to undertake such work. I spent seven-years happy times on working with her. Without her patience, guidance and support, none of this would have been possible. Her careful and valuable readings, discussions criticisms and encouragements have been most precious in widening my perspective, and have contributed substantially to most of the work done in this dissertation. I can always feel her words and smiles in every line when writing my dissertation.

I feel really grateful to my second supervisor, Jihad El Naboulsi. He greatly helped me to continue to accomplish the dissertation. His precise readings, criticisms, his expertise discussions on environmental regulation and information disclosure have contributed considerably to all of works in this dissertation. I learned a lot by working with him. His encouragements helped me to keep having confidence on myself when I have been lost on my road for a long time. He has also greatly helped me by being my co-author in one paper that has served as a basis for my discussion in this dissertation. I really hope that our collaboration will be fruitful in the future.

I am also indebted to the head of CRESE, Professor Sylvain Béal. Without his careful and encouragements, I can not have opportunities to present my articles in different academic conferences and seminars. I can not forget all joys shared with him when we were eating together with others professors at every noon in CRESE. I thank him for his

presence, support and suggestions.

I am also very grateful to Professor Lionel Thomas, Professor Julie Le Gallo and Marie-Line Duboz-Janand. Without their supports and trusts, I can not have opportunity to be a member of CRESE. Other colleagues in CRESE have also offered many enlightening thoughts and discussions that have proved to be highly useful to my work: Christian At, François Cochard, Karine Brisset-Mertz, Marc Deschamps, Yves Oytana, Sandrine Ollier, Fabien Labondance, Julie Beugnot, Florence Naegelen Mougeot and Rosalind Bell-Aldegui. I would like to thank them for their time and effort, and for the moral support that they have provided to me throughout the years.

Last, but not least, I would like to thank Jean-Philippe Roux that shares my joys, doubts and sorrows during my years as a PhD student. His daily kind gestures and his unconditional support are precious sources of motivation. I thank him for his love and patience. I would like to thank Paul-Alexandre Roux that always ate pizza and fast-food when his mother hasn't had time to cook at home. This work is also dedicated to them.

Without all these people, this work would not have been possible.

To Madame Hiriart:

To see a world in a grain of sand,

And a heaven in a wild flower.

Hold infinity in the palm of your hand,

And eternity in an hour.

— *William Blake*

Le manque de transparence dans la régulation des services publics locaux français est signalé par la Commission européenne depuis les années 1990. Conformément aux demandes de la Commission européenne, la France a adopté deux lois, la loi Sapin (1993)¹ et la loi Barnier (1995), afin d'améliorer la transparence des informations lors du processus de délégation des services publics locaux.

L'amélioration de la transparence passe notamment par l'accès à plus d'information pour les différents acteurs et une réduction des asymétries d'information entre les autorités et opérateurs privés. Depuis les années 80, les économistes s'intéressent à ces questions. Ils montrent que la transparence des marchés publics peut être améliorée par la révélation d'informations privées. En revanche, une telle révélation est coûteuse en raison du fait qu'elle alourdit les contraintes budgétaires des pouvoirs publics locaux. En effet, l'objectif de ces mécanismes est d'obtenir une plus grande efficacité et des gains d'un opérateur privé (Baron and Myerson, 1982 ; Laffont and Tirole, 1993). Cependant, pour un contrat à long terme, la révélation des informations privées n'est pas toujours efficace. En d'autres termes, il y aura une incertitude dans l'exécution du contrat. Il est préférable de divulguer des informations sur les performances de tout opérateur privé pendant la durée du contrat. Une question majeure sur laquelle cette thèse se concentre donc : plus d'accès à des informations publiques permet-il aux opérateurs potentiels de concurrencer l'opérateur existant, l'opérateur historique, pour la gestion des services publics ?

L'objectif de cette thèse est donc d'étudier le rôle que peut jouer la précision des informations publiques dans la délégation des services publics locaux, à savoir ses effets sur les choix du mode de gestion et les déterminations des contrats de délégation. Nous prenons aussi en compte les impacts des informations publiques sur le mécanisme de concurrence par comparaison qui peut être appliqué par les autorités locales dans le processus de délégation.

En s'inspirant des travaux de Hayek (1945) qui ont conçu les marchés comme des systèmes d'information dans lesquels tous les agents économiques signalent leurs souhaits, Akerlof (1970), Spence (1973) et Stiglitz (1975) établissaient des outils théoriques permettant d'analyser les asymétries d'information sur les marchés. Mais, leurs travaux se sont uniquement concentrés sur l'accès à des informations privées. Par exemple, les travaux d'Akerlof (1970) soulignent implicitement que les informations obligatoirement

1. La loi Sapin II est entrée en vigueur en juin 2017 : la loi n°2016-1691 vise à renforcer les régimes français de lutte contre la corruption pour accroître la transparence.

divulguées concernant les contrôles techniques des véhicules sont essentielles pour les acheteurs potentiels. De même, Spence (1973) montre que les travailleurs doivent signaler leurs capacités aux employeurs par le biais de qualifications publiques. Ces analyses mettent en avant les idées que si les marchés sont des systèmes de traitement de l'information, les asymétries d'information empêchent les marchés de fonctionner efficacement. Par conséquent, des politiques de divulgation sont nécessaires pour rendre les informations accessibles à tous les agents économiques sur les marchés. Plus récemment, la divulgation obligatoire a été adoptée comme approche réglementaire pour traiter des problèmes sociaux tels que l'impact environnemental des produits, qui doivent être étiquetés sur la consommation d'énergie ou l'émission de carbone.

La prise en compte des informations publiquement divulguées ne doit pas amener à négliger les réactions qu'elle engendre chez les agents économiques. Parfois, ces réactions sont tellement excessives qu'elles empêchent d'atteindre l'efficacité sociale souhaitée. Premièrement, comme le soulignent Grossman and Stiglitz (1980), certains agents économiques paient pour obtenir des informations afin d'améliorer la qualité des décisions, ce qui à son tour a une incidence sur les prix du marché. Mais d'autres agents économiques peuvent se comporter en "passagers clandestins" : ils obtiennent des informations complémentaires après avoir observé les prix du marché sans payer pour de telles informations. Si tous les agents économiques adoptent la même stratégie et se comportent de la même manière, alors l'équilibre des marchés financiers s'effondre. Deuxièmement, Morris and Shin (2002) montrent que les agents économiques peuvent réagir de manière excessive aux annonces publiques bruyantes des banques centrales. Il y a des effets dits "concours de beauté" qui sont préjudiciables au bien-être social. Ils prouvent qu'une réaction excessive peut être limitée en divulguant moins d'informations.

Ces questions deviennent essentielles lorsque des informations divulguées publiquement sont utilisées pour améliorer la transparence, il en va de même pour la performance des réseaux des services publics. Une dimension importante de l'industrie de l'eau est sa nature monopolistique. La production et la distribution de l'eau nécessitent de lourds investissements irrécupérables dans les infrastructures pour être fonctionnelles. Par conséquent, au lieu d'avoir plusieurs opérateurs concurrents sur le marché public, l'industrie de l'eau a toujours un opérateur unique (public ou privé) fournissant des services publics pour satisfaire une demande de biens de première nécessité. Ainsi, un problème vient du fait que l'opérateur unique dispose d'informations précises sur le niveau de qualité des infrastructures, puisque la distribution de l'eau est entièrement souterraine. Si l'opérateur souhaite conserver ses pouvoirs de monopole de gestion de service, il peut empêcher les autres opérateurs potentiels de connaître précisément la qualité de l'infrastructure. Mais, cela n'est pas le cas des réseaux ferroviaires et autoroutiers, ni des réseaux électriques

même si 40% des lignes électriques sont enterrées. Par exemple, l'écart entre la qualité réelle et la qualité mesurée (par exemple, le rapport entre le volume de fuites d'eau et le volume de distribution d'eau) est largement observé par les études théoriques et empiriques. Ceci implique une augmentation continue des prix de l'eau alors que la satisfaction des autorités locales et des consommateurs diminue. Cet écart peut être réduit en améliorant la transparence dans le processus de sous-traitance des services publics. À cette fin, on peut envisager la divulgation d'informations sur les spécifications du service au début du processus de délégation. Plus précisément, la divulgation d'informations va contribuer à réduire les asymétries d'information entre l'autorité locale et les opérateurs potentiels et, entre les opérateurs eux-mêmes.

La divulgation d'informations dans le secteur de l'eau peut être de trois types : l'accès à l'information, la divulgation forcée ou obligatoire et le partage de données. L'accès à l'information signifie simplement que les documents et registres utilisés dans la gestion des services de l'eau sont rendus publics par un conseil consultatif d'utilisateurs des services publics locaux, la participation d'organisations de la société civile ou des lanceurs d'alerte.² La divulgation forcée ou obligatoire est une approche réglementaire qui oblige l'agent à fournir des informations dont un autre agent a besoin pour prendre de meilleures décisions. Les programmes de diffusion de l'information évoquent incontestablement un phénomène pratique : dans la vie de tous les jours, les agents rencontrent des problèmes qui sont souvent complexes et sur lesquels ils en savent très peu et doivent prendre des décisions en incertain. De tels programmes reposent sur l'hypothèse simple selon laquelle, lorsqu'il s'agit de prendre des décisions, il vaut mieux plus d'informations que moins. Par conséquent, la divulgation aide à restaurer un certain contrôle individuel et peut également inciter les agents à se comporter plus efficacement. Dans le secteur de l'eau, par exemple, les exigences obligatoires couvrent les comptes financiers ou encore les spécifications techniques utilisées pour la fourniture des services de l'eau.³ Une telle divulgation obligatoire informe les opérateurs participant au processus de délégation et permet une négociation efficace entre l'assemblée délibérante de l'autorité organisatrice et les gagnants potentiels. Le partage de données est la possibilité pour les autorités locales de partager les données sous-jacentes et les méthodes utilisées pour soutenir les services publics de l'eau.⁴ Le partage des données permet à tous les agents économiques de comparer les performances des services d'eau fournis par les opérateurs réels (publics ou privés) avant le processus de délégation. La précision de l'information publique in-

2. Par exemple, dans l'industrie française de l'eau, cela peut être réalisé par la Commission consultative des services publics locaux (CCSPL).

3. La loi française 2006-1772 du 30 décembre 2006, "L'eau et les milieux aquatiques" ; Loi n°2015-991 du 7 août 2015 "Nouvelle Organisation Territoriale de la République".

4. Par exemple, OPEN DATA est un logiciel qui collecte tous les prix, volumes de distribution d'eau de chaque commune de France. Disponible en ligne sur "services.eaufrance.fr".

fluence à la fois la décision de la collectivité locale et les interactions stratégiques entre les opérateurs au cours de deux étapes : la phase de négociation et la phase de sélection. Dans les deux paragraphes suivants, nous présentons successivement ces deux étapes.

Si l'autorité locale veut déléguer la gestion des réseaux de distribution d'eau, le mécanisme de sélection d'un opérateur potentiel se déroule en deux étapes. Dans la première étape, l'autorité locale choisit un certain nombre de candidats potentiels en utilisant un processus d'appel d'offres restreint. Dans la deuxième étape, il y a une phase de négociation entre l'autorité locale et les opérateurs pré-sélectionnés. À la fin de la négociation, l'autorité locale choisit son opérateur final pour la durée du contrat si elle estime que la délégation surpasse la gestion publique pour améliorer la qualité de l'infrastructure. Sinon, l'autorité locale préfère conserver sa gestion publique des réseaux de distribution d'eau.

Durant la phase de négociation, une autorité locale négocie les termes contractuelles avec les opérateurs potentiels et décide de déléguer ou non le service en fonction du type d'opérateur. Cependant, les performances de l'opérateur potentiel ne sont pas disponibles pour toutes les parties. Il est bien connu aujourd'hui qu'un mécanisme de révélation classique peut être conçu et incite donc fortement les entreprises à révéler honnêtement leurs informations privées, ce qui donne un résultat socialement efficace. Mais, pour diverses raisons, certains mécanismes qui fonctionnent en théorie peuvent s'avérer compliqués à mettre en œuvre dans la pratique et ne sont pas suffisants pour traiter certains aspects des problèmes de passation de marchés. En outre, le système de réglementation reste surchargé par le grand nombre d'asymétries, d'incertitudes et d'évènements politiques. De plus, la délégation des services d'eau est un accord à long terme : la durée du contrat est trop longue. Cela implique qu'une renégociation sera anticipée dans certains cas. La renégociation du contrat peut être autorisée lorsque l'environnement change, que de nouvelles informations apparaissent ou que des erreurs de conception sont découvertes. Mais les autorités locales et les opérateurs prestataires de services peuvent gagner à renégocier au détriment des consommateurs, puisque les dépenses supplémentaires établies dans le contrat négocié doivent être incluses dans le budget et supportées par les futures administrations. En outre, dans le cadre de la concurrence pour les marchés publics, si deux opérateurs sont également efficaces, alors l'opérateur qui est le moins compétent en mesure de négocier le contrat initial ne sera pas choisi. Même si un opérateur a le plus haut degré d'efficacité technologique, il ne survivra pas à l'étape de négociation. Par conséquent, les opérateurs qui sont technologiquement moins efficaces ne sont pas incités à contrôler et à réduire les coûts de fourniture de services publics, détériorant ainsi la qualité des services. On prétend souvent que, dans le contrat de la délégation, les mécanismes complexes d'incitations ne sont pas pratiques (par exemple, un contrat de vente

ou un contrat à prix fixe) car ils sont susceptibles d'être renégociés (Laffont and Tirole, 1993). Le remède à ces problèmes est d'enrichir la théorie des incitations sur la régulation de service public par la divulgation d'informations sans minimiser l'importance et la pertinence de la littérature existant sur la conception des mécanismes. Notre approche peut donner aux autorités locales une approche règlementaire plus souple pour gérer le processus de délégation sans recourir à une renégociation ex poste.

En considérant un environnement d'information exogène dans lequel les exigences spécifiques sont divulguées au début de la négociation, nous assumons que les estimations privées des opérateurs sur la qualité du réseau communiquées à l'autorité locale peuvent signaler leur efficacité à réduire les coûts liés à la gestion. Étant donné que l'estimation privée d'un opérateur est basée à la fois sur des informations publiques et privées, la précision des informations divulguées affecte l'estimation qu'une autorité locale peut recevoir. Ainsi, l'estimation privée devient généralement une variable observable au stade de la négociation, ce qui peut améliorer les décisions des autorités locales concernant le type de contrat dans la fourniture d'un service public. Cependant, au cours du processus de négociation, un opérateur peut acquérir des informations supplémentaires qui ne sont pas observables par l'autorité locale. Ces informations supplémentaires peuvent augmenter la précision des informations privées d'un opérateur, mais peuvent en même temps rendre les signaux envoyés par le coefficient de corrélation imprécis. Une structure d'information endogène découle du biais entre la précision des informations divulguées publiquement et la précision des informations privées. Ce biais est généré par l'apprentissage erroné d'un opérateur à partir des interactions stratégiques entre opérateurs. Avec une structure d'information endogène, la collectivité peut internaliser les externalités d'apprentissage sur les coûts des opérateurs en imposant le bon niveau de transfert dans les contrats. L'autorité locale peut éliminer la possibilité de stratégie de type "hit-and-run" (Laffont and Tirole, 1993) en faisant dépendre les contraintes d'incitation de l'exactitude de l'information diffusée. Par conséquent, l'autorité locale peut s'engager à ne pas renégocier et inciter un opérateur à améliorer la qualité de l'infrastructure.

Nous montrons que les informations publiques permettent à une autorité locale de mieux définir le choix du mode de gestion. Néanmoins, des inefficacités sont susceptibles de perdurer dans la mesure où les opérateurs décident de manipuler les informations privées dont ils disposent pour augmenter leur chance de remporter la gestion déléguée des services. La manipulation des informations restreint les impacts positifs de la divulgation d'information publique et privée sur les décisions de l'autorité locale, ainsi que sur les décisions des concurrents potentiels pour obtenir le contrat de délégation. Engel et al. (2013) soulignent que les opérateurs inefficaces sont de bons négociateurs visant à acquérir davantage d'information afin d'orienter la négociation en leur faveur. Par conséquent,

la négociation est devenue stérile du fait qu'une autorité locale pourrait revenir sur ses décisions via la rupture unilatérale du contrat, ou que l'opérateur inefficace revendiquerait une renégociation. Cela nous amène à considérer le recours au mécanisme de concurrence par comparaison pour la première étape du processus de délégation en vue d'améliorer l'efficacité de la sélection des opérateurs potentiels.

Au stade de la sélection, le mécanisme d'appel d'offres de franchise et la concurrence par comparaison ont été analysés pour améliorer la concurrence dans la délégation des services publics d'eau (Chong et al., 2006 ; Chong and Huet, 2009). Dans de tels mécanismes, la concurrence est censée être bénéfique en limitant les possibilités qu'un opérateur inefficace entre dans la négociation. Ainsi, l'utilisation des solutions concurrentielles dans le processus de délégation favorise une amélioration de la gouvernance de régulation sur la gestion des services publics. Cependant, sous la pression de la concurrence, la collusion entre opérateurs potentiels peut survenir lorsque ces mécanismes sont utilisés pour attribuer des contrats de gestion de services publics locaux. Dans un modèle du jeu répété à l'infini, Chong and Huet (2009) remarquent que, lors de l'attribution des contrats, le mécanisme d'appel d'offres et la concurrence par comparaison ne peuvent pas empêcher les opérateurs potentiels de se comporter de manière collusoire s'ils sont suffisamment patients pour obtenir des pouvoirs monopolistiques. En fait, ils considèrent la concurrence par comparaison comme une solution règlementaire ex poste qui révèle des informations sur les pouvoirs monopolistiques des opérateurs et introduit des forces concurrentielles dans les services publics locaux. En revanche, lorsqu'une autorité locale utilise à plusieurs reprises la concurrence par mesure pour révéler les informations privées des opérateurs, les opérateurs sont fortement incités à s'entendre car ils ont peur d'être condamnés à une amende de la part de l'autorité locale. L'utilisation simultanée de ces deux régimes règlementaires lors de la phase de sélection ne peut donc pas améliorer l'efficacité de la prestation de services publics.

Compte tenu de ces résultats, nous nous demandons si en ajoutant la divulgation de l'information dans les solutions concurrentielles, l'utilisation de la seule concurrence par comparaison comme procédure de règlementation pourrait aider une collectivité locale à améliorer l'efficacité de la délégation. Lorsqu'elle est utilisée comme solution règlementaire ex ante, la concurrence par comparaison permet clairement à une autorité locale de révéler des informations privées d'opérateurs potentiels avant la phase de négociation. Néanmoins, sans information rendue publique, la collusion reste possible si l'on n'utilise que la concurrence par comparaison comme le montrent Auriol and Laffont (1992), Laffont and Martimort (2002) dans un contexte général, et par Tangeras (2002) dans le secteur de l'eau. Ces contributions s'appuient sur l'hypothèse de Shleifer (1985) selon laquelle une autorité locale peut créer artificiellement de la concurrence sur un marché.

Ils constatent que plus il y a d'informations privées révélées par la concurrence par comparaison, plus les opérateurs sont incités à s'entendre. Afin de décourager les opérateurs d'avoir un comportement collusif, une autorité locale doit choisir entre l'extraction de la rente et l'efficacité de la productivité sur le marché. De ce point de vue, la seule utilisation de la concurrence par comparaison ne peut pas améliorer la fourniture de services publics. Par conséquent, nous enrichissons la littérature ci-dessus en ajoutant la divulgation dans la compétition par comparaison. Au lieu de compter sur une concurrence par comparaison répétée comme dans la littérature, nous supposons que les autorités locales divulguent publiquement des informations sur les spécifications de fourniture de services publics. Cette hypothèse rend la révélation de l'information plus compliquée du fait de la précision relative des informations publiques et privées : en comparant la précision de l'information publique à celle de l'information privée, les opérateurs arbitrent entre la concurrence et la collusion afin de réussir à entrer dans la phase de négociation. Différente du résultat selon lequel la collusion est auto-imposée sous la concurrence par comparaison, par la précision de l'information publique, c'est la concurrence qui est imposée par l'auto-sélection des opérateurs. Nous montrons que l'utilisation de la concurrence par comparaison en présence d'informations publiques et privées aide l'autorité locale à réduire les possibilités de manipulation des informations lors de la phase de sélection de la délégation. Ces différentes études constituent les quatre chapitres de cette thèse.

Le premier chapitre est une revue de littérature examinant la valeur sociale de l'information publique. Le deuxième chapitre développe un modèle théorique permettant de déterminer les modes de gestion des services publics de l'eau en présence d'informations publiques et privées. Dans ce chapitre, nous supposons que l'information publique et privée portant sur la qualité de l'infrastructure est sans biais. Ainsi les parties au contrat de délégation ont la même estimation de cette variable. Le troisième chapitre examine les effets de l'information publique sur la détermination des contrats de délégation quand l'information est biaisée en raison de l'acquisition d'information par les opérateurs durant la phase de négociation entre l'autorité locale et les opérateurs pré-sélectionnés. En effet, via les coefficients de corrélations entre les informations privées des opérateurs, l'acquisition d'informations affecte les estimations publiques et privées sur la qualité de l'infrastructure durant la phase de la négociation et donc la détermination des contrats par l'autorité locale. Le fait que la précision de l'information publique ne permette pas à l'autorité locale de déterminer les contrats optimaux dans le troisième chapitre nous incite à remettre en question l'efficacité de la première étape du processus de délégation. Le quatrième chapitre contribue donc à analyser un mécanisme permettant d'améliorer l'efficacité de la sélection des opérateurs lors du processus de délégation : la concurrence par comparaison en présence de l'information publique. Nous allons donc présenter briè-

vement les manières dont chaque partie de notre travail est organisée.

Le premier chapitre de notre travail passe en revue la littérature sur la valeur sociale de la divulgation de l'information. Cette revue de littérature combine, pour la première fois, deux analyses différentes de la valeur sociale de la divulgation de l'information : les analyses théoriques et les études expérimentales. En présentant les externalités engendrées par la divulgation de l'information sur le bien-être social, cette revue de littérature met en valeur les comparaisons des deux structures d'information (information publique exogène et information publique endogène). Ces comparaisons permettent de savoir dans quelle structure d'information la précision publique et privée influence davantage les décisions stratégiques des agents économiques. Ces comparaisons ont été testées par les expérimentations dont les résultats sont également présentés dans ce chapitre.

Dans le cas où l'information publique est exogène, les agents peuvent réagir de manière excessive à celle-ci (Morris and Shin, 2002 ; Angeletos and Pavan, 2007). Cela génère des externalités informationnelles sur le bien-être. En effet, le bien-être sociale diminue avec les informations divulguées publiquement puisque les agents utilisent peu d'informations privées dans leur décision. Dans ce contexte, Angeletos and Pavan (2007) ont montré que les externalités d'information sont responsables de l'écart entre l'équilibre et l'utilisation efficace de l'information privée. La littérature sur les structures d'information exogène tente de trouver diverses solutions permettant d'améliorer le bien-être lorsque les informations publiques et privées deviennent plus précises. Premièrement, les travaux de recherche portant sur le degré de divulgation publique montrent que lorsque l'information publique est partiellement divulguée, les agents s'appuient davantage sur des informations privées dans leurs décisions stratégiques. Par conséquent, la réaction excessive des agents à l'information publique est réduite et le bien-être social est amélioré (Svensson, 2006 ; Morris et al., 2006 ; Cornand and Heinemann, 2008). Deuxièmement, Angeletos and Pavan (2007) ont analysé la qualité des informations divulguées publiquement et ont souligné que si les informations publiques sont plus précises que les informations privées des agents à l'équilibre, alors la diffusion de l'information a un impact positif sur le bien-être puisque les agents utilisent peu d'informations privées. Troisièmement, les travaux sur l'acquisition de l'information privée soulignent que les agents améliorent la précision des informations privées grâce à une acquisition et un traitement coûteux de l'information. Le bien-être social est amélioré par une volatilité réduite de la divulgation de l'information (Hellwig, 2005 ; Hellwig and Veldkamp, 2009).

Avec une structure d'information endogène, les agents apprennent davantage de l'information publique véhiculée par les marchés que de leurs propres informations privées. Les externalités d'apprentissage résultent des effets d'éviction de l'information publique sur l'information privée et ont un impact négatif sur le bien-être social (Colombo et al.,

2014; Vives, 2017; Bayona, 2018). Par conséquent, des travaux récents sur les structures d'informations endogènes cherchent à savoir comment réduire ces effets d'éviction et rendre positif l'impact de l'information publique sur le bien-être social. Premièrement, l'analyse de l'internalisation des externalités prouve que la solution "team-efficient" internalisera les externalités d'apprentissage due aux actions des agents sur le marché, et que la perte de bien-être social diminue avec la précision de l'information publique (Vives, 2017). Deuxièmement, les travaux sur l'utilisation efficace de l'information privée montrent que la réduction de l'acquisition d'informations privées augmente le bien-être social à l'équilibre sur le marché (Colombo et al., 2014; Myatt and Wallace, 2015). Troisièmement, les analyses normatives portant sur les signaux publics endogènes dans les travaux de Bayona (2018) souligne qu'une plus grande précision de l'information privée augmente la précision globale de l'information publique endogène qui a un impact positif sur le bien-être social.

À l'aide d'expériences en laboratoire, Dale and Morgan (2012) démontrent que les agents ont la même précision sur des informations privées, mais réagissent de manière excessive aux informations publiques imprécises en raison de la coordination stratégique présentée dans les expériences. La précision des informations publiques est ensuite testée dans différentes expériences. Cornand and Heinemann (2015) intègrent l'analyse des comportements collectifs dans les expériences qui testent les réactions des agents à l'information publique exogène. Ces expériences montrent que même si l'information publique est précise, les agents accordent moins d'importance à l'information publique qu'aux prédictions théoriques. En effet, les agents ont des niveaux de raisonnement limités et négligent le fait que d'autres agents dans les expériences comptent également sur le fait que d'autres reçoivent les mêmes informations publiques. Par conséquent, des croyances de hauts niveaux dans les expériences peuvent être utilisées pour expliquer pourquoi la précision de l'information publique peut être indésirable : plus le niveau de raisonnement est élevé, plus le poids que les agents accordent au signal public est élevé et, plus les effets néfastes sur le bien-être sont probables. Cependant, si les agents n'atteignent que le raisonnement de niveau 2 dans les expériences, alors le bien-être social peut être amélioré par la précision du signal public. Dans ce contexte, Cornand and Heinemann (2015) suggèrent qu'un gouvernement peut prendre des mesures politiques pour limiter la réaction excessive de l'information publique lorsque les agents ont des niveaux de raisonnement limités : un gouvernement peut ne pas divulguer complètement l'information publique comme l'ont montré James and Lawler (2012). Ces expériences montrent que ce n'est pas la divulgation publique complète, mais la divulgation partielle qui améliore le bien-être social.

Ce travail nous permet de considérer que les marchés de délégation seraient mieux à

même de fonctionner et les décisions des agents économiques seraient mieux fondées si les autorités publiques ou autres institutions/organisations diffusaient davantage d'informations. La disponibilité et la transparence de l'information pourraient éliminer une partie des défaillances liées à l'asymétrie d'information entre l'autorité locale responsable d'un service public et les délégataires. Ainsi, nous introduisons la précision des informations divulguées dans l'analyse des contrats de délégation des services de l'eau. En effet, les services de l'eau sont fournis par les municipalités locales, qui disposent d'une grande liberté sur la manière dont ces services peuvent être gérés. Nous envisageons donc d'analyser la détermination des contrats de délégation en fonction de la précision des informations publiques et privées.

Dans le chapitre 2, nous insistons notamment sur l'état des réseaux d'eau, et leur impact sur le choix du contrat de délégation. La question essentielle traitée dans ce chapitre est de savoir comment la divulgation de l'information peut être utilisée dans la conception des contrats de délégation des services de l'eau. Nous considérons que les opérateurs reçoivent deux types de signaux : un signal privé pouvant être interprété comme une opinion privée sur la variable d'état – la qualité de l'infrastructure (la proportion des fuites d'eau dans les réseaux de distribution de l'eau) ; un signal public au sens où la réalisation réelle de certaines variables est une connaissance commune parmi les opérateurs et l'autorité locale. En outre, la précision de l'information publique et privée sur la qualité de l'infrastructure amènent à une estimation sans biais entre les parties au contrat. Notre objectif est alors d'analyser les contrats de délégation de services publics en fonction de cette précision et d'étudier l'impact de la présence d'information publique sur le bien-être social.

En intégrant une information publique exogène dans le modèle théorique de Baron and Myerson (1982) et, en considérant une régulation par le volume, nous montrons que la quantité due aux fuites dépend de la précision de l'information publique et/ou privée : quand l'information est précise, l'autorité locale peut réduire la quantité de fuites tolérée sur le réseau. Cela va engendrer une hausse des prix. En revanche, quand l'information est moins précise, l'autorité locale va tolérer davantage de fuites. Cela va générer une baisse des prix. Nous montrons également que, lorsque l'information sur la qualité de l'infrastructure est précise, l'autorité locale va maintenir la gestion publique de la distribution de l'eau. Elle prend en compte la sensibilité du consommateur à la qualité des services afin de maintenir un niveau bas du prix de l'eau. En revanche, quand l'information sur la qualité de l'infrastructure est moins précise, voire imprécise, l'autorité locale est incitée à déléguer la gestion des services au secteur privé.

Une plus grande transparence informationnelle engendrée par la présence d'information publique devrait améliorer l'efficacité des schémas de contractualisation actuels. En

outre, elle permettrait de mieux observer les actions des opérateurs et de contrôler le respect de leurs engagements. Nos simulations portant sur 238 données liées aux différents degrés de l'estimation de la qualité de l'infrastructure des services publics de l'eau révèlent que le type du contrat tend à être public quand la qualité est estimée bonne. En revanche, une quantité de fuites d'eau est toujours tolérée dans les réseaux de la distribution de l'eau afin de maintenir les prix de l'eau à un bas niveau comme le montrent l'analyse empirique de Garcia and Thomas (2001), et dans l'analyse théorique récente de Cavaliere et al. (2017). Nos résultats du chapitre 2 nous amènent à nous demander si la précision de l'information publique peut réduire les rentes informationnelles laissées à un opérateur, alors qu'il a tendance à se comporter de manière stratégique au cours du processus de négociation. C'est l'objectif du chapitre 3. En considérant une structure d'information exogène, nous supposons qu'un opérateur peut non seulement coordonner son estimation privée vers l'estimation publique, mais aussi corrélérer stratégiquement son estimation privée avec d'autres. Nous nous intéressons donc à l'impact de la précision des informations publiques et privées sur les contrats de délégation lorsque les estimations sont biaisées.

Dans le chapitre 3, nous relâchons l'hypothèse du chapitre 2 selon laquelle les estimations liées à l'information publique et privée sont sans biais. Nous remarquons qu'en acquérant des informations supplémentaires, l'opérateur a tendance à surévaluer ou sous-évaluer la qualité de l'infrastructure par rapport à la situation où il n'acquiert aucune information supplémentaire. Notre objectif est alors double : dans un premier temps, nous visons à savoir si les types de contrats de délégation permettent d'inciter l'opérateur à révéler ses informations biaisées dues à l'acquisition d'informations ; ensuite nous examinons si la précision de l'information publique peut limiter les rentes informationnelles résultant des distorsions stratégiques entre les opérateurs. En effet, avant la passation de marchés, la délégation d'un service public est entourée d'incertitudes et d'asymétries informationnelles, ce qui complique la tâche des autorités locales et sape leurs objectifs visés. De plus, le processus est perturbé par divers chocs, par exemple, des variations inexplicables causées par certaines variables explicatives que les parties ne peuvent pas et ne veulent pas préciser au cours du processus. Par conséquent, les estimations ex ante de certaines variables diffèrent des observations ex poste parce que les asymétries d'information résultent de différences d'informations qui sont présentes avant la passation de marchés. Cette forme d'asymétrie d'information a été étudiée par Weitzman (1978) et Baron (1981). La divulgation de l'information peut réduire ces asymétries informationnelles, mais une complexité supplémentaire découle du fait que la divulgation de l'information peut inciter un opérateur à acquérir des informations avant de passer un marché.

Ce chapitre porte donc sur la détermination des contrats de délégation lorsque la pré-

cision de l'information est mesurée par la précision relative des signaux publics et privés. Sans considérer les coûts pour acquérir des informations supplémentaires, nous supposons qu'une autorité locale négocie avec deux types d'opérateurs dans la phase de négociation de délégation. L'opérateur décide d'acquérir des informations afin d'améliorer la précision de l'information privée. Ces informations supplémentaires peuvent affecter le coefficient de corrélation des signaux privés entre les opérateurs. L'opérateur qui n'acquière pas des informations supplémentaires, néanmoins, apprend des informations en observant ce coefficient de corrélation. Dans ce travail, le coefficient de corrélation des signaux privés est donc devenue fonction de l'information supplémentaire.

Nous trouvons que, d'un côté, cette corrélation des signaux privés est un moyen d'apprentissage public sous l'effet de la pression de coordination, lorsqu'elle envoie les informations agrégées aux opérateurs et à l'autorité locale. D'un autre côté, cette corrélation des signaux privés est un moyen d'apprentissage privé sous l'effet de la pression concurrentielle, lorsque les opérateurs décident d'obtenir des informations de cette corrélation. Cependant, les informations acquises par un opérateur peuvent être trompeuses. Ces informations trompeuses égarent les décisions stratégiques des opérateurs dans la coordination et la concurrence. Nous montrons que les conflits entre la coordination et la concurrence engendrent deux types de distorsions, qui influencent la détermination des contrats de délégation : la distorsion stratégique et la distorsion informationnelle.

En effet, la distorsion stratégique dans la détermination des contrats de délégation est liée à deux stratégies qui dépendent de la précision des informations publiques et privées. Quand l'information publique est plus précise que l'information privée, la motivation de concurrence domine la motivation de coordination dans les choix stratégiques d'un opérateur. L'opérateur observe des informations trompeuses envoyées par le coefficient de corrélation. Néanmoins, il préfère compter sur l'information publique et l'information envoyée par le coefficient de corrélation plutôt que ses informations privées, quand les autres opérateurs attachent leurs stratégies à leurs informations privées. C'est la stratégie de substituabilité qui dépend de l'apprentissage public. Cette forme d'apprentissage à partir du coefficient de corrélation a été étudiée par Vives (2014) afin d'expliquer le paradoxe d'un marché informationnellement efficace. Lorsque le coefficient de corrélation n'est pas trop grand, l'apprentissage public est bon pour la révélation complète de l'information privée en équilibre.

Quand l'information privée est plus précise que l'information publique, la motivation de coordination domine la motivation de concurrence dans les choix stratégiques d'un opérateur. L'opérateur préfère ses informations privées à l'information publique quand les autres opérateurs comptent davantage sur leurs informations privées. C'est la stratégie de complémentarité qui est liée à l'apprentissage privé. Dans ce cas, bien que la

précision de l'information privée soit plus élevée que celle de l'information publique, le coefficient de corrélation des signaux privés entre les opérateurs peut envoyer des informations trompeuses à l'autorité locale. Nous montrons que la stratégie de substituabilité et la stratégie de complémentarité amènent les opérateurs à s'écarter de deux équilibres bayésiens distincts. De plus, les informations trompeuses envoyées par le coefficient de corrélation peuvent conduire l'autorité locale à laisser les rentes informationnelles dans la détermination des contrats de délégation. C'est la distorsion informationnelle qui est due à la distorsion stratégique. Par conséquent, les rentes informationnelles cédées à un opérateur sont liées à ses décisions stratégiques d'un côté et, sont liées à ses estimations trompeuses de l'autre côté.

Nous montrons que ces distorsions peuvent être atténuées par une augmentation de la précision de l'information publique. En outre, l'autorité locale peut adapter les instruments de la politique publique afin de limiter les rentes informationnelles qu'elle pourrait concéder à l'opérateur. L'autorité locale laisse les rentes informationnelles à un opérateur afin de l'inciter à accepter le contrat (carottes) quand il est égaré par les informations trompeuses. Cependant, quand la précision de l'information publique surpasse la précision de l'information privée, l'autorité locale peut extraire des rentes informationnelles de l'opérateur qui a surestimé la qualité (bâtons). En revanche, l'autorité locale laisse des rentes informationnelles à l'opérateur qui a sous-estimé la qualité.

Nous remarquons que l'acquisition d'informations créent des externalités informationnelles qui rendent sous-optimaux les contrats déterminés au cours de l'étape de négociation de la délégation. En partant de cette remarque, nous cherchons d'autres solutions permettant d'améliorer la délégation des services publics. À cette fin, nous nous interrogeons sur l'efficacité de l'étape de sélection de délégation et, nous examinons si le mécanisme de concurrence par comparaison pourra permettre à l'autorité locale de mieux sélectionner les opérateurs en présence des informations publiques et privées. Ceci est l'objectif de notre quatrième chapitre.

Sur la base des travaux théoriques bien connus de Shleifer (1985), la concurrence par comparaison (désormais Yardstick Competition) a été étudiée comme une stratégie de régulation sur les marchés locaux (Auriol and Laffont, 1992) et, dans le secteur de l'eau (Chong and Huet, 2009 ; Tangeras, 2009). Ils montrent que Yardstick Competition est une stratégie appropriée pour révéler des informations privées des opérateurs. Mais ce mécanisme peut entraîner la possibilité d'une collusion entre les opérateurs quand le coefficient de corrélation entre les informations privées devient élevé. En effet, sans la divulgation d'informations exogènes, une autorité locale est supposée ne disposer d'aucune information sur l'état de nature du marché et les performances des opérateurs. L'autorité locale peut réduire les coûts de révélation des informations privés en observant le coefficient de

corrélation, qui devrait être le plus élevé possible. Néanmoins, ce mécanisme incite les opérateurs à s'entendre pour empêcher la collectivité locale de révéler des informations privées. Afin d'améliorer l'efficacité de ce mécanisme de régulation en réduisant la possibilité de collusion, nous intégrons les informations publiques exogènes dans Yardstick Compétition destiné à la régulation des services publics.

Dans ce dernier chapitre, nous relâchons l'hypothèse du chapitre 3 d'une information publique précise et d'une information privée imprécise. Nous constatons que même si l'information publique est imprécise et l'information privée est précise, l'opérateur préfère toujours surévaluer ou sous-évaluer la qualité de l'infrastructure des services publics de l'eau. Ce phénomène provient des pressions concurrentielles entre les opérateurs qui souhaitent remporter le contrat de délégation. Nous examinons donc si le mécanisme de concurrence par comparaison peut aider l'autorité locale à mieux sélectionner les opérateurs en allégeant les coûts de rente informationnelle.

Nous supposons que les coûts sont quadratiques et symétriques entre les opérateurs afin de capturer les effets de la sélection adverse dus à la corrélation des signaux privés. Ainsi, les décisions stratégiques des opérateurs sont symétriques. Chaque décision stratégique est fonction de l'interaction stratégique entre les opérateurs, de la réaction de l'opérateur par rapport aux informations sur la qualité du réseau et de la corrélation des signaux privés. Nous montrons que la précision des informations publiques et privées permet de renforcer l'efficacité du mécanisme de concurrence par comparaison.

En alignant les analyses théoriques d'Angeletos and Pavan (2007) et de Bergemann and Morris (2013), nous combinons la structure des coefficients de corrélation et la structure d'informations exogènes avec le mécanisme de concurrence par comparaison. La structure des coefficients de corrélation est constituée par la corrélation entre des décisions stratégiques des opérateurs et la corrélation entre la décision stratégique individuelle et l'état de l'infrastructure. La structure d'informations exogènes est constituée par la précision des informations publiques et privées. Avec ces deux structures, nous supposons qu'une autorité locale peut observer le coefficient de corrélation entre les informations privées des opérateurs tant qu'entre les précisions d'informations publiques et privées. Nous analysons l'équilibre corrélé bayésien et montrons qu'une corrélation élevée entre les informations privées peut rendre le mécanisme de concurrence par comparaison efficace. En outre, l'analyse d'équilibre de Nash bayésien fait ressortir qu'une augmentation de la précision de l'information publique génère différents niveaux de divulgation. Ceux-ci sont liés non seulement à l'interaction stratégique, mais également à la corrélation entre les décisions des opérateurs. Avec la structure des coefficients de corrélation, la divulgation des informations complètes et/ou partielles restreint les comportements de collusion des opérateurs sous les pressions concurrentielles. La concurrence dans l'étape de sélection

des opérateurs au cours du processus de délégation peut être renforcée.

Nous trouvons qu'à l'équilibre de Nash bayésien, le niveau de l'interaction stratégique dépend des précisions relatives entre l'information publique et privée. Quand ce niveau d'interaction stratégique est inférieur aux précisions relatives, la concurrence par comparaison sera plus efficace. Dans ce cas, la collusion sera plus difficilement soutenable lorsque l'information publique est suffisamment précise. Par conséquent, la concurrence au stade de la sélection peut être renforcée.

Mots clés : Services publics locaux, secteur de l'eau, la divulgation de l'information, gouvernance, informations publiques et privées, corrélation, acquisition de l'information, concurrence par comparaison.

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Acknowledgement

Résumé

Introduction and Overview

Part I. The Social Value of Information Disclosure

Chapter 1 The Social Value of Information Disclosure

- 1 Uncertainty and information disclosure
 - 1.1 Uncertainty
 - 1.2 Market regulation
 - 1.3 Types of information disclosure
- 2 Exogenous information disclosure
 - 2.1 Coordination games
 - 2.1.1 Strategic complementarity at the individual level
 - 2.1.2 Strategic complementarity at the social level
 - 2.1.3 Microfounded macroeconomic model
 - 2.2 Rational expectations equilibrium
 - 2.2.1 Imperfect competition
 - 2.2.2 Supply function competition
- 3 Endogenous information acquisition
 - 3.1 Noisy rational expectations equilibrium
 - 3.1.1 Partially revealing rational expectations equilibrium
 - 3.1.2 The precision of endogenous private information
 - 3.1.3 Endogenous public and private information
 - 3.1.4 The social value of endogenous public information
 - 3.2 Endogenous information structures in coordination games
 - 3.2.1 Multiple equilibria in coordination games
 - 3.2.2 Unique equilibrium in a coordination game
 - 3.3 Endogenous information structure in markets games
 - 3.3.1 The social value of public information with endogenous precision
 - 3.3.2 Cournot competition and the social value of information

- 4 Spillover effects of disclosure on the social value of information
 - 4.1 Payoff and learning externalities
 - 4.2 Information externalities
 - 4.3 Internalization of externalities
- 5 Experiments and the social value of disclosure
 - 5.1 Social value of public disclosure
 - 5.2 Agents' reaction to private and public disclosure
 - 5.3 The policy aimed at reducing overreaction to public disclosure
 - 5.4 Signal precision and the degree of strategic complementarity
- 6 Conclusion

Part II. The Negotiation Stage of the Delegation

Chapter 2 The Value of Information Disclosure and the Design of Delegation Contracts

- 1 Introduction
- 2 The Model
 - 2.1 Demand and Consumers' surplus
 - 2.2 The Water Utility and Social Welfare
 - 2.3 Assumptions and Timing
- 3 Policy Design
 - 3.1 The regulated volume and water price
 - 3.2 Delegation contracts
 - 3.2.1 Admissible values for the choice instruments
 - 3.2.2 The role of choke price
 - 3.2.3 Main contracts
 - 3.3 Public managements
 - 3.3.1 Consumers sensitivity
 - 3.3.2 Shadow costs of public funds
- 4 Information precision
 - 4.1 Information precision
 - 4.2 Numerical example
- 5 Conclusion
- 6 Appendix

Chapter 3 Carrots, Sticks, and Water Public Services: the precision of disclosed information and delegation contracts

- 1 Introduction
- 2 The General Model

- 2.1 Water demand
- 2.2 Water services
- 2.3 Social welfare
- 3 The Information Structure
 - 3.1 Public and private signals
 - 3.2 A noisy common knowledge structure
- 4 Contract Structures
 - 4.1 Set up
 - 4.2 Truthful reports with information structures
 - 4.2.1 Additional information
 - 4.2.2 Truthful reports
 - 4.2.3 Information precision in truthful reports
 - 4.2.4 The precision of signals without information acquisition
 - 4.2.5 The precision of estimation with information acquisition
 - 4.3 Contracts with information structures
 - 4.3.1 Expected individual rationality constraint
 - 4.3.2 The second-best solutions
 - 4.4 The second-best water prices
 - 4.4.1 The expected water prices
 - 4.4.2 The volatility of information acquisition
- 5 Screening Policy and the Optimal Menu of Contracts
 - 5.1 The choice of an operator type $(E[\tilde{\theta}_i | \hat{\theta}_i])$
 - 5.1.1 Precise public signal and imprecise private signal
 - 5.1.2 Precise private signal and imprecise public signal
 - 5.1.3 Screening policy of an operator type $(E[\tilde{\theta}_i | \hat{\theta}_i])$
 - 5.2 The choice of an operator type $(E[\tilde{\theta}_i | \hat{\theta}_i])$
 - 5.2.1 Precise public signal and imprecise private signal
 - 5.2.2 Precise private signal and imprecise public signal
 - 5.2.3 Screening policy of an operator type $(E[\tilde{\theta}_i | \hat{\theta}_i])$
 - 5.3 Transfers
- 6 Concluding Remarks
- 7 Appendix

Part III. The Selection Stage of the Delegation

Chapter 4 Strategic Learning in the Delegation of Water Services

- 1 Introduction
- 2 Setup
 - 2.1 The general model

- 2.2 Information structure
- 3 The Equilibrium
 - 3.1 Complete information
 - 3.2 Incomplete information
 - 3.2.1 The expected individual strategic action
 - 3.2.2 Ex post expected profit with Bayes Correlated Equilibrium
 - 3.2.3 Ex post expected profit with Bayes Nash Equilibrium
- 4 Disclosed information in Yardstick competition
 - 4.1 Bayes Nash Equilibrium relative to Bayes Correlated Equilibrium
 - 4.2 The degree of disclosed information
 - 4.3 Remarks
- 5 Conclusion
- 6 Appendix

INTRODUCTION AND OVERVIEW

The lack of transparency in the regulation of the French local public services has been pointed out by the European Commission since 1990's. In accordance with the European Commission' requests, France has adopted two laws, the "Sapin Law (1993)"¹ and the "Barnier Law (1995)", in order to improve the transparency of information during the delegation process of local public services.

Improving the transparency notably takes the form of access to more information for the various stakeholders and a reduction in information asymmetries between public authorities and private operators. Since the 1980's, economists have been interested in these issues. They show that the transparency of procurement can be improved by the revelation of private information. Such revelation is costly since it increases budget constraints on the local public authorities. The objective of such mechanisms is to obtain greater efficiency and gains from a private operator (Baron and Myerson, 1982; Laffont and Tirole, 1993). However, for a long-term contract, the revelation of private information itself is not always efficient. In other words, there will be uncertainty in the execution of the contract. It is better to disclose information about the performance of any private operator during the life of contract. A major question on which this thesis focus is therefore emerging: does access to more publicly disclosed information by parties benefit potential operators to compete with the existing operator, the incumbent, for managing public services?

Stiglitz (1975), Akerlof (1970) and Spence (1973) are pioneers in providing theoretical tools to analyze the problem of information in markets. Their works are based on those of earlier theorists such as Hayek who conceived markets as information systems in which all economic agents signal their wishes. They focus only on the access to private information, but not on publicly disclosed information. For example, the work of Akerlof (1970) implicitly highlights that an additional mandated information is needed to potential buyers. Disclosure is a result of regulatory requirements for vehicle inspection tests. Similarly, Spence (1973) shows that workers need to signal their abilities to employers through public qualifications. These analyses show that if markets are information processing systems, then information asymmetries prevent markets from functioning efficiently. Therefore, disclosure policies are required to make information accessible to all economic agents in markets. More recently, mandated disclosure has been adopted as a

¹Note that the Sapin Law II entered into force in June 2017: Law No. 2016-1691, aims at strengthening the French anti-corruption regimes to increase transparency.

regulatory approach to address social issues such as environmental impact of products – labeling information about energy use or carbon output.

Taking disclosed information into account should not lead to neglecting the reaction it generates among economic agents. Sometimes, they may overreact to disclosure. This prevents to achieve the intended social efficiency in at least two contexts. Firstly, as Grossman and Stiglitz (1980) pointed out, some economic agents pay for information in order to improve the quality of decisions, which in turn influences market prices. But other economic agents can behave as "free-riders": they obtain additional information after observing market prices without paying for such information. If all economic agents adopt the same strategy and behave in the same way, then the equilibrium of financial markets collapse. Secondly, Morris and Shin (2002) show that economic agents may overreact to noisy public announcements by central banks. There are the so-called "beauty-contest" effects that are detrimental to social welfare. They prove that overreaction can be limited by disclosing less information.

These issues are central when publicly disclosed information is used to enhance transparency and hence the performance of complex network-based public services. The water industry is a prominent example of such public services. One important dimension of the water industry is its monopolistic nature. Water mains need heavy sunk investment in infrastructure in order to be functional. Consequently, the water industry has always a unique operator (public or private) providing public services to satisfy the demand rather than several competing operators. Hence, a problem arises from the fact that the unique operator has precise information about the true level of infrastructure quality, because the water distribution is entirely underground. If the operator wants to keep the monopoly power in managing the service, then it can prevent other potential operators from learning precisely the infrastructure quality. This is not the case of railway and motorway networks, or power networks even if 40% of electricity lines are buried. For instance, the gap between the true quality and the measured quality (e.g., the ratio between the volume of water leaks and the volume of water distribution) is so large. This implies an ongoing increase in water prices while the satisfaction of local authority and the consumers is decreasing. This gap can be reduced by improving transparency in the process of contracting out such public services. To this end, one may consider information disclosure about the service specifications at the beginning of the delegation process.

Information disclosure in the water sector can be of three types: access to information, forced or mandated disclosure, and data sharing. Access to information simply means that documents and records used in managing water services are made publicly available by an advisory board of local public services users, the involvement of civil society organizations,

or whistleblowers.² Forced or mandated disclosure is a regulatory approach requiring the discloser to give the disclosee information which the disclosee needs to make better decisions. Mandated programs address unquestioningly a real problem: real-life showers agents with consequential and very complex decisions about which agents know very little. Such disclosure programs simply rest on the assumption according to which, when it comes to decision making, more information is better than less. Hence, disclosure helps restore some individual control and may also induce agents to behave more efficiently. In the water sector, for instance, mandated requirements cover audited accounts, technical and financial specifications used in providing water services.³ Such mandated disclosure informs operators participating in the delegation process, and enables effective negotiation between the deliberating assembly of the local authority and potential winners. Data sharing is the possibility for local authority to share underlying data and methods used to support public water services.⁴ Data sharing allows all economic agents to compare the performances of water services provided by actual operators (public or private) before the delegation process. The precision of public information influences both the decision of the local authority and the strategic interactions across operators during two stages: the negotiation stage and the selection stage. In next two paragraphs, we present successively these two stages.

In the negotiation stage, a local authority negotiates contractual requirements with potential operators and decides to delegate or not the service depending on the type of operator. However, the performance of potential operator is not available to all parties. It is well known today that a classical revelation mechanism can be designed and hence gives strong incentives to firms in order to truthfully reveal their private information, which delivers a socially efficient outcome. However, for various reasons, some mechanisms that work in theory may turn out to be complicated to implement in practice, and are not enough to deal with some aspects of contracting problems. In addition, the regulatory system remains over burdened by the sheer number of asymmetries, uncertainties, and political events. Further, water services delegation is a long-term agreement: the duration of the contract is too long. This implies that renegotiation is to be expected in some cases. Contract renegotiation may be allowed when the environment changes, new information is emerging, or design errors are discovered. But local authority and service-providing operators may gain from renegotiation at the expense of consumers, since additional expenditures established in negotiated contract must be included in the budget and borne

²For instance, in the French water industry, this can be achieved by "La Commission Consultative des Services Publics Locaux" (CCSPL).

³See for instance the French Law 2006-1772 of December 30, 2006 "L'eau et les milieux aquatiques"; Law n°2015-991 of August 7, 2015 "Nouvelle Organisation Territoriale de la République".

⁴For example, OPEN DATA is a software that collects all prices, volumes of water distribution of every municipality in France. Available online at "services.eaufrance.fr".

by future administrations. Furthermore, under competition for public contracts, if two operators are equally efficient, then the operator that is worse in its abilities to negotiate the initial contract will not be chosen. Even if an operator has the highest degree of technological efficiency, it will not survive the negotiation stage. Therefore, operators who are technologically less efficient do not have the incentives to control and reduce costs of providing public services, thereby deteriorating the quality of services. It is often claimed that in contract delegation high-powered incentives schemes are impractical (for example, a sell-out or fixed-price contract) because they are likely to be renegotiated (See Laffont and Tirole, 1993). The remedy to these problems is to enrich the theory on the delegation of public service with information disclosure without downplaying the importance and relevance of the existing literature on mechanism design. Our approach may grant local authorities more flexible regulatory approach to deal with the delegation process without resorting to ex-post renegotiation.

Under exogenous information structure when specific requirements are disclosed at the beginning of the negotiation, operators' private estimations about the quality of the network that are reported to the local authority, may signal their efficiency in reducing management-related costs. Since an operator's private estimation is based on both public and private information, the precision of disclosed information affects the estimation a local authority may receive. Hence, private estimation becomes commonly an observable variable during the negotiation stage, which may enhance the local authority decisions concerning the type of contract in the provision of a public service. However, in the process of negotiation, an operator can acquire additional information that is unobservable to the local authority. This additional information may increase the precision of an operator's private information, but can mislead the public information at the same time. An endogenous information structure stems from the bias between the precision of publicly disclosed information and the precision of private information. This bias is generated by an operator's misguided learning from strategic interactions among operators. With endogenous information structure, the local authority internalizes learning externalities on operators' costs by imposing the right level of transfer in contracts. The local authority may eliminate the possibility of the take-the-money-and-run (or hit and run) strategy (See Laffont and Tirole, 1993) by making incentive constraints depend on the accuracy of information disclosure. Therefore, the local authority may commit not to renegotiate, and induce an operator to improve the quality of infrastructure.

In the selection stage, franchise bidding mechanism and yardstick competition have been analyzed to improve competition in the delegation of public water services (Chong et al., 2006; Chong and Huet, 2009). Under such mechanisms, competition is supposed to be beneficial by limiting the possibilities that an inefficient operator enters into the

negotiation. However, under competitive pressures, the collusion among potential operators can arise when these mechanisms are used to award contracts for the management of local public services. In an infinitely repeated game framework, Chong and Huet (2009) recognize that, during the attribution of contracts, Franchise bidding mechanism and yardstick competition may not prevent potential operators from behaving collusively if they are patient enough to obtain monopoly rights. In fact, they consider yardstick competition to be a regulatory solution *ex post* that reveals information about operators' monopoly rights and introduce competitive forces into local public services. Nevertheless, when a local authority uses repeatedly yardstick competition to reveal operators' private information, operators have large incentives to collude since they are afraid to be fined by the local authority. Using these two regulatory schemes simultaneously in the selection stage may not improve the efficiency of public service provision.

With this in mind, we ask whether using only yardstick competition as a regulatory procedure can help a local authority to improve the efficiency of delegation. When used as an *ex-ante* regulatory solution, yardstick competition clearly allows a local authority to reveal private information of potential operators before the negotiation stage. However, without publicly disclosed information, collusion remains possible if only yardstick competition is used as shown by Auriol and Laffont (1992), Laffont and Martimort (2002) in a general context, and by Tangerang (2002) in the water sector. These contributions build on the hypothesis of Shleifer (1985) that a local authority can artificially create competition in a market. They find that the more private information revealed by yardstick competition, the more incentives the operators have to collude. In order to discourage the operators from colluding, a local authority must choose between the rent extraction and productivity efficiency in the market. In this view, using only yardstick competition can not improve provision of public services. Therefore, we enrich the above literature by adding disclosure in yardstick competition. Instead of relying on repeated yardstick competition as in the literature, we assume that the local authority publicly disclose information about the specifications of providing public services. This assumption makes the revelation of information more complicated because of the relative precision of public and private information: comparing the precision of public information with that of private information, operators trade off the competition and the collusion to be succeeded in entering into the negotiation. Different from the result that collusion is self-enforced under yardstick competition, by the precision of public information, it is the competition that is enforced by the self-selection among operators.

Our work is divided into four chapters. In chapter 1, we focus on the literature covering the social value of disclosed information in different economic fields. Then, in chapters 2 and 3, our analysis contributes to the literature on the role of information

disclosure in the negotiation stage of delegation, while the last chapter proposes a new competitive path to enhance the delegation process during the selection stage. In the following, we discuss how each part of our work is organized.

The first chapter of our work reviews the literature on the social value of information disclosure. A large literature spanning disclosure has investigated the social value of information. However, to the best of our knowledge, this is the first literature review which combines the theoretical and empirical analysis. The theoretical analysis distinguishes endogenous disclosed information from exogenous disclosure, while the empirical analysis generally tests agents' strategic reactions to exogenous public information. With exogenous information disclosure, agents may overreact to public information (See Morris and Shin, 2002; Angeletos and Pavan, 2007). This generates informational externalities on welfare. In fact, social welfare decreases with publicly disclosed information since agents use few private information in their decision. In this context, Angeletos and Pavan (2007) showed that information externalities are responsible for the discrepancy between the equilibrium and the efficient use of private information. The literature on exogenous information structures looks for various solutions allowing welfare to be improved when public and private information becomes more accurate. First, the research works dealing with the degree of public disclosure show that when public information is partially disclosed, agents rely more on private information in their strategic decisions. Hence, agents' overreaction to public information is reduced and the social welfare is improved (See for instance Svensson, 2006; Morris et al., 2006; Cornand and Heinemann, 2008). Second, Angeletos and Pavan (2007) analyzed the quality of publicly disclosed information and stressed that if public information is more precise than agents' private information at equilibrium, then information disclosure has a positive impact on welfare since agents use few private information. Third, the works on the acquisition of private information highlight that agents enhance the precision of private information through costly information acquisition and processing. The social welfare is increased by a reduced volatility of information disclosure (See Hellwig, 2005; Hellwig and Veldkamp, 2009).

With endogenous information structure, agents learn from more public information conveyed by markets than their own private information. Learning externalities result from the crowding-out effects of public information on private information, and have a negative impact on the social welfare (See Colombo et al., 2014; Vives, 2017; Bayona, 2018). Therefore, recent works about endogenous information structures seek to know how to reduce these crowding-out effects and turn positive the impact of public information on the social welfare. First, the analysis of internalization of externalities proves that the team-efficient solution internalizes learning externalities associated with the actions of agents in the market, and that the welfare loss is decreasing with the precision

of public information (See Vives, 2017). Second, the works on the efficient use of private information show that reducing the acquisition of private information increases the social welfare at equilibrium in the market (See Colombo et al., 2014; Myatt and Wallace, 2015). Third, the analysis of endogenous public signals in Bayona, 2018 stresses that a higher precision of the private information increases the overall precision of the endogenous public information which has a positive impact on the social welfare.

Using laboratory experiments, Dale and Morgan (2012) demonstrate that agents have the same precision of private information, but overreact to the inaccurate public information because of strategic coordination in the tests. The accuracy of public information is then tested in different experiments. Cornand and Heinemann (2015) integrate the analysis of aggregate behavior into the experiments on the reaction to exogenous public information. These experiments show that even if the public information is accurate, agents put a lower weight to public information than to theoretical predictions. Indeed, agents have limited levels of reasoning and neglect that other agents in the experiments also account for others receiving the same public information. Therefore, higher-order beliefs in the experiments can be used to explain why the precision of public information may be bad: the higher the level of reasoning, the higher the weight that agents put on public signal, and the more likely welfare detrimental effects. However, if agents only achieve level-2 reasoning in the experiments, then welfare can be improved by the precision of public signal. In this context, Cornand and Heinemann (2015) suggest that a government can take policy action to restrict the overreaction of public information when agents have limited levels of reasoning: a government completely withholds public information as showed by James and Lawler (2012). These experiments show that it is not the complete public disclosure, but the partial disclosure that improves social welfare.

This literature on the social value of information gives insights to answer the major question of this thesis mentioned above. Uncertainties and information asymmetries about the quality of the infrastructure remains important between players, operators as well as local authorities. On the basis of this well-known problem, we introduce the precision of disclosed information in the analysis of water services delegated contracts. Indeed, water services are provided by local municipalities, which have great freedom on the way such services can be managed. The resulting variety of arrangements provides an opportunity to study the role of public information in improving the governance of delegation contracts.

In chapter 2, our work builds on the growing literature that characterizes the social value of disclosed information. It intends to explore new paths to enhance the management of local public services. The main question is how information disclosure can be used in designing delegation contracts of water services. As we have mentioned, all operators

who participate in the delegation process receive a noisy public information. Combined with noisy private information, disclosed information leads to a prior common knowledge about the state of water mains. The information structure adopted in this chapter is similar to that used to regulate a duopoly in a local market in Auriol and Laffont (1992). The main difference is that the information structure in this chapter is supposed to allow the local authority as well as operators to revise their estimation about the quality of the infrastructure. In this context, both over-estimation and under-estimation of the quality of the infrastructure stem from the fact that the operators coordinate their private estimation with the public estimation whatever the precision of public information.

Integrating exogenous information structures into the theoretical model of Baron and Myerson (1982), we find that when the public information is more accurate, the over-estimation about the quality of the infrastructure arises during the negotiation stage. Thus, the local authority prefers to keep the management of its water services public, i.e., in house, instead of relying on delegation. Moreover, more precise public information leads the local authority to take consumers' sensitivity with respect to the quality of water services into account when it sets water charges. In this case, setting water charges becomes more transparent. However, when the public information is not enough accurate with respect to the precision of private information, under-estimation about the quality of the infrastructure gives the local authority incentives to delegate the sector to the private sector. The type of delegation contracts designed by the local authority depends on the volume of water leaks that is tolerated to reduce the costs of private management. Our simulations suggest that there is a precision threshold below which the local authority prefers delegated management.

Furthermore, as we assumed that information precision is normally distributed, the volume of tolerated water leaks depends on the variation in precision. In other words, the volume of water leaks can be seen as the informational rent left to an operator who under-estimates the quality of the infrastructure. This yields two effects. First, when the information is imprecise, the volume of tolerated water leaks is high enough which gives the operator strong incentives to accept the contract. Since water charges are fixed by the local authority, if an operator under-estimates the good quality of the infrastructure, then it benefits from informational rents and does not make any effort to improve the quality. On the contrary, if an operator under-estimates the bad quality of the infrastructure, then it benefits from less informational rents and improves the quality. Second, when the information is more accurate, the volume of tolerated water leaks is low. Hence, there are less informational rents left to an operator. In this case, if an operator under-estimates the bad quality or the good quality of the infrastructure, then it accepts a contract in which the local authority can share the management costs. Thus, when the

information is precise, the operator has no incentive to reduce these costs. Our results show that the precision of public information can improve the decision of a local authority about the management of water utilities. However, a quantity of water leaks is always tolerated in water mains in order to keep water prices at a low level as showed in the empirical analysis of Garcia and Thomas (2001), and in the recent theoretical analysis of Cavaliere et al. (2017). Our results in chapter 2 lead us to consider whether the precision of public information can reduce informational rents left to an operator, when it tends to behave strategically during the negotiation process. This is the objective of chapter 3. Under exogenous information structure, an operator may not only coordinate its private estimation towards public estimation, but also strategically correlate its private estimation with others.

Chapter 3 analyzes whether disclosed information enhances cooperation between parties during the delegation process. Indeed, prior to contracting, delegation of a public service is shrouded with uncertainties and informational asymmetries, which makes difficult the task of local authorities and undermines their intended goals. Further, the process is buffeted by various shocks, e.g., unexplained variations caused by some explanatory variables that parties are unable and unwilling to specify during the process. Hence, the ex-ante estimates of some variables differ from ex-post observations because information asymmetries result from differences in information that are present prior to contracting. This form of information asymmetries has been studied by Weitzman (1978) and Baron (1981). Information disclosure may reduce these information asymmetries, but an additional complexity arises from the fact that information disclosure may give incentives to an operator to acquire information before contracting.

This chapter is concerned with the design of contracts for the case in which information acquisition arises from exogenous information disclosure prior to contracting. We step away from the assumption according to which information-related estimations (public and private) are unbiased. We note that by acquiring additional information, the operator tends to overestimate or underestimate the quality of the infrastructure compared to the situation where it does not acquire any additional information. Hence, the objective of chapter 3 is double. Firstly, we determine which types of delegation contract make it possible to encourage the operator to reveal its biased information due to the acquisition of information. Secondly, we determine whether the precision of public information can limit informational rents resulting from strategic distortions between operators. Therefore, the accuracy of information disclosure is largely and fundamentally important and is measured by the relative precision of public and private signals. Without considering the costs to acquire additional information, we assume that a local authority negotiates with two types of operators in the negotiation stage. The operator decides to acquire

information in order to improve the accuracy of the private information. This additional information can affect the correlation coefficient of private signals between operators. The operator who does not acquire additional information, however, may learn from the acquired information simply by observing the correlation coefficient.

The correlation of private signals is a mean of public learning under the effect of coordination pressures because it sends the aggregated information to private operators as well as to the local authority. By contrast, it can also be a mean of private learning under the effect of competitive pressures when operators decide to get information from this correlation. However, the information acquired by an operator can misguide others' strategic decisions between coordination and competition. We show that conflicts between coordination and competition generate two types of distortions, which influence the determination of delegation contracts: strategic distortion and informational distortion.

The strategic distortion in the determination of delegation contracts is linked to two strategies which depend on the accuracy of public and private information. When public information is more precise than private information, the competition motive dominates the coordination motive in the strategic choice of an operator. The operator observes the misleading information sent by the correlation coefficient. Nevertheless, it prefers to rely on public information and information sent by the correlation coefficient rather than on its own private information, when other operators condition their strategies to their private information. It is the strategy of substitutability that depends on public learning. This form of learning from the correlation coefficient has been studied by Vives (2014) in order to explain the paradox of informationally efficient market. When the correlation coefficient is not too large, the public learning is good for full revealing private information in equilibrium.

When private information is more precise than public information, the coordination motive dominates the competition motive in the strategic choice of an operator. A given operator prefers its private information to public information when the others rely more on their private information. It is the strategic complementarity that is linked to private learning. In this case, although the accuracy of private information is higher than that of public information, the correlation coefficient of private signals between operators can send misleading information to the local authority. We show that the strategic substitutability and the strategic complementarity lead operators to deviate from two distinct Bayesian equilibria. In addition, the misleading information sent by the correlation coefficient leads the local authority to leave some informational rent in the determination of the delegation contracts. It is the informational distortion that comes from the strategic distortion. Consequently, the informational rents ceded to an operator are linked to its strategic decisions on the one hand and to its misleading estimates on the other hand.

We show that these distortions can be mitigated by increasing the accuracy of public information. In addition, a local authority can adapt public policy instruments to restrict informational rents given up to the operator. The informational rent that a local authority may concede gives strong incentives (carrots) to an operator to accept the delegation contract when its private estimation is affected by the misleading information. However, when the accuracy of public information surpasses the accuracy of private information, the local authority can extract informational rents from the operator who overestimates the quality (sticks). Otherwise, the local authority leaves informational rents to the operator who underestimates the quality.

From the analysis in this chapter, we highlight that under exogenous disclosed information, the acquisition of information creates informational externalities which make the delegation contracts determined during the negotiation stage sub-optimal. Therefore, we are concerned with other solutions that deliver efficient delegation process. We are interested by the effectiveness of the selection stage of the delegation. To this end, we examine in chapter 4 whether "the competition by comparison"⁵ can allow a local authority to efficiently choose potential operators in the presence of public and private information.

Based on the well-known theoretical work of Shleifer (1985), the competition by comparison (henceforth, Yardstick Competition) has been studied as a regulatory strategy in local markets in Auriol and Laffont (1992) and in the water sector in Tangerang (2009), and Chong and Huet (2009). They show that Yardstick Competition is an appropriate strategy to reveal privately-held information by operators. But this mechanism may result in the possibility of collusion among operators as long as the correlation coefficient of private information is high. Indeed, without exogenous information disclosure, a local authority is assumed to have no information about the "state of nature" of market and the performance of operators. The local authority can reduce the costs of information revelation by learning from the correlation coefficient, which is expected as high as possible. This expectation induces operators to collude in order to prohibit the local authority from revealing private information. Therefore, we combine exogenous public information with Yardstick Competition so as to improve the efficiency of Yardstick Competition in regulating public services.

Under exogenous public information, we relax the hypothesis of Chapter 3 of precise public information and imprecise private information. We find that even if public information is imprecise and private information is accurate, an operator always prefers to overestimate or underestimate the quality of water mains. This phenomenon stems from competitive pressures between operators wishing to win the delegation contract. We therefore examine whether Yardstick Competition with exogenous public information

⁵This mechanism is named Yardstick Competition in Shleifer (1985).

can improve the selection stage by reducing the costs of informational rents.

Considering information asymmetries, we assume that the costs are quadratic and symmetrical between operators in order to capture the effects of adverse selection due to the correlation of private signals. In this context, the strategic decisions of the operators are symmetrical. Each strategic decision is a function of three elements: the strategic interaction between operators, the operator's reaction to public information on the network quality and the correlation of private signals. We show that the accuracy of public and private information can affect the efficiency of Yardstick Competition.

Following the theoretical analysis of Angeletos and Pavan (2007) and Bergemann and Morris (2013), we combine the structure of the correlation coefficients and the information structure with Yardstick Competition. The structure of the correlation coefficients is constituted by two types of correlation: the correlation between the strategic decisions of the operators; the correlation between the individual strategic decisions and the state of the infrastructure. Moreover, the information structure includes information precision, public and private. Under these two structures, our analysis of the Bayesian Correlated Equilibrium shows that a high correlation between private information can make Yardstick Competition efficient. In addition, the Bayesian Nash equilibrium analysis shows that an increase in the accuracy of public information generates different levels of disclosure. These levels are related not only to the strategic interaction, but also to the correlation between operators' decisions. Our findings show that complete or partial information disclosure prevents collusion between operators, which is due to the intensity of competition. We find that, in equilibrium, the level of strategic interaction depends on the relative precision between public and private information. When this level is less than the relative precision of information, Yardstick Competition is more effective in choosing the potential operators than when it is used without exogenous public information. Collusion will be more difficult to sustain when the public information is sufficiently precise. Consequently, competition in the selection stage can be enhanced.

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Part I

THE SOCIAL VALUE OF INFORMATION DISCLOSURE

The Social Value of Information Disclosure

Abstract

Information disclosure has major impacts on institutional and economic transparency in modern society. It has been analyzed in the various fields such as accounting, finance, or economics. This paper comprehensively explores the existing literature on disclosure and its effects on welfare. The paper has five parts: (1) an analysis of the relationship between uncertainty and information disclosure by distinguishing between types of public information; (2) a survey of the literature documenting the social value of information under exogenous information structure; (3) an account of the research on information acquisition underlying the social impact of information precision; (4) a comprehensive summary of the spillover effects of disclosure on welfare focusing on the rationale for potential governmental interventions in internalizing externalities to improve welfare; and (5) a survey of the empirical literature documenting experiments in information disclosure.

JEL classification: D60; D70; D80

Keywords: Uncertainty; Information disclosure; Social Welfare; Information acquisition; Strategic complementarity/substitutability; Spillover effects; Information externalities.

Introduction

The study of information disclosure in economies and markets can be traced back to more than the last three decades of research on information economics. Its traditional basis, however, goes back at least to the "beauty contest" theory in Keynes' *General Theory* in the 1930s and to the discussions between Hayek and his socialist contemporaries in the 1930s about the informational role of prices and the role of market mechanisms in aggregating the dispersed information of agents in the economy.¹

Information disclosure is intended to reduce uncertainty in the strategic decision-making of market participants. Even though Keynes (1936) and Hayek (1945) have contrasting views on the functioning of markets in a world of uncertainty, for both, the objective is to reduce uncertainty by aggregating the dispersed information of economic agents. Following their pioneering works, the economic value of information has been studied in insurance markets, capital markets, and contract theory settings. Recent research shows that an agent's private information can be disclosed by signaling its type to others through price mechanisms. When participants share the same incentives for revealing information, market uncertainty may be reduced. On the contrary, the revelation of additional information may increase market uncertainty through price dispersion. Information disclosure and, in particular, the role of public information emerges gradually from these studies of the revelation of private information in market competition and finance.

The well-known "beauty-contest" game of Morris and Shin (2002) analyzes the social value of public information. Their anti-transparency result prompts debates over whether or not more public information is socially desirable. These debates generate a range of topics encompassing exogenous and endogenous information structures. Therefore two relevant strands of literature are reviewed in this paper. First, for a given item of private information, exogenous public information may increase or decrease welfare. This issue focuses on studying strategic complementarity or substitutability in agents' actions when the information structure is exogenous. For instance, in games with strategic complementarities, agents' linear best responses depend on the average action of others as well as on aggregate and idiosyncratic shocks. In such cases, social welfare necessarily increases with public information if the equilibrium degree of coordination is lower than the socially optimal degree of coordination (Morris and Shin, 2002; Hellwig, 2005; Angeletos and Pavan, 2004, 2007a,b; Hellwig and Veldkamp, 2009; Vives, 1988, 2011a,b; Myatt and Wallace, 2015).

The second topic concerns efficiency in the use and acquisition of information when the information structure is endogenous both in coordination games and market games. In coordination games, Colombo and Femminis (2008), Hellwig and Veldkamp (2009), Myatt and Wallace (2012), and Colombo et al. (2014) show that welfare can increase with public information if, and only if the costs of information acquisition are linear. However, Ui (2014) finds that, when the convexity of the

¹Although Keynes' work is largely considered as the basis of the theoretical research on information economics, it is important to highlight the legal work of the "People's Lawyer" Louis D. Brandeis (1856–1941), lawyer and member of the United States Supreme Court. Based on the principle according to which "Sunlight is the best disinfectant", mandated disclosure and transparency took over the regulatory landscape in the United States and became unquestioningly a regulatory tool since the 1930s.

costs of information acquisition is considered, then welfare may decrease with public information. Yang (2015) studies flexible information acquisition in a global coordination game in terms of efficiency in the use of information. In this case, flexibility means that agents can choose not only the quantity but also the quality of information to acquire. This flexible information acquisition model can be used to analyze the welfare effects of hybrid public information (Myatt and Wallace, 2015) in dynamic coordination games or market games.

In market games, Hellwig (1980), Kyle (1989), and Vives (2014, 2017) show that inefficiencies both in information acquisition and in the use of private information are due to agents' strategic behaviors in the marketplace. An increase in the precision of public information tends to correct these inefficiencies. In addition, while considering externalities generated by endogenous precision on the use of information in a general model, Bayona (2018) finds that the effects of endogenous public disclosure on the social value of private information depend on the weights put on private information by agents.

Recently, theoretical research works on the social value of information disclosure were extended to the experimental field. The main experiments reviewed in this paper show that if agents have level-1 and level-2 reasoning in a "beauty contest" game,² then increasing the precision of public information can improve welfare. The experimental results also highlight the importance of public policy in reducing agents' overreaction to public disclosure. This confirms the previous theoretical results that a government can design optimal contingent taxation that improves efficiency in the use of information.

The remainder of this paper is structured as follows. Section 1 starts with a brief review of a substantial literature on uncertainty and the types of information disclosure. Section 2 examines recent research on the impact of public information on strategic decisions and welfare, when access to information is exogenous. Section 3 reviews the social value of disclosure when information acquisition is endogenous. Section 4 covers the strategic interactions between information disclosure and the use of private information, which generates the spillover effects. Section 5 illustrates the main experiments that examine the social value of information disclosure. Further discussions and remarks are in the conclusion.

1 Uncertainty and information disclosure

In an economy characterized by uncertainties and dispersed information, improving disclosure is valuable to decision-makers facing strategic decisions. However, more information is not necessarily socially desirable. If information disclosure leads decision-makers to ignore or downplay their own private information in their decisions, then markets reveal less new information about market conditions. As such, information disclosure may generate externalities which increase uncertainty in the marketplace. Does information disclosure reduce or increase uncertainty about economic fundamentals? How does disclosure affect the inferences drawn by economic agents? We seek to answer these

²These are referred to as "level- k reasoning", which is developed by Stahl and Wilson (1995) and Nagel (1995). Level- k reasoning has mainly been illustrated in guessing games: players of level- k best respond to players of level- $k-1$. See Section 5 for a detailed definition.

questions through a simple review of different ideas about uncertainty.

1.1 Uncertainty

Knight (1921), in his classic book *Risk, Uncertainty, and Profit*, highlights that the uncertainty of events arises from their uniqueness. He distinguishes "measurable uncertainty" noted as "risk" from "true uncertainty" that cannot be objectively measured by probability. In the same year, Keynes (1921) stresses that it is not generally feasible to enumerate all possible states of the world. In other words, unique developments in the future make it impossible to assign an objective probability distribution to distant future states.

Besides the notion of uncertainty, Keynes brings in a new source of uncertainty in his "beauty-contest" framework. He highlights the role played by subjective guesses of "average opinion" in the formation of stock market prices (Keynes, 1936, p. 156). This new insight into uncertainty considers informational efficiency in studying individual expectations behavior. "Uncertainty" can be modeled by a set of states of nature, one of which will occur. According to the Bayesian decision making process, every event can be assigned a subjective probability by economic agents who in turn choose actions depending on the state of nature. For any given limited information, an agent chooses the best action by maximizing its expected utility function. However, it is uncertain about actions others may take. It attempts to learn from available information kept by others in order to match the state of nature and to match actions taken by others. These informational actions generate strategic uncertainties. In Keynes' model, the consequence of such strategic behavior where each agent tries to guess the average opinion before taking action increases uncertainty as to stock prices.

In contrast to Keynes, Hayek (1945) suggests that markets aggregate the dispersed information of agents in the economy. A market should be considered as a means of communicating information among agents, and it can provide informative signals for decision making. Agents make their optimal inferences from market prices and other accessible noisy public statistics that aggregate the actions of other agents, about which agents are uncertain. These noisy public statistics may be dispersed data on output, employment, investment, or volume of trade that are collected, aggregated, and processed by systems and platforms.

Following Hayek's ideas, Lucas (1973) declares that information is imperfect, not only in the sense that the future is unknown, but also in the sense that no agent is perfectly informed as to the current state of the economy. This highlights the "market uncertainty" concept. Market uncertainty concerns the unknown information in market prices, due to the lack of information, knowledge, and experience. But agents can learn from market statistics in order to deal with the lack of knowledge. Sometimes, agents learn directly from market interactions. Extending the well-known "island model", Lucas (1973) finds that agents form their rational expectations in an optimal way. This means that with respect to the state of nature, agents minimize the expectation of the square of the forecast error conditional on their available information. By contrast, Frydman (1983) shows that agents cannot optimally learn and forecast the relative precision of demand and supply parameters based on the price system or market aggregates. When formulating their decisions in the Bayesian way, the informed rational agents respond to increased price informativeness with decreased weight given

to their private information. This raises uncertainty as to market prices.

In a nutshell, Keynes' "Strategic uncertainty" contrasts with Hayek's "market uncertainty". Strategic uncertainty integrates the disclosed information into agents' strategic interactions. Limited perception makes agents guess others' behaviors. Hence, disclosure, whether public or private, conveys information about economic fundamentals; at the same time it serves as a focal point for agents' beliefs. Hayek's market uncertainty focuses on information aggregated by markets. It emphasizes that a competitive price system provides public signals for agents' decision-making, despite the lack of a central organization and disclosure of the relevant information to economic agents. Agents learn from the equilibrium price and update their beliefs based on the information gathered from their strategic transactions. In both Keynes's "strategic uncertainty" and Hayek's "market uncertainty", if agents overreact to the disclosed information, then the uncertainty in the economy increases.

1.2 Market Regulation

Market uncertainty also has highly significant normative and positive implications for microeconomics and in particular for economic regulation. Weitzman (1974, 1978) discusses whether price or quantity is a better instrument in environmental regulation under uncertainty when market participants have heterogeneous expectations about the underlying economic fundamentals, such as productivity. In the presence of uncertainty, price and quantity instruments transmit information in quite different ways. He finds that quantities are better signals in a market requiring a high degree of coordination. Other things being equal, price could better reveal information when the number of independent production units becomes larger.

Moreover, economic regulation under uncertainty considers that disclosing private information by price or quantity instruments is a second-best problem of regulation. In a notable example of air pollution regulation, Weitzman (1974, 1978) states that interactions between the regulator and the firm depend on random variables, which represent respectively, independently unobservable states of the world, such as cost shocks, benefits shocks during the performance of contracts between a regulator and a regulated firm. At equilibrium, the ex ante price instrument which maximizes the regulator's expected utility depends on the contingent messages revealed by random variables. The quantity, which maximizes the regulated firm's ex-post profit, depends on the information disclosed by the ex-ante price instrument. However, neither instrument yields an ex-post optimum because welfare effects of information disclosure depend on the source of uncertainty arising all the time.

For all the discussion above, information disclosure can reduce uncertainty in coordination games, the market, and regulation. This has an impact on the behavior of rational agents which is contingent on noisy public information and on their private information. Thus, a new source of uncertainty, reducing welfare emerges from the fact that information disclosure has negative externalities for agents' strategies. Seeking to limit this negative impact, earlier papers associate types of public disclosure with public information sources.

1.3 Types of information disclosure

Since agents' strategies are contingent on noisy public statistics, which aggregate the actions of others, the types of information disclosure affect not only agents' strategies in market equilibrium, but also the social value of increasing precision of information.

Verrecchia (2001) surveyed three extant categories of public disclosure research in accounting. The first category of research is designated as "association-based disclosure". It examines the relationships between exogenous public disclosure and price changes or trading volume. The second category is defined as "discretionary-based disclosure", where disclosure becomes endogenous. It examines managers' and/or firms' incentives to voluntarily disclose their own information. In the presence of uncertainty, a manager maximizes the current market value of a firm. If disclosure is costly, then information that favorably enhances the firm's current market value will be disclosed, but information that unfavorably improves the firm's current market value is withheld. The third category is "efficiency-based disclosure". It investigates whether disclosure arrangements are preferred or not in the absence of prior knowledge of the information. Disclosure arrangements are efficient in that they lead to a reduction in information asymmetry and they are preferred unconditionally. This category highlights the link between public disclosure and information asymmetry reduction. A high quality disclosure, either exogenous or endogenous, reduces information asymmetry and decreases the private benefits of information gathering.

In economics, the types of information disclosure are combined with public information resources. If public information monitors fundamentals, then it is exogenous. If public information tracks market activity, then it is endogenous. For example, firms that supply homogeneous products are uncertain about the shocks of demand in the market. The public indicators of economic activity enable firms to make supply forecasts. This public information is exogenous. As there is interaction among firms, they use strategies that are contingent on noisy public information and private information. The information about the strategies of competitive firms can be aggregated and transmitted by the average price in the market. This information is considered endogenous. Both exogenous and endogenous information disclosure have been widely studied in linear-quadratic normal games with incomplete information in order to analyze the social value of disclosure. Agents' reactions to public disclosure of the state-relevant payoff are analyzed as strategies in information acquisition and the use of information. Depending on agents' reactions, the social value of public disclosure under exogenous information structures may differ from that under endogenous information structures.

In an environment with exogenous information disclosure, agents may have access to more or less precise private information. If agents overreact to public information, then an increase in the precision of public information is not socially desirable (Morris and Shin, 2002). But, this result is overthrown in other research works. Providing more precise public information is always welfare improving if the equilibrium degree of coordination is lower than the socially optimal degree of coordination, or if agents use their private information inefficiently (e.g., Angeletos and Pavan, 2007a; Hellwig and Veldkamp, 2009; Vives, 2011b; Colombo and Femminis, 2014). In recent theoretical analysis, Ui and Yoshizawa (2015) characterize the social value of public information under exogenous information structures for eight types of games and find, however, that welfare is increasing with the precision of

public information.

In an environment with endogenous disclosure, whether or not the precision of public information improves welfare depends on agents' responses to the precision of privately-held information, and on the marginal cost of information acquisition. If the marginal cost private information exceeds that of public information, then welfare necessarily increases with public information (Colombo and Femminis, 2008; Hellwig and Veldkamp, 2009). If agents ignore their responses to private information, then the endogenous public disclosure may be uninformative (Colombo et al., 2014; Vives, 2017). More recently, by extending the analysis of Ui and Yoshizawa (2015), Bayona (2018) explored welfare effects of the precision of disclosed information under endogenous public information structures. The author finds that higher precision of endogenous public disclosure increases the overall precision of signals and thus improves welfare.

2 Exogenous information disclosure

Agents receive some information (private or public), which is partially or freely accessible, intended to guide their strategic actions in the marketplace. Each agent benefits from greater access to information that reduces the uncertainty about the fundamentals of the economy or about the strategies of other agents. However, providing more public information may lead agents to ignore or downplay the private information in their strategic actions and hence increase uncertainty. In the following, we describe the welfare effects of an increase in the precision of public information in coordination games and illustrate how more precise disclosure affects agents' strategic behaviors in competitive markets.

2.1 Coordination games

The social value of information disclosure in coordination games with exogenous information disclosure has been studied by Morris and Shin (2002), Svensson (2006), Morris et al. (2006), and Cornand and Heinemann (2008) in the beauty contest; by Angeletos and Pavan (2004) in an investment game; by Hellwig (2005) in a business-cycle framework; and by Angeletos and Pavan (2007a,b) in a general economic application. In these games, agents have symmetric linear-quadratic payoff functions and receive normally distributed public and private signals about the state of fundamentals. Public information is of a double-edged nature: it conveys information about economic fundamentals and it serves as a focal point to coordinate the actions of individual agents. As in Keynes' view of the "beauty contest", each agent's optimal action depends not only on its expectation of the exogenous fundamental, but also on its expectation of other agents' average actions. Different results are obtained to answer whether providing more precise public information is socially desirable in coordination games with strategic complementarity.

2.1.1 Strategic complementarity at the individual level

Morris and Shin (2002) consider that, when choosing an individual action, each agent puts a positive weight on the expected fundamental state and on the expected actions of others. Since this weight

indicates the extent to which an agent is motivated to coordinate its actions with others' actions, it reflects a strategic complementarity of actions at the individual level. If it is large (close to 1), then an agent's decision is predominantly influenced by the anticipation of what others will do, rather than by its own expectation about the underlying state. Hence, this level of strategic complementarity induces agents' overreaction to public information. In other words, agents put a greater weight on public information to align their decisions. Morris and Shin (2002) find that if agents have access to very precise private information, then an increase in the precision of public information generates inefficiently high price volatility that reduces welfare. This is one of the pioneering papers that investigate the social effects of public information in economies with strategic complementarity in individual actions. However, they do not say much about the degree of public disclosure that can improve welfare.

Svensson (2006) relaxes their result of "anti-transparency" and points out that a critical threshold for public information disclosure can be defined. Whenever the degree of disclosure is greater than this critical value, social welfare is increasing. In a reply to Svensson's comment, Morris et al. (2006) agreed with the issue concerning the degree of disclosure. Nevertheless, they imposed a restriction specifying that the precision of public information must be no lower than that of private information. There can be a critical threshold for public information disclosure such that social welfare is increasing with public information. The results of Morris and Shin (2002), Svensson (2006), and Morris et al. (2006) showed that the social value of public information is strictly limited by the strategic complementarity in individual actions with a high precision of private information.

On the basis of these previous results, Cornand and Heinemann (2008) reconsidered the assumption according to which knowledge is common to all agents, and stressed another issue from Svensson's (2006) comment in a more elaborate "beauty contest" model. They added a second component to the degree of disclosure, *the degree of publicity*, which is the proportion of agents who receive public information.³ The optimal degree of publicity depends on the weight given to strategic uncertainty and on the relative precision between public and private signals. For those who receive public information, greater precision of disclosed information about the fundamentals enhances the efficiency of private decision-making. Therefore, the degree of publicity reduces social inefficiency resulting from the private value of coordination.

Cornand and Heinemann (2008) also find that strategic complementarity at the individual level generates an overreaction to public information. However, they highlight the fact that if more precise public information reaches only a fraction of agents, then partial disclosure can reduce the overreaction of agents; moreover, if the public information is at least twice as precise as the private information, then the optimal degree of publicity increases with disclosure. Satisfying these two conditions, an increase in information precision can improve the expected welfare. Further, they argue that since information is partially disseminated, the degree of publicity may generate a problem of manipulation of information that deteriorates the social value of public information.

³Since the information provider chooses agents or media to communicate the policy, the degree of publicity is exogenous in Cornand and Heinemann (2008). There is no endogenous information acquisition as in Sims (2003) and Reis (2004), who consider that agents face costs of acquiring, absorbing, and processing information and have limited capacity to incorporate available information.

In summary, in the coordination game with strategic complementarities at the individual level, agents' overreaction to public information reduces welfare. There are nonetheless two conditions that allow increased precision of public information to improve welfare: a threshold value of precision in public disclosure can be exogenously set up; and more precise public information reaches only a fraction of economic agents. Having said that, however, Angeletos and Pavan (2004, 2007a,b) observe that these conditions are not necessary to analyze the social value of public information in games with strategic complementarities. When taking into account the comparison of the degrees of coordination, they ask whether social welfare increases or decreases with public information. To this end, they compare the equilibrium degree of coordination relative to the socially optimal degree of coordination; at the same time they compare the equilibrium use of information relative to the socially optimal use of information.

2.1.2 Strategic complementarity at the social level

In an investment game with strategic complementarity and information heterogeneity, Angeletos and Pavan (2004) note that the precision of public announcements, policy measures, and news in the media affects the interpretations of such information across economic agents. They describe two kinds of public information precision: (i) the *absolute* precision of public information, which is a reduction in the level of common uncertainty for a given level of idiosyncratic uncertainty, and (ii) the *relative* precision of public information, which is a reduction in the heterogeneity of expectations across market participants for a given level of overall uncertainty. Agents align their investment decisions in accordance with the precision of information in their information structures. But, the level of coordination, at equilibrium, is not high enough with regard to the socially optimal level. Therefore, Angeletos and Pavan (2004) investigate the social value of information disclosure with the degree of coordination.

The authors consider that strategic complementarities may be present at the social level. Integrating the degree of coordination into the welfare function, they examine how the precision of public information affects equilibrium allocations and improves social welfare. If the equilibrium degree of coordination is lower than the socially optimal degree of coordination, then welfare increases with the relative or absolute precision of public information. By contrast, if the equilibrium degree of coordination is higher than the socially optimal degree of coordination, then welfare may decrease with public information. This result stems from the fact that, even though agents have precise private information, they overreact to public information.

Angeletos and Pavan (2007a,b) analyzed the social value of public information with strategic complementarities in a general economic application. To examine the socially optimal coordination, they distinguish the efficient use of information from the equilibrium use of information. To this end, they consider "team efficiency"⁴ as a benchmark, in which an optimal strategic action of each agent is contingent on a given exogenous information structure. This optimal strategic action is

⁴The concept of "team efficiency" is based on the idea that information is dispersed and cannot be communicated to a "center" (Hayek, 1945; Radner, 1962). Further, Arrow (1985) points out that agents' decision making and knowledge are dispersed, and the "team efficiency" is to determine an allocation of information and a set of decision rules for the individual agent so as to optimize some given payoff function.

considered to be the most efficient use of information. Introducing the accuracy and the commonality of information into the coordination game, they find the equilibrium use of information presented as the second-best strategic action of each agent and then analyze the effects of disclosure on the equilibrium use of information.

For a given commonality, equilibrium welfare necessarily increases with the accuracy of information. However, whether welfare increases or not with the commonality depends on the relationship between the equilibrium and the efficient use of information. For example, welfare necessarily increases with the commonality if the equilibrium use of information is lower than the efficient use of information. Indeed, a high strategic complementarity in equilibrium strengthens the reactions of agents to public information. Releasing more information publicly increases welfare, hence the commonality of information is socially desirable. By contrast, if the equilibrium use of information is higher than the efficient use of information, then more disclosure is not socially desirable because welfare decreases with public information.

Angeletos and Pavan (2004, 2007a,b) also stressed that welfare could be enhanced by a policy intervention. For instance, a linear tax system may give strong incentives to agents to align their decisions. A tax rate that is contingent on ex-post aggregate activity may also correct agents' incentives to align their decisions. The optimal contingency of the tax rate is measured by the gap between the equilibrium level of coordination and the optimal level of coordination. For example, a policy intervention implements an efficient allocation as the equilibrium if and only if a tax rate can increase with the aggregate activity so that agents' overreaction to information disclosures is reduced. As a result, welfare is improved.

In a nutshell, the works of Angeletos and Pavan (2004, 2007a,b) show that when strategic complementarity at the individual level is smaller than strategic complementarity at the social level, more information disclosure improves coordination and so has positive effects on welfare. However, they do not say much about the social value of private information with strategic complementarity. Hellwig's (2005) analysis can provide some insights into this.

2.1.3 Microfounded macroeconomic model

To analyze the welfare effects of disclosure, Hellwig (2005) presents a micro-founded macroeconomic model in which economic agents are heterogeneously informed about the underlying monetary shocks. In this model, the author describes the relevant efficiency benchmark as a "*Decentralized Information Optimum*" that is the solution to a planner's problem. Under the assumptions adopted in this work, the social planner can dictate to all agents how they should act depending on their information structures. In this way, the author may compare the equilibrium use of information with the efficient use of information in a specific application, namely, an incomplete nominal adjustment model with monopolistically competitive agents.

Hellwig (2005) notes that there is a complementarity in the pricing strategies of agents because of the exogenous public information, and hence private information is inefficiently used in equilibrium. Agents in equilibrium pay too much attention to public information, but too little to private information sources. However, the author finds that if the equilibrium pricing strategies coincide with

efficient pricing, then agents use the available information efficiently. Thus, any improvement in the precision of information is welfare-enhancing. But any difference between the efficient pricing and the equilibrium pricing strategies induces inefficiencies in the use of information. These inefficiencies may be large enough to make disclosure socially undesirable.

In addition, the author analyzes welfare effects of information disclosure by addressing the questions of output volatility and price dispersion in the markets. When information is homogeneous, agents in equilibrium make the use of public information more efficient than the use of private information. For example, in monopolistic price-setting model, a greater weight on public information minimizes output volatility. Although agents are heterogeneously informed in the marketplace, the higher the strategic complementarity in price-setting decisions, the more weight is put on public information by agents. The price dispersion is thus reduced because private information has less of an impact on price adjustments. As a result, total welfare increases with public information.

However, if agents decide to condition their price-setting decisions on private information, then they neglect the point that, by doing so, the uncertainty of overall demand is rising. This uncertainty finally increases the overall price dispersion, which departs from the socially desirable level. Therefore, improving private information may be welfare-reducing. Overall, Hellwig (2005) points out that, if the social planner prefers to increase output volatility and reduce price dispersion, then greater precision in information disclosure should improve welfare. Otherwise, more precise private information reduces welfare.

To sum up, in coordination games with strategic complementarity, there are two conditions ensuring that increased precision of public information can improve welfare. For a given precision of private information, the equilibrium degree of coordination is lower than the socially optimal degree of coordination. In addition, the equilibrium use of information is lower than the efficient use of information if the social value of private information is taken into account.

2.2 Rational expectations equilibrium

Considering how providing more precise public information affects agents' strategic behaviors in competitive games with exogenous information disclosure, we turn back to Hayek's insight of viewing the price system as a way to transmit information. Together with Hayek's insight, the concept of rational expectations equilibrium (henceforth REE) is that prices serve a dual role as indexes of scarcity and conveyors of information. This concept was first proposed by Muth (1961) and later developed by Lucas (1973). Radner (1979) and Grossman (1981) introduced the analysis of private disclosures of information by equilibrium prices into rational expectations.

In the competitive price-setting model, each agent is endowed with private information about others. The beliefs of agents influence their actions, which then affect the informational efficiency of prices. In other words, information revealed by market prices can allow agents to condition their expectations on their information structures. Hence, rational expectations equilibrium is informationally efficient if prices are sufficient statistics that aggregate information about the actions of others. However, if prices are fully revealing at equilibrium, then more precise private information generates an additional free-riding effect in information acquisition. The informational advantage of

informed agents in the marketplace decreases and they have no incentives to purchase costly information. Consequently, the competitive market breaks down. This is the notable Grossman-Stiglitz paradox about the impossibility of informationally efficient markets (Grossman and Stiglitz, 1980).

If economic agents realize that prices can convey information, then they neglect the impact of their responses to precise private information on the actions of others. In other words, economic agents at equilibrium do not take into account the fact that the use of private information in their strategic action affects the informativeness of prices. Therefore, providing more precise public information reduces total welfare. This is the well-known "schizophrenia" problem defined by Hellwig (1980), where the REE is not informationally efficient.

The solution, making REE implementable, is that the privately-held information can be predicted by the joint information of others. In doing so, a setup of a competitive supply function with a continuum of agents is employed to prevent prices from being fully revealed, and hence prevent the market from collapsing. Agents, such as sellers, compete to satisfy a downward sloping demand; then each agent receives a noisy signal about the uncertain valuation of the commodity. In such an environment, Kyle (1989) and Vives (2011a,b) characterize a unique symmetric linear Bayesian supply function equilibrium, where the social value of private information is taken into account to model agents' strategic behaviors.

2.2.1 Imperfect competition

Kyle (1989) examines a rational expectations equilibrium in the context of imperfect competition, and then sets out a competitive model with exogenous information disclosure. Since private information of informed agents is revealed and conveyed by market prices to uninformed agents in a financial market, the author introduces a noisy trade to prevent prices from being fully revealed. He derives a symmetric linear Bayesian equilibrium, where each agent faces a linear residual supply curve. All agents are aware of the price impact of their trades in financial markets and compete in supply schedules. The author finds that if informed agents have the same degree of risk aversion and the same precision of information, then they act as monopolists at a unique symmetric linear Bayesian equilibrium. They withhold any precision of private information about the liquidation value of the commodity from markets in order to restrict the quantity they trade monopolistically. Thus, the precision of privately-held information is welfare-reducing.

Further, he argues that private information should be precisely analyzed so as to model an agent's capacity to influence market prices at the same time as the agent learns from prices. To this end, he compares the imperfect competitive model to Hellwig's (1980) competitive model. He finds that informational efficiency in imperfect competition is lower than in perfect competition.⁵ Then, he examines the sensitivity of quantities traded by informed agents to their own private information. He shows that the quantity traded by each informed agent is more sensitive to its precise private information. Thereby, market prices become more informative at equilibrium with imperfect competition than in the competitive model. In addition, he notes that, since the informativeness of

⁵Informational efficiency is defined as the fraction of private information of informed agents aggregated and disclosed by market prices.

prices at equilibrium is limited by the monopoly power of agents, agents get more marginal value from their precise private information. Even when agents are risk-neutral, they have incentives to purchase costly information in order to enforce their market power. As a result, the informativeness of prices may be reduced at the symmetric linear Bayesian supply function equilibrium.

Kyle (1989) explicitly models agents' strategic behaviors depending on the precision of private information. He points out that reducing exogenous information disclosure by the market is beneficial to economic agents, who have the capacity to acquire and process information. The strategic behavior model can be a special information aggregation solution to the "schizophrenia" problem. Having said that, the work of Kyle (1989) does not say much regarding the social benefits of the precision of public information. His analysis, however, opens up the study of strategic behaviors in acquiring information at a cost under exogenous information structures.

2.2.2 Supply function competition

Based upon Kyle's analysis, Vives (2011a,b) considered more elaborate supply function competition, in which noise traders are ignored, even though the presence of noise traders prevents trade from collapsing. He extended Kyle's analysis to study how the precision of private information is associated with adverse selection and market power when public information is exogenous.

In these works, the author assumed that a finite number of agents compete in supply functions in a homogeneous product market. All agents have the same prior distribution over the random production costs. Information about the costs of other agents is assumed to be acquired at a cost. As long as costs are correlated, the precision of an agent's private information is useful for improving the estimation of cost parameters. Therefore, the correlation between the cost parameters across agents and the precision of private information are used to determine adverse selection and market power.

When the correlation coefficient is different from one, there is a unique market clearing price for a given exogenous information structure in a symmetric linear-Bayesian supply function equilibrium. This equilibrium is privately revealed, but it is distorted because of the effects of the precision of private information on market friction, such as adverse selection and market power. If there is no correlation between the cost parameters, or the received private information is perfect, then each agent does not learn about its cost parameter from prices. The adverse selection problem disappears; the total welfare increases with the precision of private information.

If the cost parameters are correlated, or the information received is imperfect, then there is an adverse selection problem. For instance, when the cost parameters are positively correlated, a high price conveys the information that the costs of other agents are high. On the contrary, if the cost parameters are negatively correlated, then a high price may convey the information that the costs of other agents are low. Therefore, agents rely more on their private information in the supply competition, although the equilibrium price aggregates information about the costs of other agents in the marketplace. The precision of information disclosure increases, the adverse selection problem worsens, and the slope of the supply function becomes steeper in the marketplace. Welfare can decrease with both public and private information.

A negative correlation also shows that a high equilibrium price may be good news for an agent, who has lower costs than others. The agent reacts more to public information conveyed by prices, and the supply functions become flatter. Vives (2011b) finds, nevertheless that if the information conveyed by market prices is perfect, then agents no longer have any incentive to increase the precision of their private information by acquiring information. Market prices cannot thus contain any additional information on the cost parameters; the equilibrium collapses. This result is consistent with the paradox of Grossman and Stiglitz (1980). Hence, more precise public information is not valuable in strategic supply competition when there is a negative correlation between the cost parameters.

Further, Vives (2011a,b) finds that more precise private information generates market power over and above the full information level. In supply function equilibrium, there is an additional welfare loss due to market power induced by private information. Vives (2011b) uses the aggregate Lerner Index to compare the supply function competition model with three other competitive contexts: perfect competition, Cournot competition, and collusion.

When the correlation is positive, market power makes prices converge towards the collusive level. But when the correlation is negative, market power is reduced. Market competition is intensified with respect to the full information level. If both the correlation and the precision of private information are nearly perfect, then a Bayesian Cournot equilibrium appears. In this case, an agent sets a quantity strategy depending only on its private information. In addition, when there are two agents, welfare can increase both with public and private information because market power in the marketplace is weak. But when there are three or more agents, welfare decreases with public information because market power is high.

Finally, compared with Bayesian Cournot competition equilibrium, market power in the supply function competition model induces both distributive and aggregate inefficiencies. These inefficiencies increase not only with the correlation of cost parameters, but also with noisy privately-held information. Vives (2011b) points out that the solution to restore the efficiency is a quadratic subsidy. For example, if a quadratic subsidy can be used to "compensate" for the distortion generated by the market power added in total costs, then an agent would act effectively as if it was competitive. This subsidy increases with the cost adjustment, and the correlation of costs. It gives incentives to agents to behave competitively in supply decisions, which both depend on their own private information and on public information conveyed by prices. Greater precision of exogenous public information about aggregate uncertainty can improve the efficiency of supply function competition.

In summary, Kyle (1989) and Vives (2011a,b) examined the effects of the precision of disclosed information on agents' strategic behaviors in competition games. They found that, for a given precision of exogenous public information, more precise private information generates inefficiency in rational expectations equilibrium and supply function competition. When reacting to its private information, an agent in equilibrium ignores the impact of its action on the informativeness of prices. In order to improve the efficiency in rational expectations and supply function competition, more precise public disclosure reaches only economic agents, who have the capacity to acquire and process information. Their result confirms the idea of "the degree of disclosure" in coordination games. Meanwhile, questions remain to be treated: Can public information improve or reduce welfare when economic agents strategically acquire additional information under endogenous information

structures?

3 Endogenous information acquisition

In the literature cited above, the social value of disclosure is analyzed within an exogenous information structure. Public information serves as a focal point for economic agents to predict the actions of others and coordinate their own. The overreaction of agents to public information may generate welfare-reduction in games and in markets.

When adjusting the strategies that are contingent on noisy public and private information, agents can improve the precision of a signal by learning from aggregated information or by acquiring additional information. This constitutes an endogenous source of public information. Whether better information precision increases or decreases welfare depends on a comparison between the equilibrium and the socially optimal strategy profile. This issue is central in a few recent contributions on the social value of disclosed information in games and in markets under endogenous information structures. For instance, Hellwig and Veldkamp (2009) and Myatt and Wallace (2012) extend the "beauty contest" game to the case in which public information is endogenous. Vives (2017) examines the welfare effects of public information in markets under endogenous information structures.

In coordination games or market games with endogenous information structures, economic agents react to both variation in price (the volatility and the dispersion of price) and variation in the average action by changing the precision of the information they acquire in equilibrium. Thus, three approaches to endogenous public information can be identified. First, agents learn from information aggregated and disclosed by the price, or agents learn from interactions with others. Second, agents choose whether or not to pay for acquiring additional information. Finally, agents choose the capacity to process and transmit information. The present section reviews a few recent contributions linked to such approaches.

3.1 Noisy rational expectations equilibrium

In rational expectations equilibrium, prices are the only variables economic agents can use to enhance the precision of their private information. But the fully revealing rational expectations equilibrium through market prices collapses in economic models with endogenous public information. Specially, if information can be freely communicated by prices, then no economic agents would ever pay to gain precision. Therefore, the noisy rational expectations model is set up in order to prevent equilibrium collapsing.

3.1.1 Partially revealing rational expectations equilibrium

Grossman and Stiglitz (1980) analyzed the capital markets with heterogeneous agents. They extended the noisy rational expectations model introduced by Lucas (1973) and proposed a competitive rational expectations equilibrium model to examine the effects of partial information conveyed by prices on agents' strategic decisions under endogenous information acquisition. They found that the fully revealing rational expectations equilibrium breaks down if more precise private informa-

tion of informed agents makes market prices fully informative. This paradoxical result hinges on a free-riding effect in information acquisition. This means that uninformed agents decide to freely get information about the underlying fundamentals from market prices which become endogenous public signals.

Grossman and Stiglitz (1980) determined a unique linear partially revealing rational expectations equilibrium, which is strictly linked to the fraction of agents who decide to become informed. Indeed, the full revelation of private information by market prices is prevented by a random noise term added to the aggregate supply. Price movement can be caused by either supply shocks or noisy trading. Hence, the price will be more informative with more precise noisy terms. While seeking to improve the precision of private information to raise its expected utility, an agent pays to become informed when everyone else is uninformed. If the marginal benefit of information acquisition is higher than the marginal cost of information acquisition, then agents in equilibrium have incentives to acquire information. The paradox is resolved.

A minor limitation of Grossman and Stiglitz (1980) is that their static model does not say much about the welfare effects of private information, even though endogenous public signals have both informational and allocation roles; agents' information acquisition decisions are strategic substitutes. On the basis of their work, the note of Ou-Yang and Wu (2017) shows that when private information tends to be perfect, the market converges to strong-form efficiency. There is still significant trade between informed and uninformed agents for any finite information costs. Although market prices become more informative, welfare increases with precise private information because net trade increases. As a result, in market games with endogenous public information, welfare can increase with the precision of private information if it tends to be perfect.

Verrecchia (1982), in line with Grossman and Stiglitz (1980), relaxed the special assumption of a single piece of acquired information. Then, the author assumed the characterization of rational expectations equilibrium with heterogeneous information found by Hellwig (1980) and modeled the idea that market prices can aggregate information about agents' actions. He showed that there is a rational expectations competitive equilibrium, in which the level of precision of costly information is endogenously determined.

3.1.2 The precision of endogenous private information

Verrecchia (1982) analyzed a large competitive market where economic agents have heterogeneous preferences about risky and less-risky assets. Under this setting, each agent learns from prices and costly information acquisition. Thus, private information is endogenously determined.

The author assumed that each agent may acquire costly information if the price does not depend on its actions. In other words, each agent in equilibrium takes into account that its response to private information affects the informativeness of the price. When all agents behave in this way, prices aggregate the total amount of dispersed information acquired by agents, but partially reveal it. This gives strong incentives to agents to acquire more information. Therefore, equilibrium prices and information acquisition have to be solved simultaneously because each affects the other. He found that prices can reveal more information because the level of noise in the relationship between

agents' demands and equilibrium price is reduced; agents become more risk tolerant as a group; and the cost of acquiring information decreases.

Moreover, more precise costly information acquired by agents yields more precise information partially revealed by prices. Hence, prices serve not only as a transmitter but also as an aggregator of information. Agents can benefit from the informativeness of prices and information acquisition. Their utility increases with the level of precision of endogenous private information. The informationally efficient market is reinforced by resolving the paradox of Grossman and Stiglitz (1980) and Hellwig's (1980) "schizophrenia" problem.

The contribution of Verrecchia (1982) yields another issue that agents' strategies for information acquisition depend on environments with endogenous public and private information. This issue is developed by Manzano and Vives (2011).

3.1.3 Endogenous public and private information

Considering noisy rational expectations model, Manzano and Vives (2011) are interested in public learning and private learning from information aggregated by market prices. They used a CARA-Gaussian model in which the equilibrium is based on an agent's decision about information acquisition. Within this framework, both public and private information track market activity, so they are endogenous.

Manzano and Vives (2011) found that endogenous public information is not the only source of multiple equilibria. The key factor is what those authors refer to as the level of the precision of private information relative to the precision of public information. They assumed that a fraction of agents privately learn further information from market prices. In addition, there is a correlation between noise terms of private information across agents. The level of the informativeness of price increases with this correlation. By market prices and the correlation, agents decide which information they depend on more for improving their strategies. In this case, private information may be more or less precise than public information. For instance, if the actions of others depend more on private information, then an agent has more incentives to rely on its private information. This is private learning due to strategic complementarity in actions. The private precision increases. By contrast, an agent finds that it is optimal to base its action on the improved public information when the actions of others depend on the private information. This is public learning due to strategic substitutability in actions. The public precision increases. Therefore, there are multiple equilibria in the rational expectations model when private learning is stronger than public learning.

The authors also asked under what conditions a unique rational expectations equilibrium arises with endogenous information structures and showed the following among others. When the precision of private information is higher than that of public information, agents overreact to endogenous private information. Hence, an agent's utility is not stable at multiple equilibria and the market is informationally inefficient. But when private information is less precise than public information, a unique rational expectations equilibrium arises. An increase in the informativeness of price due to a high correlation can reduce agents' overreaction to private information. As a result, each agent's expected utility is stable at the unique equilibrium.

They showed that Grossman and Stiglitz' (1980) results about the partial revelation of prices is robust when endogenous private information is taken into account. But this paper does not analyze the social value of information under endogenous information structures. To this end, Vives (2017) considers the social value of endogenous public information in market games, while Colombo et al. (2014) study the social value of information when the precision of private information is endogenously determined.

3.1.4 The social value of endogenous public information

Conducting welfare analysis of market games, Vives (2017) examined whether providing precise information is socially valuable in rational expectations equilibrium. The author compared two characteristics of public information: exogenous and endogenous. He assumed that agents' supply function strategies are conditional on market prices. If information about the fundamentals is commonly sent to agents by the price, then it is exogenous. By contrast, if an agent's strategies are dependent on public information about the actions of others that the price aggregates, then public information is endogenous. He then studied the effect of the use of private information on the social value of endogenous public information in relation to exogenous public information.

The precision of endogenous public information depends quadratically on the best-response function of agents to private information. A high precision of private information increases the overall precision of endogenous public information, which improves welfare. If agents overreact to exogenous public information sent by market prices, then they reduce enough weight placed on privately-held information in equilibrium for endogenous public information to be less informative. This is a negative crowding-out effect of exogenous public information on endogenous public information that causes welfare loss in market games. Therefore, Vives (2017) proposes "the team-efficient solution" so as to reduce the negative impact of exogenous public information on the use of private information. He found that the efficient use of private information generates a higher precision of endogenous public information, which in turn increases the accuracy of information. More precise information, public or private, increases welfare.

This result is similar to that reported by Angeletos and Pavan (2007a, 2009). The analysis of Vives (2017) can be applied to business cycle policy, demand schedule competition, and monopolistic competition. Nevertheless, it does not show that endogenous public information can overturn the social value of private information in market games, as demonstrated by Colombo et al. (2014) and Bayona (2018). The next section deals with the role of public information in coordination games with endogenous information structures. Agents are assumed to acquire or pay attention to information at a cost.

3.2 Endogenous information structures in coordination games

In coordination games with endogenous public information, information can be acquired at a cost. Depending on their strategic actions, economic agents decide whether or not to adjust their information precision by acquiring more information. This issue has been explored in Hellwig and Veldkamp (2009) and Myatt and Wallace (2012).

3.2.1 Multiple equilibria in coordination games

Hellwig and Veldkamp (2009) examined the relationships between information acquisition and strategic actions of agents. In their model of coordination games with endogenous information structures, they found that a strategic complementarity between agents' actions also induces the coordination motives in information acquisition. For instance, "agents who want to do what others do, want to know what others know". Moreover, the source of multiple equilibria is what they refer to as the marginal value of additional public information relative to the marginal value of additional private information.

Those authors considered that there is a co-variance between the average price and the unobserved state, which is conditional on endogenous information structures. Although a higher precision of endogenous public information increases the co-variance, agents can improve the precision of private information at a cost. For a given private collection of information, if the marginal value of additional public information is higher than that of additional private information, then multiple equilibria emerge from a stronger co-variance, which reveals better information about the actions of others. Likewise, for a given co-variance, if the marginal cost of improving the precision of private information is higher than the marginal value of additional public information, then multiple equilibria arise from more public information acquisition. Hence, welfare decreases with endogenous public information if improving the precision of private information is costly.

Further, in their dynamic model with continuous and costly information acquisition, Hellwig and Veldkamp (2009) showed that agents may improve the precision of information at a non-convex cost. Public or private information acquisition is more valuable if and only if others do so as well. But an increase in the precision of public information results in a decrease in the precision of private information. They referred to this effect as a crowding-out effect of endogenous public information on endogenous private information. Multiple equilibria appear when agents react to more valuable public information, then welfare decreases with endogenous public information.

They also stressed that additional information leads agents to know more about the underlying state and the actions of others if their incentives for information acquisition are "knowing what others know". The combination of information acquisition and endogenous public information leads to multiple equilibria in coordination games. By contrast, if information is privately collected by each agent (the signals are uncorrelated), then it may not directly inform an agent about the actions of others. In this case, the uniqueness of equilibrium can be ensured, which increases with the precision of endogenous private information. This full privacy of information is a more restrictive requirement than that of Morris and Shin (2002) to guarantee a unique equilibrium. Myatt and Wallace (2012) pointed out, however, that the full privacy of information is neither necessary nor sufficient for the uniqueness of equilibrium.

3.2.2 Unique equilibrium in a coordination game

Myatt and Wallace (2012) analyzed the social value of endogenous public information in a coordination game by relaxing two conditions in the model developed by Hellwig and Veldkamp: first, the cost function of public information acquisition is non-convex; second, public information measured

by the correlation coefficient of information noise between any two agents is exogenous.

Using a more elaborate "beauty-contest" model, the authors considered convex costs of information acquisition to examine whether welfare increases or decreases with public information. They found that the convexity of cost functions ensures a unique equilibrium in a coordination game with endogenous information structures. As the source of public information is the correlation coefficient between different agents' observations of an informative signal, the precision of public information is endogenous. Likewise, the precision of private information is endogenously determined because each agent may acquire noisy information and pay for the processing to improve its precision.

In their static model, Myatt and Wallace (2012) found that as the costs of improving precision are high, an increase in the precision of public information results in a decrease in the precision of private information. In order to reduce the marginal cost, an agent chooses to acquire the clearest information or the most accurate information. If all agents act in the same way, then their coordination motives are strong; a unique equilibrium is guaranteed. Welfare increases with the precision of private information, but decreases with endogenous public information.

While demonstrating further their findings, Myatt and Wallace (2012) set up a dynamic information-acquisition analysis, in which costs can be associated with the transmission, processing, and incorporation of information in the decision-making processes; meanwhile agents have a constrained capacity in acquiring and processing information. Then, referring to the application of Sims' (2003) rational inattention and the Shannon Capacity in the dynamic model, they found a critical value of entropy-based cost guaranteeing a unique equilibrium. This threshold value depends on the level of the precision of information and the coordination motive. When the coordination motive is strong, convex costs of acquisition make the social value of public information with endogenous precision closer to that with exogenous precision. In other words, in the unique equilibrium of the coordination game, welfare decreases with endogenous public information for any strictly convex costs.

In summary, Myatt and Wallace (2012) showed that the convexity of costs of information acquisition is necessary to ensure a unique equilibrium of the coordination game, which is quite different from Hellwig and Veldkamp (2009). In addition, they analyzed the flexibility in endogenous information acquisition, which is based on the rational inattention theory. The endogenous information structure defined by Myatt and Wallace (2012) is extended to the welfare analysis on the use of information in supply functions competition and Cournot markets (see Myatt and Wallace, 2015).

3.3 Endogenous information structure in market games

Endogenous information structure in market games can be tracked back to Hwang's (1995) analysis. Recall that agents' strategic actions are based on information acquisition, which is one of the sources of endogenous information structure. In line with Vives (1984, 1988), Hwang (1995) examined how efficiently agents acquire information in different market structures. He found that the incentives of an agent to acquire information vary with the nature of competition among agents. When the precision of information is given, the expected welfare is the largest in a competitive equilibrium, where more information is endogenously disclosed. But if the precision of information is endogenously determined by profit-maximizing agents, then there is more private information that is acquired, but

used little by oligopoly and monopoly agents. The expected welfare increases with the precision of private information, but it is less important than in a competitive equilibrium.

Hwang's (1995) analysis outlined the relationship between the incentives of information acquisition and information friction in markets. Recent works investigate three questions. First, how the precision of endogenously determined private information affects the social value of public information (e.g., Myatt and Wallace, 2014; Colombo and Femminis, 2014; Colombo et al., 2014). Second, how the characterization of private information affects the equilibrium of market games when the public information is endogenous (e.g., Myatt and Wallace, 2015; Bergemann et al., 2015). The last question is about the welfare effects of endogenous public precision relative to exogenous public precision, when endogenous information acquisition becomes flexible (Yang, 2015). We specifically review the works of Colombo et al. (2014) and Myatt and Wallace (2015), which demonstrate that the social value of public information under endogenous information structures can be different from under exogenous information structures.

3.3.1 The social value of public information with endogenous precision

In a more general Gaussian-quadratic setting, Colombo et al. (2014) compared the social value of public information when its precision is endogenously and exogenously determined. To this end, the authors analyzed private information acquisition at the unique equilibrium relative to the socially optimal level.

The authors extended the model of Angeletos and Pavan (2007a) and assumed that agents adjust private information acquisition in response to variations in the precision of public information; at the same time agents can improve the precision of information at a linear cost. Acquisition costs depend on the level of the precision of information. They asked how the acquisition of private information can affect the social value of public information in endogenous and exogenous environments.

Colombo et al. (2014) found that if the equilibrium degree of coordination is lower than the social optimal coordination, then agents acquire too much private information and use it inefficiently in their strategic decisions. An increase in the precision of public information results in a decrease in the precision of private information, which then reduces private information acquisition. Hence, welfare increases with more precision of public information. The authors referred to this effect as a positive crowding-out effect of public information on the acquisition of private information. By contrast, if the equilibrium degree of coordination is higher than the socially optimal coordination, then agents overreact to public information, and inefficiently reduce the acquisition of private information. An increase in the precision of public information has a negative crowding-out effect on the precision of private information. However, this negative effect can be mitigated by the fact that agents reduce the cost of information acquisition enough to offset any decrease in their expected payoff. As a result, the total effects of public information on welfare are positive.

While Colombo et al. (2014) highlighted that the social value of public information with endogenous precision is positive if the cost of private information acquisition is linear, Ui (2014) showed that this result can be different if the cost of information acquisition is strictly convex.

3.3.2 Cournot competition and the social value of information

The role of information acquisition in supply functions competition has been examined in Kyle (1989) and Vives (2011a,b, 2014) when information is exogenously disclosed. Myatt and Wallace (2015) extended the analysis to an environment where information is endogenously disclosed by setting up Cournot competition with demand uncertainties. They considered a differentiated-product Cournot model in order to analyze the relationships between endogenous information acquisition and the inefficient use of information. Then, they focused on the possible discrepancies between the acquisition and the use of the information, when there are many information sources. In their differentiated Cournot model, information signals differ not only in their precision, but also in their correlation, which is the source of endogenous public information. They asked how agents can use their information in equilibrium when the precision can be improved at a cost.

In line with their previous analysis, they assumed that the precision of information depends on the accuracy of information (the sender noise), the attention that each supplier devotes to the information sources (the receiver noise), and the overall clarity of information (the total precision). In addition, the cost of information acquisition is considered to be continuous, differential, and convex. The authors found that in Cournot competition, agents use their information inefficiently. From the perspective of agents, the profit in equilibrium is directly influenced by both the accuracy and the clarity of information acquired. When the correlation of information signals is high, each agent increases its profit by acquiring more private information. If all agents behave in the same way, then they acquire too much new information, but use it too little. In this case, agents coordinate their strategies towards the collusive equilibrium. Consequently, the expected output is lower; the market price rises. An increase in the precision of information may increase the profits and lower consumers' surplus. Aggregating total industry profits and consumers' surplus, however, social welfare increases with endogenous public precision. Moreover, when the precision of public information is higher than the precision of private information, then an increase in the precision of private information increases not only the total profits, but also information sharing about demand conditions, which is better for consumers and welfare. As a result, social welfare increases with endogenous private precision.

To sum up, Myatt and Wallace (2015) showed that equilibrium profits, consumer surplus, and social welfare all vary with the precision of disclosed information. Increasing information precision raises the use of new information, and is profit-enhancing. Since agents acquire too much new information relative to the social optimum, consumers are in favor of more variance in market prices or in the differentiation of products. Therefore, social welfare tends to increase either with high precision of public information or with more new private information. But Myatt and Wallace (2015) argued that a social planner may distort the decisions of agents by taxing or subsidizing information acquisition in order to give incentives to Cournot agents to efficiently use information acquired. This proposition about information manipulation remains an issue for further research.

Throughout all the situations mentioned above, the social value of disclosed information is invariably related to the strategies of the acquisition and the use of information. The interactions between the acquisition and the use of information generate externalities, which means that the social value of public information under endogenous information structures can be different from that under ex-

ogenous information structures. In next section, we review some research works that focus on such externalities.

4 Spillover effects of disclosure on the social value of information

As mentioned in the literature cited above, a large group of agents take their decisions under dispersed information about the relevant economic fundamentals. The information that agents choose to acquire about the underlying fundamentals tends to improve the alignment between agents' actions with the fundamentals, as well as with other agents' actions. The choices between private and public information have spillover effects on the social value of information.

Recent studies argue that spillover effects of disclosure on the social value of information can be thought of as three types of externality: a payoff externality, a learning externality, and an information externality. Table 1 resumes these studies. Since an agent's utility function depends on the fundamentals, exogenous public information generates a payoff externality, while endogenous public information generates an information externality. A learning externality stems from the reaction of agents to exogenous or endogenous public information. Moreover, the payoff externality is combined with the learning externality to study the social value of disclosed information when public information is exogenous or endogenous.

4.1 Payoff and learning externalities

In a business cycle framework, Hellwig (2005) pointed out that if agents efficiently use available private or public information in equilibrium, then any increased precision in the information is socially desirable. However, the inefficient use of information generates externalities on welfare in equilibrium. In this case, whether or not providing more precise information disclosures is socially desirable depends on the interaction between payoff externalities and learning externalities.

Hellwig (2005) considered that payoff externalities arise from the inefficient use of private information, while learning externalities result from under-reactions or over-reactions of agents for public information. He found that the interaction between the use of private information and the reactions to public information creates excessive complementarities in price-setting decisions. When learning externalities are positive, and stronger than payoff externalities, any improvement of the precision in the disclosed information can mitigate negative payoff externalities on welfare. Welfare increases with the precision of exogenous public information. Nevertheless, when payoff externalities are stronger than learning externalities, improving the precision of private information reduces welfare.

In contrast with the analysis of Hellwig (2005), Myatt and Wallace (2012, 2015), Colombo et al. (2014), and Vives (2017) stressed that endogenous information disclosure causes learning externalities, which increase uncertainties about the fundamentals. Such learning externalities are linked to a crowding-out effect of endogenous public information on the use of exogenous private information (see section 3.3.1). Economic agents can improve the precision of information by learning more from the market outcomes. But an increase in the precision of information leads agents to ignore or attribute less weight to the private information in their strategic actions. The market outcomes reveal,

Table 1: Information Disclosure and Learning Externalities.

Model	Information acquisition	Correlation coefficient	Nature of learning	Key variable	Externalities	Is precision good?
Grossman and Stiglitz (1980)	Endogenous	Between “private noise” in individual agent’s information and “noise” in information aggregated by price	Exogenous	Price	Information externalities	Paradoxical effects of information acquisition
Hellwig (1980)	Exogenous	Between noise in private information and learning from price	Exogenous	Price	Learning externalities due to substitutabilities in agents’ strategic decisions	No, it generates “schizophrenic” actions, as agents are price-takers and they neglect the effects of learning from the price on price movements
Hellwig (2005)	Exogenous	Between the “reaction” to common knowledge, relative to the social planner solution and “aggregate volatility”	Exogenous	Price	Learning externalities due to complementarities in agents’ strategic price-settings	Yes
Cornand and Heinemann (2008)	Exogenous	Between “idiosyncratic noise” across agents who receive public information	Exogenous	Investment	Learning externalities due to complementarities in strategic actions	Depends on agent’s abilities to predict the induced beliefs of others
Angeletos and Pavan (2007a)	Exogenous	Between the equilibrium and the efficient use of information	Exogenous	Investment	Payoff externalities due to the agents’ strategic actions under the condition of the level of coordination in the economic environment	Depends on the degree of coordination in equilibrium
Hellwig and Veldkamp (2009)	Endogenous	Between the information noise of any two agents	Exogenous	Investment	Learning externalities due to complementarities in information acquisition	Relies on the nature of information and the level of coordination faced by agents
Vives (2011b)	Exogenous	Between agents’ costs. Through this correlation coefficient, agents learn from the the market price about costs	Exogenous	Price	Learning externalities due to price-setting decisions	Generates some adverse selection and market power problems, which reduce welfare in the marketplace
Manzano and Vives (2011)	Exogenous	Between the private noise across informed agents	Exogenous	Investment	Learning externalities due to strategic information acquisitions	Yes
Myatt and Wallace (2012)	Endogenous	Between the observations of an information source across two agents	Endogenous	Investment	Learning externalities due to the agent’s desire for coordination	Depends on the attention paid to the information by agents, when there is costly access to available information
Myatt and Wallace (2014)	Exogenous	Between the information noise across sectors of an economy	Exogenous	Price	Information externalities due to complementarities in information acquisition	Relies on how much information a policy-maker decides to acquire and transmit
Myatt and Wallace (2015)	Endogenous	Between the information observed by two different suppliers in Cournot competition	Exogenous	Quantity	Information and learning externalities due to strategic coordination in information acquisition	Relies on both suppliers’ strategies and consumer preferences
Vives (2017)	Endogenous	Between the information learned by agents and the private information	Endogenous	Price	Information and learning externalities due to inefficient use of private information	Providing more precision of information, public or private, is welfare-improving
Bayona (2018)	Endogenous	Between endogenous public information and private information	Endogenous	Price / Quantity	Information and payoff externalities due to the equilibrium endogenous degree of coordination relative to the socially optimal exogenous degree of coordination	More precise endogenous public information makes the social value of private information positive if the equilibrium degree of coordination is lower than the socially optimal degree of coordination

in turn, less new information about market conditions. As a result, when learning externalities are negative, and stronger than payoff externalities, an increased precision of public information reverses the social value of private information from positive to negative.

4.2 Information externalities

The issue of information externalities has been studied in Amador and Weill (2010, 2012), Manzano and Vives (2011), and Vives (2014, 2017). When public information is endogenous, information externalities arise from the interaction between exogenous private information and endogenous public information.

In Amador and Weill (2010), information about agents' actions is endogenously aggregated by prices. More precise exogenous public information about economic fundamentals renders endogenous public information less precise. In fact, an increase in the precision of exogenous public information induces agents to use their private information less, which reduces the informativeness of prices. The authors refer to an information externality as a negative crowding-out effect of exogenous public information on the precision of endogenous public information. Consequently, welfare decreases with the precision of exogenous public information.

In addition, if agents learn only from information aggregated by prices, then they acquire less private information. In this case, an increase in the precision of public information improves welfare. An information externality is a positive crowding-out effect of the precision of endogenous public information on exogenous private information. By contrast, if agents learn through prices, then a negative information externality can be amplified because agents have fewer incentives to acquire any available information. Therefore, welfare can decrease with public disclosure. In the same spirit, Vives (2017) argued that whether such a crowding-out effect contributes positively or negatively to the social value of information disclosure depends on whether agents under-invest or over-invest in the acquisition of private information.

In a recent study, Bayona (2018) found that the interaction between information and payoff externalities characterizes whether agents over-invest, under-invest, or equally invest in private information in relation to the efficient strategy. When payoff externalities are stronger than information externalities, an increase in the precision of endogenous public information renders the social value of private information negative. When payoff externalities are lower than information externalities, providing more precise public and private information increases welfare.

4.3 Internalization of externalities

Vives (2017) internalized payoff externalities and information externalities in the rational expectations model to study the social value of disclosed information. Internalizing all externalities, the author found that more precise public information together with an efficient use of private information can improve welfare.

The analysis of Vives (2017) is based upon a comparison between the equilibrium and the socially optimal use of private information. He highlighted that the level of precision makes welfare increase with endogenous public information. Moreover, he showed that the incentives for an agent

to efficiently acquire and use information vary with the nature of competition among agents. For example, in the context of competitive equilibrium with incomplete private information, maximizing the expected utility depends on the equilibrium outputs (the strategies in market decisions), and the precision of information (the interaction between the acquisition of information and the use of information).

The author also showed that a "team-efficient" solution can be one possible way to internalize externalities due to inefficiency in the use of information. Such a solution reveals that more precise information disclosure, whether public or private, can reduce welfare loss. Finally, the "team-efficient" solution can be implemented with tax-subsidy schemes. The optimal tax reduces over-use of private information, whereas the optimal subsidy reduces under-use of private information.

5 Experiments and the social value of disclosure

As mentioned in Verrecchia (2001, p. 173): "It would be of some interest to know the nature and type of efficiency that exist in real institutional settings, and if they do exist, whether they have any economic significance". In other words, as the theory of disclosure matures, it seems reasonable to inquire whether the empirical literature can provide additional insights into the economic consequences of disclosure. This section illustrates different experiments about the social effects of public disclosure.

These experiments are mainly built on the "beauty contest" model of Morris and Shin (2002). In experimental settings, agent's payoff is determined by two criteria: how well an agent's action matches an unknown fundamental; how well it matches the average actions of other agents. The relative importance of both criteria can be varied and controlled in the different experiments. In addition, recent experimental studies focus on examining *limited levels of reasoning* in a beauty contest game as an explication of agents' overreaction to public information.

The theory of limited levels of reasoning has been developed in seminal papers like Stahl and Wilson (1995) and Nagel (1995). Cornand and Heinemann (2014) are the first to run two-player experiments by applying limited levels of reasoning to the beauty contest. Limited levels of reasoning are based on the presumption that agents' behaviors can be classified into different levels of reasoning. Thus, it is a cognitive hierarchy model, where participants are assumed to have limited ability to correctly guess others' actions in coordination games. For instance, the level-0 of reasoning corresponds to a participant's non-strategic behaviors, when its strategies are selected randomly without forming any beliefs about its opponents' behaviors (Shapiro et al., 2014). In other words, if a participant neglects the coordination motive in the payoff function, then the level-0 of reasoning is its best response to the first-order expectation of the fundamental. Then, Cornand and Heinemann (2014) and Baeriswyl and Cornand (2016) argued that the level-1 of reasoning is defined as the best response of a participant to its belief, in which it assumes that other participants behave according to the level-0 of reasoning. The level-2 of reasoning is designed as the best response of a participant to its belief, in which it guesses that other participants behave with the level-1 of reasoning, and so on. Therefore, with these theoretical issues in mind, we go over the main recent experiments examining the social value of information disclosure.

5.1 Social value of public disclosure

The empirical study of the social value of public disclosure is set up by Dale and Morgan (2012). The experiments examined one of the theoretical results in Morris and Shin (2002) that welfare loss is due to inefficient use of information. They examine agents' overreaction to public disclosure relative to the efficient use of information. This overreaction becomes less correlated with the underlying fundamentals in experiments. They tested agents' strategic decisions too. When controlling for the precision and type of information agents receive, the authors observe the underlying state variable in each experimental treatment. Thus, they determined the impact of public disclosure on the agent's payoff. Their experimental results about the negative value of more public information are close to the theoretical predictions of Morris and Shin (2002).

Dale and Morgan (2012) considered that the underlying state variable is uniformly distributed in their experiment. Under the assumption that all agents are better informed in the marketplace, they set up three treatments. In each treatment, they examined whether or not the additional information shifts choice behavior and leads to welfare losses.

In the first treatment, participants receive only the unbiased private information about the underlying state variable. In equilibrium, each participant chooses an action that converges towards the state variable. Results show that, on average, participants put about 90% weight on the signal. In the second treatment, the authors add a second item of private information which has lower precision than the first. They find that, participants tend to overreact to the low information precision by putting 26% weight on it rather than the theoretical 20% weight. Comparing the second treatment with the first one, welfare increases by about 7% due to the additional information. But the gains are really reduced because of the low precision of the additional private information. In the third treatment, rather than adding an item of private information, the authors add an item of noisy public information. The experimental results show that participants overreact to this additional public information and welfare falls. In summary, from a policy perspective, their experimental results outline that the coordination motive has a negative payoff externality on the social value of public disclosure.

The main contribution of these experiments is to examine the extent to which actual behavior adjusts to public information and the welfare consequence of this adjustment. Though the experimental results confirm the theory that public disclosure generates a significant welfare loss, the controlled environment is limited to noisy public information. In this limited environment, the payoff externality generated by public disclosure can be examined only in the case of low precision. However, Dale and Morgan (2012) do not examine the effects of high precision of information disclosure. By contrast, Cornand and Heinemann (2014) took into account the high precision of information disclosure in their experiments studying agents' reactions to private and public information. The controlled environment focuses on the variation of the coordination parameter rather than the precision of information disclosure.

5.2 Agents' reaction to private and public disclosure

The framework of Morris and Shin (2002) provided another prototype of an experiment on the welfare effects of transparency in environments with strategic complementarity. In a game with strategic complementarity, an agent has incentives to align its action on the expected actions of others. When the precision of public and private information is the same, the equilibrium strategic decision is affected more by public than by private information. Cornand and Heinemann (2014) examined this theoretical prediction in a laboratory experiment.

The authors aimed at measuring and analyzing how much public information is disclosed compared to private information in a game with weak strategic complementarity. To this end, they proposed a “beauty contest” game experiment characterized by both fundamental and strategic uncertainties. In this experiment, three questions are tested: (i) whether participants put more weight on public information than on private information; (ii) whether the observed weights are in line with equilibrium prediction; and (iii) how change in the coordination parameter r affects these weights.

They first defined the equilibrium weight on the private information, which decreases with the degree of coordination. Second, they assigned five different degrees of coordination in order to measure participants' reactions to private and public information. According to each degree, participants should choose an action either to get close to the fundamental state or to coordinate the same strategy. The authors found that when they have incentives to coordinate their actions, participants put more weight on public information than private information. Specially, if the degree of coordination is increased, then participants put larger weights on public information. Therefore, experimental results are in line with theoretical predictions.

Moreover, when adding and testing the limited levels of reasoning, Cornand and Heinemann (2014) found that each participant takes into account the fact that others receive the same public information as it does, but underestimate the information contained in the public disclosure about others' beliefs. Hence, the experiment exhibits participants' overreaction to public information; nevertheless, this overreaction is weaker than theoretical predictions.

Furthermore, their experiment showed that for a given degree of coordination, at level-1 or level-2 reasoning of a cognitive hierarchy, an increase in the precision of public information always improves welfare. However, if participants use higher levels of reasoning, then negative welfare effects of public information are observed. Higher-order beliefs can be used to explain why more precision of public information may increase uncertainty. For example, at level-2 reasoning, participants consider that public disclosure provides more information about others' actions than private information, but they neglect that others also put higher weights on public information. As a result, the welfare-loss effects stemming from overreaction to public disclosure are generated from the level-2 reasoning. To sum up, Cornand and Heinemann's experiment adduces clear evidence that, in line with what theory predicts, more public information may be socially undesirable.

5.3 Policy as a tool to reduce agents' overreaction to public disclosure

Overreacting to public information is not only related to agents' higher levels of reasoning in their strategic decisions, but also to the quality of public disclosure. The quality of public disclosure at-

tracts attention to the principal's communication strategies that tend to reduce agents' overreaction. Communication strategies can be partially public, meaning that information is only disclosed to a fraction of market agents (Cornand and Heinemann, 2008). It can also be partial transparency, meaning that information is disclosed to all market agents, but with ambiguity (Heinemann and Illing, 2002; Baeriswyl and Cornand, 2010). The degree of transparency is determined by the idiosyncratic inaccuracy of the disclosed information.

Baeriswyl and Cornand (2014) carried out a laboratory experiment to test these two theoretical predictions cited above. First, in their experimental protocol, they predicted that there is an equivalence relationship between the degree of partial publicity and the degree of partial transparency. The optimal degree of publicity yields the same average weight assigned to public disclosure (relative to private information) and the same welfare as the optimal degree of transparency. Then, the theoretical model with a continuum of agents is adjusted to a finite number of agents in the experiment. Last, three treatments of disclosure strategy are set up: (i) the first treatment examines the original model of Morris and Shin (2002), in which each participant receives private and public information (the MS treatment); (ii) the second treatment applies the strategy of partial publicity, where only a fraction of participants receives the public information (the PP treatment); and (iii) the third treatment implements the strategy of partial transparency, where each participant receives the public information with idiosyncratic noise (the PT treatment).

During the six sessions of the experiment, the authors kept the same degree of coordination parameter. Even though participants played within their own group, they did not know the identity of others in their group. In addition, the authors tested the effects of disclosure on the participants' behaviors every three sessions by changing the order of informational treatment.

The experimental results showed that participants overreact to public information in all treatments. In the first treatment (MS), the overreaction to public information is not as strong as predicted by Morris and Shin (2002). The results confirmed also Cornand and Heinemann's observations about agents' reaction to public and private information. In both the partial publicity (PP) and the partial transparency (PT) treatments, participants assigned a large weight to the semi-public information. In the partial publicity treatment (PP), the results showed that the partial publicity strategy reduces overreaction if and only if uninformed participants cannot react to public information, but not the informed participants' perception of partial public information. In the partial transparency treatment (PT), the experimental results showed that the partial transparency strategy also reduces the overreaction to public information, but not as much as theory predicts. As there is some ambiguity surrounding public disclosure, participants may not precisely understand the public information and behave cautiously by reducing their overreactions. In addition, the experimental results show that the partial transparency strategy turns out not to reduce overreaction as strongly as the partial publicity strategy.

By the importance of communication strategies that aim at reducing overreaction to public disclosure, the experiment of Baeriswyl and Cornand (2014) highlighted the issue of policy implementation and fairness. Having said that, the effectiveness of partial publicity is limited by the manipulation of information disclosure. For example, the principal can choose to release its information to a selected audience, but these informed agents may benefit from the gain of information manipulation. In other

words, informed agents may overreact to the unfavorable information and withhold the favorable information. By contrast, with partial transparency, public information tends to be released with the same degree of ambiguity to all agents. Disclosing information to a limited number of agents only seems unfair and arbitrary. But releasing information to all agents with the same degree of ambiguity does not create any discrimination. Therefore, partial transparency (PT) can be preferable to partial publicity (PP). In both cases, public disclosure has to be carefully formulated since the principal may either enhance or reduce market reaction.

Partial transparency is examined in another experiment carried out by Baeriswyl and Cornand (2016) which tests participants' reactions to changes in the precision of signals and in the degree of strategic complementarities.

5.4 Signal precision and the degree of strategic complementarity

In the “beauty contest” framework, the weight assigned to public disclosure in equilibrium depends not only on the precision of information, but also on the degree of strategic complementarity. Baeriswyl and Cornand (2016) ran an experiment in order to test these predictions by varying the precision of public information and the degree of strategic complementarity. In particular, they applied limited levels of reasoning in a controlled experimental environment.

First of all, the authors determined the equilibrium weight assigned to public information in the first-order expectation of the fundamental, and the weight assigned to public information in the beauty contest action of each participant. They found that the latter is larger than the equilibrium weight; there is an overreaction to public information. Then, they ran an experiment with three treatments, each of which presents a different degree of relative precision of private and public information. To this end, the authors defined a special information structure. Each participant receives private and public information about the fundamental state. The private information is different for each participant; at the same time the public information is considered common knowledge among participants. According to each treatment, however, the authors designed different values of the error term to change the controlled interval in which public information is uniformly distributed. Last, in the experiment, each participant has to take two decisions: the first decision is to form the best expectation about the fundamental state; the second decision is to choose an action corresponding to the coordination motive in the beauty contest. The reserved utility and the weight assigned to the coordination in sessions one to four are different from those in sessions five and six.

The experimental results confirmed the theoretical prediction by showing that strategic complementarity induces participants to overreact to public information. Meanwhile, participants underweight precise public information; or overweight imprecise public information. The weights assigned to the precise public information in the first-order expectation of the fundamental (the payoff motive), and in the beauty contest action (the coordination motive) are lower than the weights predicted in theoretical analysis. Therefore, the negative effects of public information on welfare not only come from the overreaction to public information, but also from over-weighting imprecise public information, or under-weighting precise public information.

Moreover, it is worth noting that, when public information is precise, overreaction may be ben-

official. Indeed, an overreaction to precise public information reduces the error of under-weighting precise public information in the first-order expectation. However, when public information is imprecise, overreaction may be detrimental because it increases the uncertainty about the underlying state. In other words, the overreaction may exacerbate the error of over-weighting the imprecision of public information in the first-order expectation.

Furthermore, the experiment of Baeriswyl and Cornand (2016) showed that partial transparency is called into question. Indeed, this communication policy may lead agents to use information inefficiently because they overweight inaccurate information. This problem is studied in the experiment of Cornand and Heinemann (2015) which took into account the limited levels of reasoning. On the basis of a theoretical model of James and Lawler (2011, 2012) in which a government can take policy actions against fundamental shocks, Cornand and Heinemann (2015) showed that with limited levels of reasoning, public information is less detrimental to welfare than predicted by theory. Complete transparency may be optimal if participants act upon the limited levels of reasoning. When participants adopt the level-1 and level-2 of reasoning, increasing the precision of public information always raises expected welfare. By contrast, when public information is less precise than private information, it is partial publicity with limited levels of reasoning that tends to improve expected welfare.

Table 2 resumes the main experiments that study how much the degree of public disclosure can be beneficial for welfare. As described in this table, three experiments examining the overreaction to public information highlight the importance of limited levels of reasoning in analyzing the social value of disclosure. The experimental results show that when agents have the level-1, level-2 of reasoning, increasing the precision of public information can improve expected welfare in a "beauty contest" game.

Conclusion

The purpose of this paper is to shed the light on the development of research attempting to study the social value of disclosed information. These works focus on the question of how well the characterization of disclosure influences the strategic decisions and actions of agents in different market structures with incomplete private information. This characterization includes: exogenous disclosure; endogenous disclosure; the degree of disclosure; the volume and the quality of disclosure; the transparency; the efficiency of disclosure choice; and the incentives for disclosing information. All these characteristics involve interactions both among agents, and between public information and private information. Therefore, welfare may increase or decrease with more information disclosures, which aim to reduce uncertainty in the marketplace.

The literature reviewed in this paper supports the idea that a rich set of externalities is generated by the disclosed information, such as payoff externalities, learning externalities, and information externalities. These externalities may result from: (i) discrepancy between the use of information and the acquisition of information in equilibrium, (ii) discrepancy between the equilibrium and the efficient use of information, and (iii) discrepancy between the equilibrium and the efficient degree of coordination. According to the interaction between these externalities, an increase in the precision

Table 2: Experiments on Public Disclosure in Finance.

Study	Objectives	Experiments	Summary of experimental results
Dale and Morgan (2012)	Examining theoretical predictions about the negative effects of public information on social welfare	Controlling the quality of additional information	In line with the theoretical predictions, the experiment shows that participants overreact to low quality public information.
Cornand and Heinemann (2014)	Testing agents' reactions to private and public information with the sole coordination motive	Controlling the degree of coordination parameter; Introducing limited levels of reasoning in the laboratory	When the degree of coordination is increased, participants put greater weight on public information. The weight assigned to public information in the experiment is less than predicted in equilibrium.
Baeriswyl and Cornand (2014)	Examining the central bank's communication strategy of reducing the agents' overreactions to public disclosure	Three treatments in the laboratory: (i) payoff motive treatment; (ii) partial publicity treatment; and (iii) partial transparency treatment. Adding idiosyncratic noise to the received public information.	In line with theoretical predictions, communication strategies can reduce the overreaction to public information. The limited levels of reasoning lead participants to put less weight on public information than predicted in equilibrium.
Cornand and Heinemann (2015)	Examining the role of limited levels of reasoning in agents' strategic choices	Testing four variants of the model of Morris and Shin (2002): (i) partial publicity; (ii) effects of transparency to socially desirable coordination; (iii) the higher level of reasoning explaining the negative effects of public information on expected welfare; and (iv) policy actions against fundamental shocks.	(i) With level-2 reasoning, a limited degree of publicity can be optimal if and only if public information is less precise than private information; (ii) if coordination is socially desirable, then public information is beneficial in equilibrium; (iii) with level-2 reasoning, increasing precise public information improves the expected welfare in a "beauty contest" game; and (iv) under limited levels of reasoning, private information may have negative welfare effects on expected welfare.
Baeriswyl and Cornand (2016)	Examining the overreaction to public information due to strategic uncertainty, and over or under-weighting of public information due to fundamental uncertainty	Controlling the precision of public disclosure in two experimental treatments: (i) fundamental uncertainty; and (ii) strategic uncertainty.	Participants overreact to public information due to strategic complementarity; and tend to over-weight inaccurate public information, or under-weight precise public information because of the limited levels of reasoning. In line with theoretical predictions, the communication policy, such as partial publicity is called into question because participants over-weight imprecise public information.

of public or private information may increase or decrease welfare.

In order to reduce externalities and improve the social value of disclosure, some policy intervention is discussed by a part of the literature reviewed in this paper. Taxation is considered a current policy intervention to correct inefficiencies in information acquisition and in the use of information. Besides taxation, the principal's communication strategies intend also to reduce the overreaction of agents to public information due to strategic complementarities in coordination games, as demonstrated by the experimental results. These strategies of communication may be either partial publicity or partial transparency. It will be the respective government's responsibility to be more transparent and provide the much needed public information in order to guarantee the market mechanism.

A growing number of researchers have extended the analysis to the capacities of economic agents in processing information, as in *the rational inattention* literature.⁶ If agents' capacities for processing information are limited, or if information processing is costly, then agents choose not only how much information to acquire, but also the kind of information to acquire. This flexibility of information acquisition makes it possible to obtain the efficient coordination in which welfare increases with public information.

These insights mentioned above should help us further study the social value of disclosure under more general information structures. For example, a dynamic model is suitable for examining the efficiency of disclosure and agents' incentives to acquire information at a convex cost. In addition, a possible direction for further research would be to analyze welfare effects of disclosed information on the interaction between agents in economies, such as environmental economies or contract regulation. In doing so, the social value of information disclosure could be useful in more elaborate models.

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Part II

THE NEGOTIATION STAGE OF THE DELEGATION

The Value of Information Disclosure and the Design of Delegation Contracts

Abstract

In the Utilities sector, many quality-related uncertainties such as the quality of water mains affect the design of delegation contracts. The main purpose of this paper is to examine how the public/private estimation of the infrastructure, e.g. water leakage, affects agents' payoffs and its impact on the shape of such contracts. We show that, from a policy perspective, when the private estimation converges to the public estimation, disclosure is generally efficiency enhancing, and the design of the contract signals the quality of the facility in two ways. First, a large precision of disclosed information leads to an overestimation of the quality, meanwhile a lack of information precision results in an underestimation of the quality. Second, an increase in the precision allows local authority to shape a better delegation contract. In addition, a good quality leads local authority to keep the management public, which implies a low-level water prices.

JEL classification : D82; D86; L33; L51;

Keywords: Disclosure, Asymmetric Information, Delegation Contracts, Signaling, Water Utilities.

1 Introduction

Information disclosure has been introduced to increase transparency in the market, which can be achieved in different ways: access to information, data disclosure and mandatory disclosure. Transparency through public release has an instrumental value inasmuch as it prevents economic agents from being ripped off and misled by those they are dealing with. Since disclosure is valuable to the degree that it is supposed to improve efficiency of markets, different disclosure programs have been developed around the world. The main purpose of such programs is to assist broader public decision-making such as public policy of development and regulation. Therefore, disclosure becomes a primary policy instrument that requires players in the marketplace to disseminate and share the underlying data or methods used to support a policy decision.

In the Utilities sector, disclosure has been used to inspire resource conservation, to reduce market failures, and to improve public services quality and management. These can be achieved through making official data, annual reports about the fundamental readily accessible, available to all interested individuals and institutions. In doing so, disclosure may ensure institutional quality, scientific credibility; and provide the simplest respond to information-related market failures. For example, a market failure may come in the form of inadequate supply of information generating market frictions. By hiding information, the worry is that some agents are stopping others from knowing things they are entitled to know. Thus, providing accurate and useful information congruent to the policy goal is critical for the effectiveness of the policy itself aiming at regulating markets. Up to the early 2000's, the information structure that has been dealt with in almost all economic models did not consider information disclosures and yet, some interesting questions remain unanswered about the social value of disclosure and how it is used (or ignored) in decision-making.

According to the transparency in the Utilities sector, the water industry provides a specific picture. Since water services can be managed either by local authorities or contracted out to potential service providers (private operators), all parties do not fairly benefit from accessing information about the quality of such services. Conventional critics emerge by comparing water prices and service quality between public management and contracting-out management. Negative critics of contracting-out management argue that as private operators hold more information than local authorities, they benefit from high water prices at the cost of consumers. Positive critics of contracting-out support that under private management, costs are covered and the quality of services becomes better. By contrast, under public management, local authorities keep water prices at a low-level, but the quality of water services has not been yet improved. In a regulatory context, the quality of water services is measured by the quality of the distributed water itself, the satisfactions of consumers; and the quality of the infrastructure, such as the frequency of network failures. Since 1992, all these indicators have been collected as databases and disclosed as public information, to which users and citizens have access. Nevertheless, the true state of the infrastructure is still uncertain to both local authorities and potential service providers.¹ In this case,

¹“For decades, some water networks built around the time of the Civil War are ignored by politicians and residents accustomed

reducing water leaks in the distribution networks is one of the most important issues currently affecting the improvement of water services,² which is a regulatory object.

The subject of this paper is to study the role of information disclosure in the water sector, in particular, the design of delegation contracts. Based on the recent literature concerning the social value of disclosure (for example, Morris and Shin, 2002; Angeletos and Pavan, 2007; Hellwig and Veldkamp, 2009; Myatt and Wallace, 2015; Vives, 2017), we examine the contracting relationship between a local authority who is entitled to provide a public service (e.g. drinking water), and a private operator interested by one of the delegation contracts.³ It bridges the gap between disclosure and efficiency in the design of delegation contracts in the Utilities sector. We are interested by such a question: does the public release of information allow a local authority to improve the quality of decision-making? To our knowledge, no attempt has been made to analyze the impact of information disclosure on the design of delegation contracts.

Our model considers that all players in the market place, local authorities as well as potential operators have access to some public information about the quality of the infrastructure measured by a quality index representing, for instance, the rate of water leakage (for example, Elnaboulsi and Alexandre, 1997; Elnaboulsi, 2001, 2009; Garcia and Thomas, 2001, 2003; Canneva and Garcia, 2010; Cousin and Taugourdeau, 2016; Cavaliere et al., 2017). However, an operator is relatively more successful in binding part of its information and retains control over some information of interest. Hence, there is an array of privately held information that is woefully asymmetric yet is not disseminated. In some cases, the operator may also develop mechanisms to hold back some strategic information falling under the umbrella of confidentiality for commercial and industrial purposes as well as intellectual property rights issues. Such asymmetric information affects the efficiency of the delegation contracts; thus, given the public signal and the information privately held by the operator, we analyze the effects of disclosure on the decision-making process of a local authority. With the exogenous information structure “ $\hat{\theta}_i$ ” adopted in this paper, we find that the precision of disclosed information can allow the local authority to improve its decision-making, then to set up an optimal delegation contract, in which any increase in the precision of information about the state of the infrastructure directly reduces the informational distortion.

Moreover, there are two opposite effects of an increase in the precision of information disclosure on the estimation about the quality of the infrastructure. One is the overestimation of the quality, the other is underestimation of the quality. In the first situation, the less water leaks left to the operator, the higher is the water prices. Local authorities prefer to keep the management of water services. This result confirm the finding in Martimort and Sand-Zantman (2006). In the second situation, nevertheless, local

to pay almost nothing for water delivery” (The New York Times, 2010, see Cousin and Taugourdeau, 2016).

²The Water Framework Directive (2002) established by the European Union is a supranational level enforcement strategy which requires utilities to set water prices that cover both the cost of water supply and the cost of water leakage reduction (Elnaboulsi, 2009).

³In France, “Sapin Law” (1993) national legislative framework emphasizes “transparency” in the form of the private sector participation and the conduct of the bidding process. “Barnier Law” (1995) strengthens “information disclosure” by regulating contract duration and operators’ obligations. Transparency is one of the key factors to improve governance of public procurement and regulation, including delegation contracts in public water services (Saussier and Tirole, 2015).

authorities decide to delegate the water services to the operator by tolerating some level of water leaks. The type of contracts depends on the average estimation about the quality and the public-policy choice variable.

Furthermore, the volume regulation sounds more relevant than the price regulation in our model, where the major concern is the quality of the infrastructure. Water utilities normally offer service to everyone at the mandated tariffs, meanwhile, the volume regulation depends on public and private estimation about the quality. In this case, a local authority maximizes its expected social welfare conditional on the information structure provided by the operator, and targets its estimated volume in the proposed delegation contracts. This volume includes the volume of water leaks tolerated by the local authority in the reason of economies of scale (for example, Elnaboulsi and Alexandre, 1997; Garcia and Thomas, 2001, 2003; Elnaboulsi, 2001, 2009; Reynaud and Thomas, 2005, 2013; Destandau and Garcia, 2014). The precision of public and private estimation allows the local authority and the operator to build their decisions on the expectations of the quality of the infrastructure. For instance, when the local authority estimates a good quality of the infrastructure, its decision of delegation depends on whether or not the water price increases. The quality is good enough that water leak is reduced, but it raises the variable part of water price depending on the estimation. By contrast, when the operator underestimates a good quality, its decision of managing water services is linked to the expected volume. The local authority can give incentives to the operator to accept the contract by tolerating a level of water leaks in the water distribution. We find that, the expected volume of distributed water designed in the delegation contracts increases with underestimated quality of the infrastructure. Such level of water leaks is an information rent given up to the operator at the cost of consumers. But this information rent decreases with the precision of disclosed information about the quality of the infrastructure.

In our paper, we find a threshold value of precision, on which the optimal volume is drawn from the complete information about the quality of water services. Distortion on incentives in reducing water leaks is thus linked to the lack of information precision. In addition, the public transfer depends indirectly on the estimation of the service quality. Combining with a social weight $\varphi \in (0, 1)$ assigned to the operator's utility by a local authority, we assume a *public-policy choice variable* $\lambda \in (0, 1)$, which is increasing with a good precision of the quality of water services. Further, our numerical example shows that when the quality of water services is estimated good because of a high precision of information disclosure, a local authority keeps the management of such services. When taking into account consumers' sensitivity to the quality, the local authority uses Ramsey-Boiteux pricing rules to ensure the efficient marginal cost pricing in public managements.

Let us now review the relevant literature. Although our concern is on the quality of decision-making in the design of delegation contracts, this paper is broadly based on the literature on the social value of public information. In their seminal contribution, Morris and Shin (2002) assume that economic agents have access to private/public information sources. They show that raising the precision of public signals may reduce expected welfare. Since then, a large body of theoretical works has attempted to analyze

welfare effects of disclosed information in different economic fields (for example, Angeletos and Pavan, 2004, 2007; Hellwig, 2005; Morris et al., 2006; Cornand and Heinemann, 2008; Hellwig and Veldkamp, 2009; Myatt and Wallace, 2012, 2015; Ui and Yoshizawa, 2015; Vives, 2017 and Bayona, 2018). These works highlight, however, that if the fundamental motive is stronger than the coordination motive, then the precision of disclosed information can be favorable to increase welfare.⁴ We extend their assumptions to consider that a private information structure $\hat{\theta}_i$ will be announced by an operator during the process of procurement. It combines the public signal $\tilde{\theta}$ with the weighted idiosyncratic information $d\Delta\theta_i$, where $d \in (0, 1)$. Although such information structure can be found in Auriol and Laffont (1992), it is in line with Bergemann et al. (2015).

Bergemann et al. (2015) examine how the structure of private information influences aggregate volatility through three type correlations: the correlation between the sum of the aggregate shock and the idiosyncratic shock, the correlation between any two agents' actions, and the correlation between any agent's action and any other agent's individual shock. They find a Bayesian equilibrium, which depends linearly on the precision of public and private information. In our paper, nevertheless, we focus on the correlation between the precision of public estimation and the precision of private estimation. Whatever the weight put on its idiosyncratic estimation, the matter at stake is that the operator coordinates its revised estimation with that of local authorities. From this perspective, we assume that under the fundamental and coordination motives, the correlation between the precision of public estimation and the precision of private estimation tends to one unite. It means that the average estimation about the quality of the infrastructure becomes common knowledge between a local authority and the operator. Then, we ask how the precision of information affects the delegation decisions and the shape of delegation contracts. The relationship between our model and the existing literature can be partially summarized in Table 1.

The remainder of this paper is organized as follows. Section 2 describes the model. Section 3 presents the theoretical analysis of policy design under no biased estimation about the quality of the infrastructure. Section 4 analyses the precision of disclosed information, and provides a numerical example. Section 5 briefly concludes by alluding to an extension of our model in which the estimation is biased.

2 The Model

We consider a two-period sequential model in order to analyze contracting relationship between a risk-neutral regulator, i.e. a local authority, and a private operator. The true quality of the infrastructure $\theta \in \Theta \equiv [\theta^-, \theta^+]$ is unknown to both the local authority as well as the operator. The local authority, however, may estimate the quality based on some publicly disclosed information, such as annual reports and statistics. This public estimation given by $\tilde{\theta} \in \Theta$ represents a quality index and is published by

⁴In the informational framework of Morris and Shin (2002), three motives can be highlighted: (1) a fundamental motive, that induces agents to predict and fit an exogenous fundamental value; (2) a coordination motive, which gives incentives to agents to match the value set up by the market; and (3) a competition motive, that makes agents benefit from the competition in the market. When information is imperfect, a conflict emerges between the fundamental and coordination motives.

the local authority at the beginning of procurement. Given $\tilde{\theta}$, the operator's private estimation of the quality is given by $\tilde{\theta}_i \in \Theta$. Therefore, all players in the marketplace face private and public disclosed information.

2.1 Demand and Consumers' surplus

The inverse demand function is assumed to be linear and is given by $P(\tilde{\theta}) = a - b(1 + \tilde{\theta})q_i$, where $a > 1$ is the choke price supposed to be large enough,⁵ and b is a positive parameter.⁶ The volume of distributed water, $q_i(\tilde{\theta})$, is a function of the quality index $\tilde{\theta}$, so that $q_i(\tilde{\theta}) = (1 + \tilde{\theta})q_i$. Subscript i denotes the winning operator. Since the local authority chooses only one firm to manage its water networks, we assume that $q_i \equiv q$ for notational simplicity purposes.

It is worth noting that the prior public estimation $\tilde{\theta}$ may reflect the leakages in the water main.⁷ Indeed, water leaks linked to the state of networks is one of the three main components in the quality index. The two others are respectively the quality of consumers' service and the water quality itself. For instance, the quality of consumers' service may include all type of inquiries such as billing, water quality, and other service-related issues (see Destandau and Garcia, 2014). The water quality component represents the physico-chemical and microbiological characteristics of distributed water (see Mosheim, 2006). Water leaks can generate consumers' dissatisfaction if the broken water main shouldn't have been immediately repaired, in addition, they can degrade the water quality when the leakage happens in industrial area. In what follows, we restrict the quality index to water leaks as a measured parameter.

Note that, under our setting, the variable part of inverse demand function depends on the public estimation of the quality of water mains, which affects the water price. Therefore, for a given volume of water distribution, the gross consumers' surplus in one municipality is given by

$$V(\tilde{\theta}) = \int_0^{q(\tilde{\theta})} P(u)du, \quad (1)$$

and the consumers' surplus is

$$SC(q, \tilde{\theta}, \tilde{\theta}_i) = \int_0^{q(\tilde{\theta})} P(u)du - [a - b(1 + \tilde{\theta})q](1 + \tilde{\theta}_i)q. \quad (2)$$

This expression depends on both the public estimation and the private estimation of the quality of water main. It may be useful to follow the reasoning using Figure 1, 2 and 3. Figure 1 gives the graphical definition of consumer surplus depending only on the public estimation $\tilde{\theta}$; then, if an operator has own

⁵Note that the parameter a represents a municipality demographic and geographical characteristics. It may represent a fixed charge or an access tariff corresponding to provisions for capital stock renewal and debt service (see Porcher, 2014, 2017).

⁶The inverse demand function resulting from consumers' utility maximization program given by $V(q_i(\tilde{\theta})) = aq_i(\tilde{\theta}) - (\frac{b}{2})q_i(\tilde{\theta})^2 + M$, where $M \geq 0$ represents the aggregate amount of a numerical commodity (residual income). It is exogenous and can be neglected through the further analysis (see Elnaboulsi et al., 2018).

⁷Different empirical studies outlined that the water volume consumed by users is far less than the distributed volume (see Garcia and Thomas, 2001; Boyer and Garcia, 2008; and Destandau and Garcia, 2014). Because of the substantial operational cost in the water sector, the operator either increases the volume of water produced without improving the distribution network, or keeps the same volume of water produced by repairing leakages in the distribution networks.

private estimation $\tilde{\theta}_i$ about the true state of water mains, then consumer surplus is modified. Indeed, using the water price fixed by a local authority, consumers pay for water distributed by the operator. Hence, depending on the relationship between $\tilde{\theta}$ and $\tilde{\theta}_i$, consumers' surplus can be positive (see Figure 2) or negative (see Figure 3).

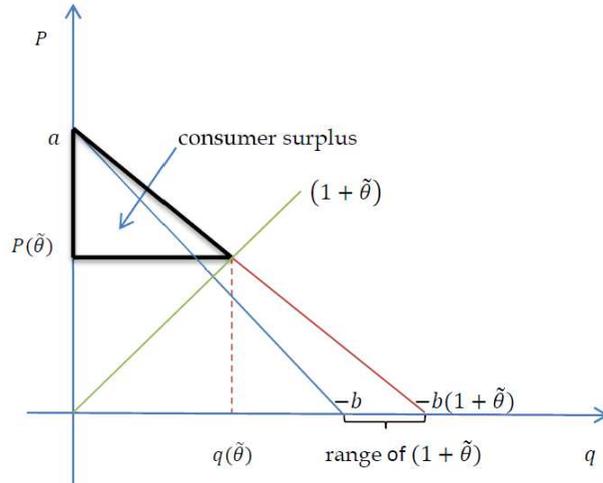


Figure 1 – The consumer surplus depending only on $\tilde{\theta}$

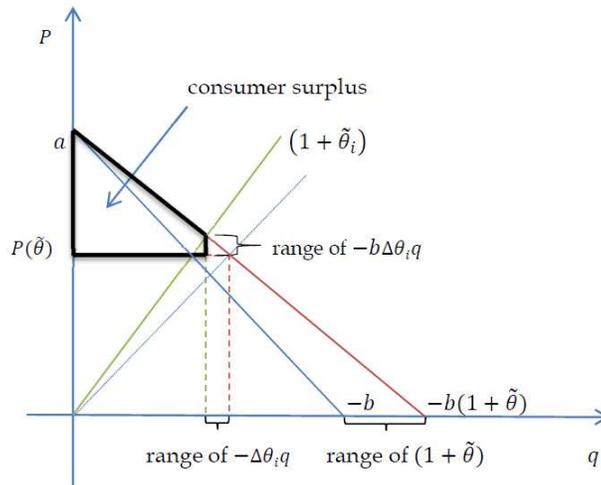


Figure 2 – The consumer surplus when $\tilde{\theta}_i > \tilde{\theta}$

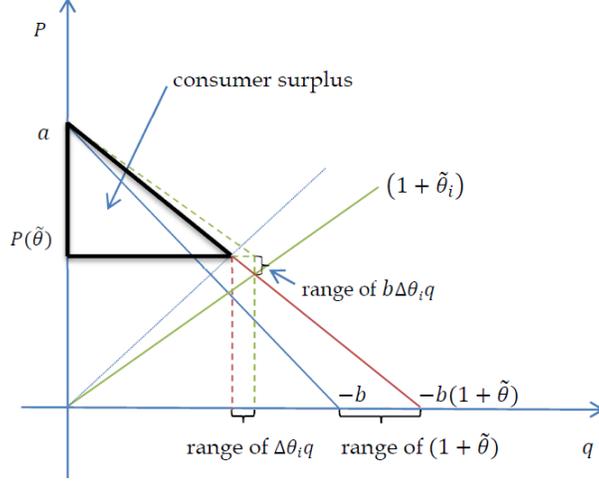


Figure 3 – The consumer surplus when $\tilde{\theta}_i < \tilde{\theta}$

Note that the variation of consumer surplus depends on the discrepancy between private and public estimation, such that $\Delta\theta_i = \tilde{\theta}_i - \tilde{\theta}$ (see Figure 2 and 3). $\tilde{\theta}_i > \tilde{\theta}$ is meant to that the quality privately estimated is better than that publicly estimated; it follows that the variation of consumer surplus in Figure 2 is $\frac{1}{2}bq^2[(1 + \tilde{\theta})^2 - (\Delta\theta_i)^2]$ as a function of the true value $\tilde{\theta}$ and $\Delta\theta_i$. By contrast, $\tilde{\theta}_i < \tilde{\theta}$ indicates that the quality privately estimated is worse than that publicly estimated. Then, the variation of consumer surplus in Figure 3 is $-\frac{1}{2}bq^2(1 + \tilde{\theta})(\Delta\theta_i)$.

2.2 The Water Utility and Social Welfare

Any operator managing water services, either private or public, has a linear cost function $C_i(q, \tilde{\theta}_i)$ given by:

$$C_i(q, \tilde{\theta}_i) = (c + \tilde{\theta}_i)q \quad \text{if } q > 0, \text{ and } C(0, \tilde{\theta}_i) = 0, \quad (3)$$

where $C_q > 0$ and $C_{\tilde{\theta}_i} > 0$. In our model below, we will focus on ex post operational costs generated by shocks on the quality of water services, such as network maintenance costs and/or investments. Accordingly, we normalize c to one.⁸

A public authority decides to delegate its water services to a private operator, then it has to share the profit of operating and managing the water services with the operator. We impose the accounting convention that the public authority receives the entire profit and gives back a fraction $(1 - t)$ of it to

⁸The similar cost function depending on an unobserved and unknown state of the world can be found in Weitzman (1978). The author assumes that the regulators' knowledge of this uncertainty can be represented by a probability distribution; then the regulator perceives the cost function as an estimate.

the operator. Thus, the transfer function takes the form:

$$T_i \left(\pi_i(q, \tilde{\theta}, \tilde{\theta}_i) \right) = -t\pi_i(q, \tilde{\theta}, \tilde{\theta}_i), \quad (4)$$

where $t \in [0, 1]$ determines the operator's marginal sharing of profits. The realized profit of managing water services $\pi_i(q, \tilde{\theta}, \tilde{\theta}_i)$ is determined by:

$$\pi_i(q, \tilde{\theta}, \tilde{\theta}_i) = P(\tilde{\theta})q(\tilde{\theta}_i) - C_i(q, \tilde{\theta}_i). \quad (5)$$

Therefore, the payoff function of the operator is written as:

$$U_i \left(t, q, \tilde{\theta}, \tilde{\theta}_i \right) = (1-t) \left[P(\tilde{\theta})q(\tilde{\theta}_i) - C_i(q, \tilde{\theta}_i) \right]. \quad (6)$$

This is similar to the policy of a revenue guarantee in the regulation of the urban transportation analyzed in Caillaud and Quinet (1993).

A public authority has the social welfare function:

$$W(q, \tilde{\theta}, \tilde{\theta}_i) = SC(q, \tilde{\theta}, \tilde{\theta}_i) - T_i \left(\pi_i(q, \tilde{\theta}, \tilde{\theta}_i) \right) + \varphi U_i \left(t, q, \tilde{\theta}, \tilde{\theta}_i \right), \quad (7)$$

where $\varphi \in [0, 1]$ is a social weight on the operator's payoff function as in Baron and Myerson (1982). Let $\lambda = [t + \varphi(1-t)]$, hence this relation can be simplified and given by:

$$W(q, \tilde{\theta}, \tilde{\theta}_i) = \int_0^{q(\tilde{\theta})} P(u)du - P(\tilde{\theta})q(\tilde{\theta}_i) + \lambda \left[P(\tilde{\theta})q(\tilde{\theta}_i) - C_i(q, \tilde{\theta}_i) \right]. \quad (8)$$

λ can be considered as a public-policy choice variable. It is easy to see that for any $t \in [0, 1]$ and $\varphi \in [0, 1]$, λ is monotone nondecreasing in the marginal transfer t , and the social weight φ . Further, as $\frac{\partial^2 \lambda}{\partial t \partial \varphi} = -1 < 0$, a high marginal transfer strictly reduces the marginal effect of public funds on λ . In other words, there is a substitution effect between social weight and marginal transfer. As we will see later in the paper, we need to consider that $\frac{\alpha}{\alpha+1} < \lambda \leq 1$ in order to ensure positive price and volume. For φ close to 0 and $0 \leq t < 1$, the public authority prefers to delegate water services to a private operator and hence, maximizes the sum of consumers' surplus and the transfer. Any increase in φ implies a larger λ , which indicates that the public authority put more weight on the part of realized profits left to the operator. In particular, $\lambda = 1$ yields two cases:

- $\varphi \geq 0$ and $t = 1$; the social welfare function is the sum of consumers' surplus and realized profits of managing water services. One possible interpretation is that the public authority prefers to keep public the management.
- $\varphi = 1$ and $0 \leq t < 1$; the public authority may enjoy some marginal returns of contract-out management by delegating water services.

For tractability, we will study below each of these cases according to exogenous information structures

$(\tilde{\theta}, \tilde{\theta}_i)$ about the quality of the infrastructure θ .

2.3 Assumptions and Timing

Recall that the quality of the infrastructure in terms of water leaks θ is uncertain at the time of the delegation. We assume that θ normally distributed with a mean μ_θ and the precision $\tau_\theta \equiv \frac{1}{\sigma_\theta^2}$. A public authority who announces the delegation process discloses a quality index representing the state of water services given by $\tilde{\theta}$.⁹

Now, we can describe the information structure that all parties in the delegation process are assumed to observe a two-dimensional signal. In the first dimension, the signal $\tilde{\theta}$ is publicly observed and common to all parties; whereas in the second dimension, the signal $\tilde{\theta}_i$ is privately observed and idiosyncratic to the operator i . Thus, we have the following assumptions.

Assumption 1: The public signal is noisy: $\tilde{\theta} = \theta + \eta$, where $\tilde{\theta}$ is jointly normally distributed with: $\tilde{\theta} \sim N(\mu_\theta, \sigma_\theta^2)$, and $\sigma_\theta^2 = \sigma_\theta^2 + \sigma_\eta^2$. The random variable η is normally distributed with zero mean and precision given by $\tau_\eta \equiv \frac{1}{\sigma_\eta^2}$; moreover, η is assumed to be independent of the state θ . The precision of public signal is $\tau_{\tilde{\theta}} \equiv \frac{1}{\sigma_\theta^2 + \sigma_\eta^2}$.¹⁰

Assumption 2: Given $\tilde{\theta}$, and based on the operator's prior beliefs, the private signal $\tilde{\theta}_i$ can be written as $\tilde{\theta}_i = \tilde{\theta} + \Delta\theta_i$, where the idiosyncratic signal $\Delta\theta_i$ is assumed to be normally distributed with zero mean and precision given by $\tau_{\Delta\theta_i} \equiv \frac{1}{\sigma_{\Delta\theta_i}^2}$.

Though this information structure of bivariate normally distributed signals appears in games of incomplete information (for example Morris and Shin, 2002; Angeletos and Pavan, 2007), it is similar to that of Myatt and Wallace (2012, 2015), in which η is the “sender noise”, and $\Delta\theta_i$ is the “receiver noise”. Given Assumptions 1 and 2, the private estimation can be written as $\tilde{\theta}_i = \theta + \eta + \Delta\theta_i$, where random variables η and $\Delta\theta_i$ are independently and identically distributed. Hence, the precision of the private signal can be written as $\tau_{\tilde{\theta}_i} \equiv \frac{1}{\sigma_\theta^2 + \sigma_{\Delta\theta_i}^2} = \frac{1}{\sigma_\theta^2 + \sigma_\eta^2 + \sigma_{\Delta\theta_i}^2}$.

Assumption 3: During the negotiation process, an operator interested by the delegation contract may report in its drafting specifications a noisy private estimation of the state of water mains to the public authority. The announced estimation is a common knowledge and is given by: $\hat{\theta}_i \equiv \tilde{\theta} + d\Delta\theta_i$, where $d \in [0, 1]$.

The noisy announcement defined in *Assumption 3* is similar to the one adopted by Auriol and Laffont (1992) who assume that the distribution of the idiosyncratic part is discrete. An alternative normalization assigns a weight 1 to the idiosyncratic shock $\Delta\theta_i$ and $\frac{1}{(1-r)}$ to the aggregate shock $\tilde{\theta}$, as in Bergemann et al. (2015). Note that the weight d could simply be an exogenous parameter or it could be the result of some optimization (see Bergemann et al., 2015), we focus on the first possibility:

⁹For example, under the obligation of informational transparency in the water sector imposed by the European Water Framework Directive (2000), local authorities have to publish a quality index regarding water facilities based on some statistics and annual reports Elnaboulsi (2009).

¹⁰The assumption of normality is very convenient analytically but presents the drawback that price and quantity may take negative values with the parameters of the random variables (Vives, 2008).

- 1) When $d = 0$, then the operator's announced estimation becomes $\hat{\theta}_i \equiv \tilde{\theta} = \theta + \eta$. The operator announces a quality index identical to the one revealed by the public authority.
- 2) When $d = 1$, then the operator's announced index is $\hat{\theta}_i \equiv \tilde{\theta} + \Delta\theta_i$. This simply means that $\hat{\theta}_i \equiv \tilde{\theta}_i$. The operator announces exactly its own private estimation.
- 3) Finally, if $d \in]0, 1[$, then $\hat{\theta}_i \equiv \tilde{\theta} + d\Delta\theta_i$. In its drafting specifications, the operator reports a different estimation of the quality index to the public authority.

Assumption 4: Given $\hat{\theta}_i$, both public and private signals about the state of water services are unbiased, such that the equality $\mathbb{E}[\hat{\theta}_i | \tilde{\theta}_i] = \mathbb{E}[\tilde{\theta}_i | \hat{\theta}_i] = \mathbb{E}[\mathbb{E}[\theta | \hat{\theta}_i]] = \mathbb{E}[\hat{\theta}_i] = \mathbb{E}[\theta] = \mu_\theta$ should be hold.¹¹ It is simply meant to that, under the fundamental and a coordination motive, both public and private signals converge to μ_θ , the average estimation of the state of water mains.

Concerning the timing of the game, we focus on the design of the optimal delegation contract. Thus, we only consider the situation where a public authority is more concerned by the contracting process itself rather than the selection of a potential operator through auctioning. Figure 1 summarizes the timing of the delegation process.¹²

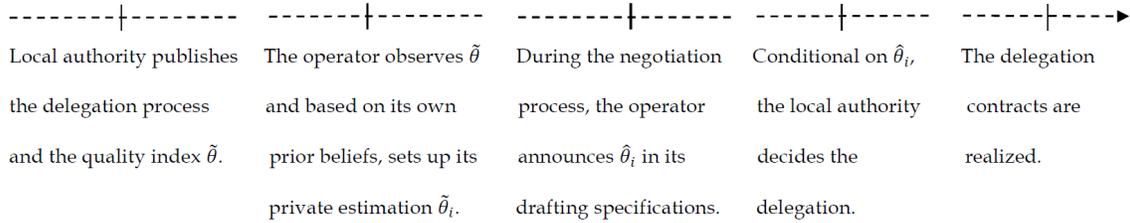


Figure 4 – The timing of the delegation process

As showed in this figure, local authority publishes the quality index $\tilde{\theta}$ in the first stage. Then, in the second stage, an operator observes and evaluates imperfectly $\tilde{\theta}$ on the basis of its prior beliefs. At the same time, the operator sets up its private estimation $\tilde{\theta}_i$ and decides whether to participate to the delegation process. If it does, during the negotiation process, the operator announces $\hat{\theta}_i$ in its draft specifications to the local authority. Finally, conditional on $\hat{\theta}_i$, the local authority and the operator revise their estimations.

Since we focus on the revised estimation *without bias*, the local authority decides whether or not to delegate the management of water services with respect to the level of estimation about the service quality.

¹¹See Appendix 10.2.1 and 10.2.2 in Vives (2008, Chapter 10, pp. 376-380)

¹²For instance, the French “Sapin Law” (Law 93-122 of the 29th of January 1993) governs the conduct of the delegation procedure. In brief, during the bidding process, the public authority establishes a shortlisted operators with whom it may negotiate the best delegation contract. According to the *intuitu personae* principle, the French local authorities have the right by the Constitution to individually negotiate the best contract with the selected operators. At the end of this negotiation phase, the local authority chooses the final winner depending on operators’ best drafting specifications. We do not consider this negotiation phase in our model.

3 Policy Design

3.1 The regulated volume and water Price

Before setting an optimal contract, a local authority needs to determine the regulated volume and price under which the contract is feasible. Given the fact that the volume of distributed water is imperfectly observable by all parties, the social welfare function to be maximized can be written as:¹³

$$\begin{aligned} \max_{\langle q \rangle} \mathbb{E} \left[W(q, \tilde{\theta}, \tilde{\theta}_i | \hat{\theta}_i) \right] &= \int_0^{q(\mathbb{E}[\tilde{\theta} | \hat{\theta}_i])} P(u) du - \left[a - b(1 + \mathbb{E}[\tilde{\theta} | \hat{\theta}_i])q \right] (1 + \mathbb{E}[\tilde{\theta}_i | \hat{\theta}_i])q \\ &+ \lambda \left([a - b(1 + \mathbb{E}[\tilde{\theta} | \hat{\theta}_i])q](1 + \mathbb{E}[\tilde{\theta}_i | \hat{\theta}_i])q - (1 + \mathbb{E}[\tilde{\theta}_i | \hat{\theta}_i])q \right), \end{aligned} \quad (9)$$

Lemma 1. Under the information structure adopted in this paper, when public-policy variable is $\lambda \in]\frac{a\mathbb{E}[\Delta\theta_i | \hat{\theta}_i]}{(a-1)(1+\mathbb{E}[\tilde{\theta}_i | \hat{\theta}_i])}, 1]$, the regulated volume and prices that maximize the expected welfare function depend on revised public and private estimation:

$$q \left(\mathbb{E}[\tilde{\theta} | \hat{\theta}_i], \mathbb{E}[\tilde{\theta}_i | \hat{\theta}_i] \right) = \frac{a(1 + \mathbb{E}[\tilde{\theta} | \hat{\theta}_i]) - [a - (a-1)\lambda](1 + \mathbb{E}[\tilde{\theta}_i | \hat{\theta}_i])}{b(1 + \mathbb{E}[\tilde{\theta} | \hat{\theta}_i])^2 - 2b(1 + \mathbb{E}[\tilde{\theta} | \hat{\theta}_i])(1 + \mathbb{E}[\tilde{\theta}_i | \hat{\theta}_i])(1 - \lambda)}, \quad (10)$$

$$P \left(\mathbb{E}[\tilde{\theta} | \hat{\theta}_i], \mathbb{E}[\tilde{\theta}_i | \hat{\theta}_i] \right) = \frac{[(a+1)\lambda - a](1 + \mathbb{E}[\tilde{\theta}_i | \hat{\theta}_i])}{(1 + \mathbb{E}[\tilde{\theta} | \hat{\theta}_i]) - 2(1 + \mathbb{E}[\tilde{\theta}_i | \hat{\theta}_i])(1 - \lambda)}. \quad (11)$$

By Jensen's inequality, if $q(\cdot)$ defined in (10) is increasing and convex in $\mathbb{E}[\tilde{\theta} | \hat{\theta}_i]$, then $\mathbb{E} \left[q \left(\mathbb{E}[\tilde{\theta} | \hat{\theta}_i] \right) \right] > q \left(\mathbb{E} \left[\mathbb{E}[\tilde{\theta} | \hat{\theta}_i] \right] \right)$. This simply means that the local authority has an “information-loving” attitude since it considers the public signal conditional on the private announcement. By contrast, if $q(\cdot)$ is decreasing and concave in $\mathbb{E}[\tilde{\theta}_i | \hat{\theta}_i]$, then $\mathbb{E} \left[q \left(\mathbb{E}[\tilde{\theta}_i | \hat{\theta}_i] \right) \right] < q \left(\mathbb{E} \left[\mathbb{E}[\tilde{\theta}_i | \hat{\theta}_i] \right] \right)$. In this case, the local authority has an “information-averse” attitude to the announced estimation. Further, we can show that if $P(\cdot)$ defined in (11) is decreasing and convex in $\mathbb{E}[\tilde{\theta} | \hat{\theta}_i]$, while increasing and convex in $\mathbb{E}[\tilde{\theta}_i | \hat{\theta}_i]$, then $\mathbb{E} \left[P \left(\mathbb{E}[\tilde{\theta} | \hat{\theta}_i], \mathbb{E}[\tilde{\theta}_i | \hat{\theta}_i] \right) \right] > P \left(\mathbb{E} \left[\mathbb{E}[\tilde{\theta} | \hat{\theta}_i] \right], \mathbb{E} \left[\mathbb{E}[\tilde{\theta}_i | \hat{\theta}_i] \right] \right)$.

Lemma 2. Under *Assumption 4*, when $\lambda \in]\frac{a}{a+1}, 1]$ and $\mathbb{E}[\theta] \in]-1, \frac{(a-1)}{2}[$, the expected volume of distributed water and the water price defined in Lemma 1 can be simplified:

$$q = \frac{(a-1)\lambda}{b(1 + \mathbb{E}[\theta])[2\lambda - 1]}, \quad (12)$$

$$P = \frac{(a+1)\lambda - a}{[2\lambda - 1]}. \quad (13)$$

Proof. See Appendix.

The expected volume of distributed water and prices are positive for any $\lambda \in]\frac{a}{a+1}, 1]$ as well as $\mathbb{E}[\theta] \in]-1, \frac{(a-1)}{2}[$. This also ensures that the second order conditions are satisfied. In addition, for a given

¹³Reynaud and Thomas (2005) point out that in the water industry, greater leakage characterizes a lower efficient network. Since leakage occurs between the production stage and the distribution, a natural measure of network quality is the ratio of billed water to produced water. Hence, our study focuses on the volume of the distributed water rather than the volume of the produced water.

estimated quality index of water mains, the expected volume of distributed water increases with the parameter a which represents demographic and geographical characteristics of a given municipality.¹⁴

Proposition 1: When the quality of the infrastructure is estimated *without bias* by both the local authority and the operator, the expected volume of distributed water is decreasing in $\mathbb{E}[\theta]$, and the curve is convex in the expected quality of water mains for any $\lambda \in]\frac{a}{a+1}, 1]$ and $\mathbb{E}[\theta] \in]-1, \frac{(a-1)}{2}[$.

Proof. Differentiating (12) with respect to $\mathbb{E}[\theta]$ yields:

$$\frac{\partial q}{\partial(\mathbb{E}[\theta])} = \frac{-(a-1)\lambda}{b(1+\mathbb{E}[\theta])^2(2\lambda-1)} < 0, \quad (14)$$

$$\frac{\partial^2 q}{\partial(\mathbb{E}[\theta])^2} = \frac{2(a-1)\lambda}{b(1+\mathbb{E}[\theta])^3(2\lambda-1)} > 0, \quad (15)$$

as $a > 1$.

This proposition indicates that if both signals are unbiased, then $\mathbb{E}[\theta]$ may be referred to as ex post common value of the quality of water mains, with which the local authority and the operator coordinate their estimations. $\mathbb{E}[\theta] \in]-1, 0]$ signals that the quality is estimated to be “bad”; the expected volume of distributed water increases. However, $\mathbb{E}[\theta] \in]0, \frac{(a-1)}{2}[$ signals an estimated better quality, and the expected volume of distributed water decreases with it. In particular, $\lim_{\mathbb{E}[\theta] \rightarrow -1} q(\mathbb{E}[\theta]) = +\infty$. In this case, if the local authority does not undertake any policy to improve the quality of the infrastructure and reduce water leaks, then it has to produce more and more volume to fulfill its legal responsibility in providing water services, which is not economically and environmentally efficient. Henceforth, we find the following result.

Corollary 1. $\forall \lambda \in]\frac{a}{a+1}, 1]$, and $\mathbb{E}[\theta] \in]-1, \frac{(a-1)}{2}[$, the expected volume of distributed water is decreasing and convex in λ , whereas the water price is increasing and concave in λ .

Proof. Differentiating (12) with respect to λ yields:

$$\frac{\partial q}{\partial \lambda} = \frac{-(a-1)}{b(1+\mathbb{E}[\theta])(2\lambda-1)^2} < 0, \text{ and } \frac{\partial^2 q}{\partial \lambda^2} = \frac{4(a-1)}{b(1+\mathbb{E}[\theta])(2\lambda-1)^3} > 0. \quad (16)$$

$$\frac{\partial P}{\partial \lambda} = \frac{(a-1)}{(2\lambda-1)^2} < 0, \text{ and } \frac{\partial^2 P}{\partial \lambda^2} = -\frac{2(a-1)}{(2\lambda-1)^3} < 0. \quad (17)$$

Intuitively this means that any public intervention on the network may reduce water leaks and enhance efficiency. To improve the quality of water mains in the case of delegation, a local authority either puts more weight on the operator’s utility, or leaves more profits to the operator. Having said that, it is worth to analyze how the expected volume of distributed water and the price vary with respect to φ and t before analyzing the conditions under which a given operator may have positive profits when managing

¹⁴For instance, touristic areas have a higher level seasonal consumption. Further, urban and semi-urban areas have a less per-household water consumption than rural areas.

the water networks. Since λ is monotone nondecreasing in φ and t , then under our assumptions:

$$\frac{\partial q}{\partial \varphi} = \frac{-(a-1)(1-t)}{b(1+\mathbb{E}[\theta])(2\lambda-1)^2} < 0, \text{ and } \frac{\partial^2 q}{\partial \varphi^2} = \frac{4(a-1)(1-t)^2}{b(1+\mathbb{E}[\theta])(2\lambda-1)^3} > 0, \quad (18)$$

$$\frac{\partial q}{\partial t} = \frac{-(a-1)(1-\varphi)}{b(1+\mathbb{E}[\theta])(2\lambda-1)^2} < 0, \text{ and } \frac{\partial^2 q}{\partial t^2} = \frac{4(a-1)(1-\varphi)^2}{b(1+\mathbb{E}[\theta])(2\lambda-1)^3} > 0. \quad (19)$$

Thus, a local authority may use either the marginal transfer t or the social weight φ as a policy instrument to improve the quality of the infrastructure. Both cases generate a higher water price:

$$\frac{\partial P}{\partial \varphi} = \frac{(a-1)(1-t)}{(2\lambda-1)^2} > 0, \text{ and } \frac{\partial^2 P}{\partial \varphi^2} = \frac{-4(a-1)(1-t)^2}{(2\lambda-1)^3} < 0, \quad (20)$$

$$\frac{\partial P}{\partial t} = \frac{(a-1)(1-\varphi)}{(2\lambda-1)^2} > 0, \text{ and } \frac{\partial^2 P}{\partial t^2} = \frac{-4(a-1)(1-\varphi)^2}{(2\lambda-1)^3} < 0. \quad (21)$$

On the one side, for a given marginal transfer t , the expected volume of distributed water is decreasing and convex on the social weight φ , but the water price is increasing and concave on φ .¹⁵ This simply means that any increase in the social weight yields high-level water price because the local authority is more concerned by the state of water mains. In this case, the consumers pay any improvement of water services through the shadow price of public funds.

On the other side, for a given social weight φ , the expected volume of distributed water is decreasing and convex with respect to the marginal transfer t , whereas the water price is increasing and concave on t . This conclusion is economically intuitive. The local authority may use a part of profits to improve the quality of the infrastructure in order to reduce water leaks. It follows that the expected volume of distributed water decreases, which implies an increase of water prices. In addition, the local authority conveys some information on the quality of water mains to the operator. The latter may ask a higher price inasmuch as it keeps a good quality of the infrastructure in managing the service.

3.2 Delegation contracts

In the last section, we defined the feasible regulated volume of distributed water and the corresponding prices under unbiased estimation about the quality of water mains. Both variables depend on λ . In this section, we examine the design of delegation contracts under admissible values for the choice instruments and the choke price.

3.2.1 Admissible values for the choice instruments

Note that, for a given volume of distributed water, one may check the condition under which the price covers the marginal cost in managing the service. Under the assumptions adopted in this paper, the

¹⁵The social weight φ may also represent the shadow price of public funds.

following expression must hold:

$$\frac{(a+1)\lambda - a}{[2\lambda - 1]} \geq (1 + \mathbb{E}[\theta]), \quad (22)$$

This yields,

$$\lambda \geq \frac{[a - (1 + \mathbb{E}[\theta])]}{[(a+1) - 2(1 + \mathbb{E}[\theta])]}, \quad (23)$$

which is true for any $\mathbb{E}[\theta] \in] - 1, \frac{(a-1)}{2}[$. Thus, from Equation (23), according to $\mathbb{E}[\theta]$, we distinguish different range of λ .

Lemma 3. The public-choice variable λ satisfies:

- 1). when $\mathbb{E}[\theta] \in] - 1, 0[$, $\frac{[a - (1 + \mathbb{E}[\theta])]}{[(a+1) - 2(1 + \mathbb{E}[\theta])]} \leq \lambda < 1$,
- 2). when $\mathbb{E}[\theta] = 0$, $\lambda = 1$,
- 3). when $\mathbb{E}[\theta] \in] 0, \frac{(a-1)}{2}[$, $\lambda \geq \frac{[a - (1 + \mathbb{E}[\theta])]}{[(a+1) - 2(1 + \mathbb{E}[\theta])]} \geq 1$.

The first case indicates that when water mains are estimated to be in “bad” conditions, any increase in $\mathbb{E}[\theta]$ highers λ . As the local authority values the quality more, λ is adjusted accordingly. In second case, λ can be set up to its maximum value when there is not any estimation about the quality. Recall that when $\lambda = 1$, the local authority may keep the public management of water services (e.g. $\varphi = 0$ and $t = 1$), or contract-out the management (e.g. $\varphi = 1$ and $0 \leq t < 1$). Finally, when $\mathbb{E}[\theta] \in] 0, \frac{(a-1)}{2}[$, water mains are estimated to be in “good” conditions, however, an increase in $\mathbb{E}[\theta]$ implies that λ may be beyond its maximum value under our assumptions. In this case, the local authority has incentives to keep public the management of a “good” quality water infrastructure and hence, consumers may benefit from low water price level.

By this lemma, a local authority is interested by delegating water services to a private operator if and only if $\forall \mathbb{E}[\theta] \in] - 1, 0[$. Thus, it may set the price $P \equiv \min\{1, P(\lambda, a)\}$, where $P(\lambda, a) = \frac{(a+1)\lambda - a}{[2\lambda - 1]}$ and $\lambda \in [\frac{[a - (1 + \mathbb{E}[\theta])]}{[(a+1) - 2(1 + \mathbb{E}[\theta])]}, 1) \subset] \frac{a}{a+1}, 1[$. In particular,

$$\lim_{\lambda \rightarrow \frac{[a - (1 + \mathbb{E}[\theta])]}{[(a+1) - 2(1 + \mathbb{E}[\theta])]}} P = (1 + \mathbb{E}[\theta]) = C_q, \text{ and } \lim_{\lambda \rightarrow 1} P = 1. \quad (24)$$

In fact, this expected water price is equivalent to the marginal value of information in the cost functions. It is worth noting that $P(\cdot)$ in (24) is similar to the socially inefficient fixed-fee mechanism as demonstrated in Cavaliere et al. (2017). Any improvement in the quality of the infrastructure lowers the volume of distributed water that is economically intuitive; then increases the price of water services in order to cover ex post extra costs linked to the marginal value of information. Therefore, if the quality of the infrastructure is underestimated such that $\mathbb{E}[\theta] \in] - 1, 0[$, as we can see in Equation (24), the private operator has no incentives to reduce costs under delegation contracts, which yields higher prices. An evident issue arises then: how to define the optimal delegation contract when water prices depends on the average estimation of the quality of mains.

We return now to our equations (12) and (13), and calculate the profit. First, we write $\pi(\mathbb{E}[\theta])$ as

$$\pi(\mathbb{E}[\theta]) = \frac{\lambda(a-1)[(a+1)\lambda - a - (2\lambda-1)(1+\mathbb{E}[\theta])]}{b(1+\mathbb{E}[\theta])(2\lambda-1)^2}; \quad \forall a > 1. \quad (25)$$

Since $\pi(\mathbb{E}[\theta]) \geq 0$ for all λ and $\mathbb{E}[\theta]$. Therefore, by Lemma 3,

Proposition 2. $\forall a > 1$ and $\mathbb{E}[\theta] \in]-1, 0[$, the expected profit function is:

- positive, decreasing and convex in $\mathbb{E}[\theta]$, if and only if $\lambda_{min} \in [\frac{a-(1+\mathbb{E}[\theta])}{(a+1)-2(1+\mathbb{E}[\theta])}, 1[$;
- increasing and concave in λ for any $\mathbb{E}[\theta] \in]-1, \frac{(a-1)}{1-2\lambda}]$, and decreasing and concave in λ if $\mathbb{E}[\theta] \in]\frac{(a-1)}{1-2\lambda}, 0[$.

Proof. See Appendix.

Proposition 2 shows the conditions under which the profit is insured to be positive by a local authority when delegation process happens. Under delegation contracts, any improvement in the quality of the infrastructure, i.e. an increase in $\mathbb{E}[\theta]$, implies less profits. This is economically intuitive since, for a given level of water prices, an increase of $\mathbb{E}[\theta]$ yields higher costs; at the same time lowers the volume of produced and distributed water due to a reduction in water leaks.

Any increase in λ means that a local authority tends to share more costs of running water services with the operator for a given φ . In this case, the profit increases for any value of $\mathbb{E}[\theta] \in]-1, \frac{(a-1)}{1-2\lambda}]$ and then decreases if $\mathbb{E}[\theta] \in]\frac{(a-1)}{1-2\lambda}, 0[$. By the definition of λ , the expected profits are higher when the local authority uses more public funds (higher φ), or draws less amount of profits from the operator (lower t). Having said that, for a better public estimation of the quality of water mains, the profit decreases for admissible values of λ . Intuitively this means that a high marginal value of information generates a better-estimated infrastructure quality.¹⁶ As a result, water mains are expected in “good” structural conditions, and hence the network is facing a small leakage rate.

For example, if the local authority decides to contract out such “good” water services, it may update its public instruments λ to be high in order to give the operator incentives to improve the quality. We distinguish between two cases. On the one hand, the local authority draws less amount of profits from the operator. A low-level water price can be held for a given φ . On the other hand, for a given t , the local authority uses more public funds to share the costs. Thus, consumers pay for a higher water price as soon as the water services is contracted-out. Both cases show that when the quality of the infrastructure is publicly estimated to be good state, a local authority prefers to keep such water services in favor of the consumers.

However, if the quality of the infrastructure is underestimated at the time of the delegation, then a local authority may allow a certain level of leaks which increases the expected volume of produced and distributed water. This is detrimental to consumers to pay for the higher level of distributed water than before the delegation. Therefore, the local authority adjusts the public-policy choice by reducing λ in

¹⁶Here, both a local authority and the operator underestimate or overestimate the quality, due to the precision of information (see Section 4). Such precision may differ between agents. However, we ignore this case in the present paper.

order to reduce the price of distributed water. Our results in Proposition 2 come from the assumption that the quality of the infrastructure becomes posterior common knowledge between a local authority and the operator through the convergence of private estimation towards the public estimation. This assumption is opposed to the assumption of Martimort and Sand-Zantman (2006), who consider that the quality of the facility is only known by the principal. Hence, our results are different from their findings. They find that the realized profits increase with the innate quality of the facility. By contrast, we find that the realized profits can decrease with public disclosure of information about the quality of the infrastructure.

3.2.2 The role of choke price

From Proposition 2, we summarize $\forall \mathbb{E}[\theta] \in]-1, 0[$,

$$\mathbb{E}[\theta] \leq \frac{(a-1)}{1-2\lambda} \iff \frac{\partial \pi}{\partial \lambda} \geq 0.$$

This observation does not, by itself, allow us to characterize the design of public instruments across the range of estimation, since $\mathbb{E}[\theta]$ and $\frac{(a-1)}{1-2\lambda}$ might be updated. For a given value of a , the estimation of the quality can be established by referring public reports of interventions (the budget of water, the overall budget of the municipality, investment charges,...). Then, a local authority adjusts its public instruments by observing both the public estimation and the choke price. The latter represents the fixed effects of water consumption in municipalities, which are associated with the geometrical and demographic characteristics.

We observe that, for a given public instrument λ , and the quality of the infrastructure $\mathbb{E}[\theta] \in]-1, 0[$, if the fixed effects a become high, then the operator obtains a high operating profit. In fact, the expected volume of water distribution is directly increasing in a , and the water price is increasing in a . Moreover, for a given level of $\mathbb{E}[\theta]$, the larger is the choke price, the higher is the minimum value of λ . A local authority adjusts its public-policy choice variable to enable the expected water price to cover the costs, because the costs of improving the quality in areas with a strong choke price are important.¹⁷

To satisfy this more stringent criterion, we specify two levels of choke price, which affect the decision-making about the type of delegation contracts. For the same level of choke price, it is the estimation of the quality of networks that predicts the choice of delegation contracts. For an equal estimation of the quality, it is the choke price that affects the kind of delegation contracts. Therefore, it is the weak choke price when a varies over the interval $]1, 2[$, whereas it is strong choke price when a is beyond the value of 2.

This definition is based on the fact that for a baseline annual household water consumption of 120 cubic meters, the fixed part of the tariff represents 25% of the total price, and there are additional fees going to the Basin Agency and a value added tax for the State (see Porcher, 2014, 2017). Each consumer

¹⁷Porcher (2014; 2017) shows that the fixed-part of water price includes some hidden cost related to the improvement of water services, which leads to an increasing water price in the future. This “hidden cost” are linked to the debt and investment in the water sector.

pays a fixed charge corresponding to provisions for capital stock renewal and debt service. A marginal tariff corresponds to operating expenses of the volumetric charge.¹⁸

A weak choke price indicates that there are low levels of per-household water consumption in one municipality, such as urbanized and semi-urbanized areas with a lot of working inhabitants. The higher incomes of per-household, the less choke price. For example, the previous studies on the French water sector (Reynaud 2007, 2008; Porcher, 2014) show that the share of income devoted to water bills is less in the higher income class than in the lower income class. By contrast, a high-level of choke price indicates that there is a low consumption density, and an important investment of water networks in rural areas. In addition, touristic areas are associate with higher choke price because of a high-level seasonal consumption.

Bring our above analysis together, we characterize two levels of the optimal adjustment of public-policy choice variable which correspond to the different choke price. This leads us to the following main result of this paper.

Proposition 3. Restricting to $\mathbb{E}[\theta] \in]-1, -(a-1)[$, where $a \in]1, 2[$, so $\lambda^* = \frac{(1+\mathbb{E}[\theta]) - a}{2\mathbb{E}[\theta]} \in \left[\frac{a - (1+\mathbb{E}[\theta])}{(a+1) - 2(1+\mathbb{E}[\theta])}, 1 \right)$, maximizes the expected profit $\pi(\mathbb{E}[\theta])$. When $a \geq 2$, for $\mathbb{E}[\theta] \in]-1, 0]$, then $\lambda^* = 1$. A local authority must ensure $\pi(\mathbb{E}[\theta]) = \left[\frac{(a-1)}{b(1+\mathbb{E}[\theta])} - \frac{(a-1)}{b} \right] > 0$ under a unique water price $P = 1$.

Proof. See Appendix.

Proposition 3 indicates that λ depends both on the average estimation of the quality and the choke price a , when the quality of the infrastructure is estimated “bad” situation. In areas with a weak choke price $a \in]1, 2[$, the optimal solution of public-policy choice variable λ^* varies with the average estimation of the quality. By contrast, in areas with a strong choke price $a \geq 2$, a local authority applies the maximum public-policy choice variable $\lambda^* = 1$. In other words, a local authority leaves the entire operational profit to the operator ($t = 0$), and puts the weight $\varphi = 1$ on operator’s utility in its social objective. Then, we can provide an example showing the relationship between λ^* and $\mathbb{E}[\theta]$.

Example: The fixed effects of water consumption presented by the choke price $a \in]1, 2[$, and the optimal adjustment of public-policy choice variable λ^* is increasing in the average estimation of water services $\forall \mathbb{E}[\theta] \in]-1, -(a-1)[$.

$$\begin{aligned} \lim_{\mathbb{E}[\theta] \rightarrow -1} \lambda^* &= \frac{a}{2}, \quad 1 < a < 2, \\ \lim_{\mathbb{E}[\theta] \rightarrow -\frac{1}{4}} \lambda^* &= 2\left(a - \frac{3}{4}\right), \quad 1 < a < \frac{5}{4}, \\ \lim_{\mathbb{E}[\theta] \rightarrow -\frac{1}{5}} \lambda^* &= \frac{5}{2}\left(a - \frac{4}{5}\right), \quad 1 < a < \frac{6}{5}, \\ \lim_{\mathbb{E}[\theta] \rightarrow -\frac{1}{6}} \lambda^* &= 3\left(a - \frac{5}{6}\right), \quad 1 < a < \frac{7}{6}, \end{aligned}$$

¹⁸We also borrow some empirical techniques studying water demand for a given community (see Nauges and Thomas, 2003; Reynaud and Thomas, 2005; Porcher, 2014, 2017) to define the choke price a . It represents the population (ages, wealth), the population connected to the water supply networks, and the community itself (size, customer density, industrial density, etc.).

where $3(a - \frac{5}{6}) > \frac{5}{2}(a - \frac{4}{5}) > 2(a - \frac{3}{4}) > \frac{a}{2}$.

Further, using 238 numerical simulations, we illustrate that, for $\forall \mathbb{E}[\theta] \in]-1, -(a-1)[$ and $a \in]1, 2[$, the optimal adjustment of public-policy choice variable λ^* generates different level expected profits.

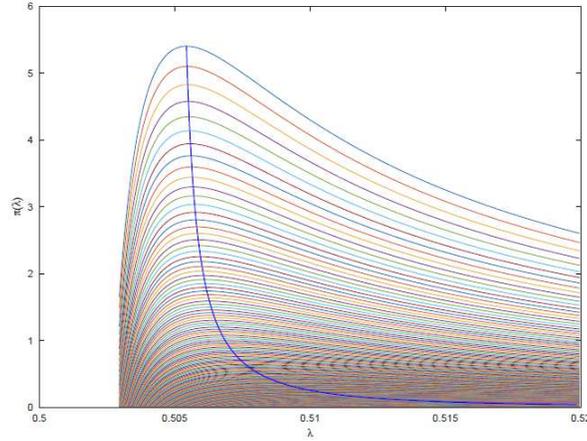


Figure 5 – The expected profits depending on λ for $\forall \mathbb{E}[\theta] \in]-1, -(a-1)[$ and $a \in]1, 2[$

In Figure 5, each level curve describes the expected profit for a specific public-policy variable λ affected by $\mathbb{E}[\theta]$ and a . A lower estimation of the quality $\mathbb{E}[\theta]$ generates a higher level curve. As the estimation improves, the expected profits tend to be zero. The downward sloping movement represents an increase in informativeness of signals, which improves the estimation of the quality. For any level estimation, an increase in the choke price a therefore leads to an increase in public-policy variable; then an increase in public-policy variable first leads to an increase and later to a decrease in the expected profits. It is worth noting that for any $\mathbb{E}[\theta]$ and a , the curve of maximums of the expected profit is decreasing and convex in λ . By proposition 3 and Figure 5, an increase in the estimation of the quality results in different designs of contract.

3.2.3 Main contracts

What are main contracts designed by a local authority for $\forall \mathbb{E}[\theta] \in]-1, -(a-1)[$ and $a > 1$? From Figure 5, we identified, for example, three threshold values of $\mathbb{E}[\theta]$ as demonstrated in Figure 6. The expected profits depending on λ^* are positive if the estimation is $\mathbb{E}[\theta] \in [-0.92, -0.40]$. In this case, the delegation contracts designed by a local authority are favorable to potential operators who may have different underestimations about the quality of water services. When there are better estimations, such that $\mathbb{E}[\theta] \in [-0.40, -0.11]$, some public-private partnership contracts may be proposed by a local authority. Hence, the expected profits are guaranteed to be positive by any high-level of λ^* . Intuitively this means that the local authority should have shared more costs of managing good quality of water services. However, it would also have been true if the local authority had kept the public management of such services: it does not want to raise λ^* at the cost of consumers.

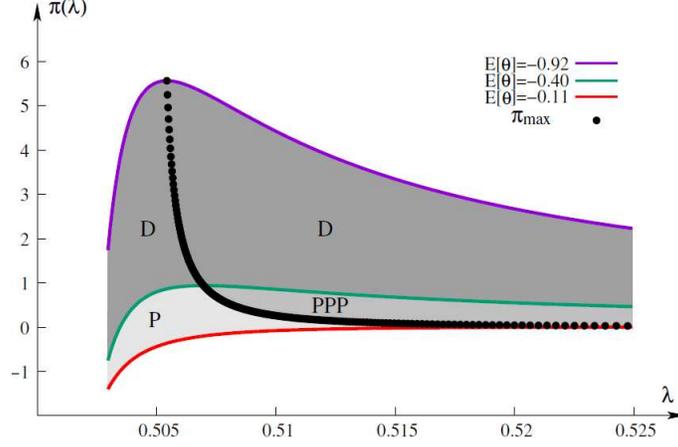


Figure 6 – The choice of delegation contracts

Now, we write the different contracts as function of ex post average estimation $\mathbb{E}[\theta]$ and the choke price a .

- The delegation contracts.** When ex post average estimation of the quality of the infrastructure is $\forall \mathbb{E}[\theta] \in]-1, -(a-1)[$; the choke price is $a \in]1, 2[$, a local authority can decide an optimal public-policy λ^* which is larger than the minimum public-policy choice variables λ_{min} . In this case, λ^* satisfies

$$\lambda^*(\mathbb{E}[\theta]) = \frac{(1 + \mathbb{E}[\theta]) - a}{2\mathbb{E}[\theta]}, \quad (26)$$

then, $P(\mathbb{E}[\theta])$ and $q(\mathbb{E}[\theta])$ are defined by

$$q(\mathbb{E}[\theta]) = \frac{a - (1 + \mathbb{E}[\theta])}{2b(1 + \mathbb{E}[\theta])}, \quad (27)$$

$$P(\mathbb{E}[\theta]) = \frac{a + (1 + \mathbb{E}[\theta])}{2}. \quad (28)$$

Henceforth, the expected consumer surplus, the operator's expected profit if it wins the delegation contract, and the expected social welfare are given by $SC(\mathbb{E}[\theta])$, $\pi(\mathbb{E}[\theta])$ and $W(\mathbb{E}[\theta])$

$$SC(\mathbb{E}[\theta]) = \frac{[a - (1 + \mathbb{E}[\theta])]^2}{8b(1 + \mathbb{E}[\theta])}, \quad (29)$$

$$\pi(\mathbb{E}[\theta]) = \frac{[a - (1 + \mathbb{E}[\theta])]^2}{4b(1 + \mathbb{E}[\theta])}, \quad (30)$$

$$W(\mathbb{E}[\theta]) = \frac{[a - (1 + \mathbb{E}[\theta])]^2}{8b(1 + \mathbb{E}[\theta])} \left[1 - \frac{a - (1 + \mathbb{E}[\theta])}{\mathbb{E}[\theta]} \right]. \quad (31)$$

- The public-private partnership contracts.** As $\forall \mathbb{E}[\theta] \in]-1, 0[$; the choke price is $a \geq 2$, all different levels of λ converge towards the value of one when the quality of water services is estimated to be better. Thus, a local authority ensures that the operator has positive expected profit by fixing

a high-level of λ^* , such that $\lambda^* = 1$. In this case, the expected volume of distributed water is given by

$$q(\mathbb{E}[\theta]) = \frac{(a-1)}{b(1+\mathbb{E}[\theta])}, \quad (32)$$

then a unique water price is set up as

$$P = 1. \quad (33)$$

Using the results of (32) and (33), we find that $\forall \mathbb{E}[\theta] \in]-1, 0[$ and $a \geq 2$,

$$SC(\mathbb{E}[\theta]) = \frac{(a-1)^2}{2b(1+\mathbb{E}[\theta])}, \quad (34)$$

$$\pi(\mathbb{E}[\theta]) = \frac{-(a-1)\mathbb{E}[\theta]}{b(1+\mathbb{E}[\theta])}, \quad (35)$$

$$W(\mathbb{E}[\theta]) = \frac{(a-1)[(a-1) - 2\mathbb{E}[\theta]]}{2b(1+\mathbb{E}[\theta])}. \quad (36)$$

It is noteworthy that the expected volume of distributed water defined in Equation (32) is higher than that in Equation (27). This reflects that municipalities' demographic and geographical characteristics have strong effects on water consumption. In addition, the unique water price defined in Equation (33) can cover the marginal cost of improving the quality of water services. Nevertheless, the expected social welfare is reduced because the operator's expected profits decreases.

Since $\lambda^* = 1$, a local authority may leave entire operational profits to the operator in order to give it incentives to maintain or improve the quality. In this case, the marginal transfer becomes $t = 0$, but the operator undertakes all the operational costs. Moreover, as the local authority interests the operator's economic scale in managing water services in areas characterized by a high choke price, for example, in rural areas and touristic areas, it puts a social weight $\varphi = 1$ on the operator's payoff. Hence, another mode of contracting out the public water services can be proposed by the local authority is the public-private partnerships. Recall that in this mode of management, the local authority should have shared the costs with the operator. Nevertheless, it does not want to raise water price at the cost of consumers. Fixing a unique water price, the local authority has to tolerate some water leaks in the networks of distributed water. Comparing Equation (32) with Equation (27), we remark that the local authority gave up some information rent to a cost-efficient operator when it chooses the public-private partnership contract. This information rent can be measured by water leaks tolerated in the water networks; at the same time depends on ex post average estimation of the quality, such that $q_{leak}(\mathbb{E}[\theta]) \equiv \frac{(a-1+\mathbb{E}[\theta])}{2b(1+\mathbb{E}[\theta])}$. We refer to it as a cost of signalling information on the quality of the infrastructure that the local authority shares with the operator. We resume main contracts in Proposition 4.

Proposition 4. A local authority and the operator estimate the quality of the infrastructure *without bias*. When the quality is underestimated, such that $\mathbb{E}[\theta] \in]-1, -(a-1)[$; and when the choke

price a is weak, the delegation mechanism $\{\lambda^*(\mathbb{E}[\theta]), q(\mathbb{E}[\theta]), P(\mathbb{E}[\theta])\}$ given in (26), (27), and (28) is feasible and maximizes the expected social welfare. For $\forall \mathbb{E}[\theta] \in]-1, 0[$, when the choke price is high enough to be $a \geq 2$; and if the quality is estimated to be better, the delegation mechanism $\{\lambda^* = 1, q(\mathbb{E}[\theta]), P = 1\}$ given in (32) and (33) can guarantee positive expected profits.

Regarding a small level of choke price $a \in]1, 2[$, the better the quality is estimated to be, the more expected volume of water distribution is reduced because of the less water leaks. In order to improve or maintain the quality, the operator increases operating expenses. At the same time, a local authority undertakes a part of costs. If the local authority can fund its economic interventions through its part of sharing profits, then it holds a low-level water price. On the contrary, if a local authority does not have enough transfer to fund its economic interventions, then it increases the water price to make consumers pay for the improvement of water services. Equation (28) shows that the expected water price increases in both the fixed effects of water consumption and the average estimation of the quality. In addition, it captures the long-run effects of the choke price for some level of the quality of water mains (see Nauges and Thomas, 2003). This is economic intuitive in urbanized areas with a strong population density, where local authorities tend to choose the delegation (for example, Martimort and Sand-Zantman, 2006; Reynaud and Thomas, 2005; Porcher, 2014). The water price is high in cities with higher incomes, where water services are delegated to an operator; consumers pay higher unit prices for the improvement of the quality of such services.

When the choke price is $a \geq 2$, for example, in rural areas with a low consumption density, the maintenance of the quality of the infrastructure is more difficult, costly than in urbanized and semi-urbanized areas. Moreover, increasing water price is not favorable for consumers who have already paid more for access to networks. Therefore, if the water services is estimated to be better, but there is an important investment in water networks, then a local authority may offer a public-private partnerships contract to the operator by fixing a unique water price. We illustrate, in Table 2, the different delegation mechanisms depending on ex post estimation of the quality of the infrastructure and the choke price.

In the next section, we study the decision-making of a local authority when the quality of water services is overestimated, in other words, $\forall \mathbb{E}[\theta] \in]0, \frac{(a-1)}{2}[$. Recall that the public-policy choice variable λ tends to be the value of one when ex post average estimation signals the quality better than it should be. In this way, there will be two possibilities: A local authority manages the water services and undertakes all operational costs ($t = 1$, and $\varphi \geq 0$); it can also contract out the management of water services to an operator through a public-private partnerships contract or a concession contract. The operator must undertake entire costs ($\varphi = 1$, and $0 \leq t < 1$). In the first case, the social objective of the local authority is subject to its budget constraints. Nevertheless, in the second case, the objective function of a local authority is subject to the operator's break-even constraint. For tractability, we focus on analyzing the first case.

3.3 Public managements

We consider directly the weight put on expected profits $\varphi \geq 0$ in the social objective of a local authority. As the public-policy choice variable is $\lambda = 1$, it is the local authority who draws entire profits ($t = 1$) when it manages itself the water services. Thus, the local authority maximizes the expected welfare function subject to its budget constraint,

$$\begin{cases} \underset{<q>}{max} \mathbb{E}[W|\hat{\theta}_i] = \mathbb{E}[SC|\hat{\theta}_i] + \mathbb{E}[\pi|\hat{\theta}_i], \\ \text{subject to} \\ \mathbb{E}[\pi|\hat{\theta}_i] \geq 0. \end{cases} \quad (37)$$

The problem defined by (37) can be rewritten as,

$$\underset{<q>}{max} \mathbb{E}[L|\hat{\theta}_i] = \mathbb{E}[SC|\hat{\theta}_i] + (1 + \varphi)\mathbb{E}[\pi|\hat{\theta}_i], \quad (38)$$

where $\varphi \geq 0$ can be viewed as the shadow price of binding budget constraint. It is also referred to as the cost of public funds. Maximizing (38), we obtain the expected volume of distributed water, noted as $q_L(\cdot)$.¹⁹ By *assumption 4*,

$$q_L(\mathbb{E}[\theta]) = \frac{(a-1)(1+\varphi)}{b(1+\mathbb{E}[\theta])(1+2\varphi)}. \quad (39)$$

Given the expected volume of distributed water in (39), we have a unique water price as²⁰

$$P_L = \frac{(a+1)\varphi + 1}{1+2\varphi}. \quad (40)$$

Moreover, the profit of managing water services is the source of the budget of a local authority. Integrating equation (39) into its budget constraint, we find an optimal condition of φ when ex post average estimation of water services is $\mathbb{E}[\theta] \in]0, \frac{(a-1)}{2}[$,

$$\varphi^* = \frac{\mathbb{E}[\theta]}{a-1-2\mathbb{E}[\theta]}. \quad (41)$$

This optimal condition (41) generates a solution maximizing (38) by saturating the budget constraint, such that $\mathbb{E}[\pi|\hat{\theta}_i] = 0$. Therefore, the expected volume of distributed water becomes

$$q_L^*(\mathbb{E}[\theta]) = \frac{a-(1+\mathbb{E}[\theta])}{b(1+\mathbb{E}[\theta])}, \quad (42)$$

¹⁹We can show that $q_L(\mathbb{E}[\hat{\theta}|\hat{\theta}_i], \mathbb{E}[\hat{\theta}_i|\hat{\theta}_i])$ is decreasing and convex in $\mathbb{E}[\hat{\theta}|\hat{\theta}_i]$ and $\mathbb{E}[\hat{\theta}_i|\hat{\theta}_i]$, by Jensen's inequality, so $\mathbb{E}[q_L(\mathbb{E}[\hat{\theta}|\hat{\theta}_i], \mathbb{E}[\hat{\theta}_i|\hat{\theta}_i])] > q_L(\mathbb{E}[\mathbb{E}[\hat{\theta}|\hat{\theta}_i]], \mathbb{E}[\mathbb{E}[\hat{\theta}_i|\hat{\theta}_i]])$.

²⁰We can show that $P_L(\mathbb{E}[\hat{\theta}|\hat{\theta}_i])$ is decreasing and linear with $\mathbb{E}[\hat{\theta}|\hat{\theta}_i]$, by Jensen's inequality, so $\mathbb{E}[P_L(\mathbb{E}[\hat{\theta}|\hat{\theta}_i])] > P_L(\mathbb{E}[\mathbb{E}[\hat{\theta}|\hat{\theta}_i]])$. The local authority is neutral with revised public estimation. Nevertheless, by Jensen's inequality, if $P_L(\mathbb{E}[\hat{\theta}_i|\hat{\theta}_i])$ is increasing and concave with $\mathbb{E}[\hat{\theta}_i|\hat{\theta}_i]$, then $\mathbb{E}[P_L(\mathbb{E}[\hat{\theta}_i|\hat{\theta}_i])] < P_L(\mathbb{E}[\mathbb{E}[\hat{\theta}_i|\hat{\theta}_i]])$. The local authority has aversion to the revised private estimation.

and the correspond expected water price is

$$P_L^*(\mathbb{E}[\theta]) = 1 + \mathbb{E}[\theta] = C_{q_L}. \quad (43)$$

Solutions defined by equations (42) and (43) verify the conditions of Kuhn-Tucker.

Further, if $\varphi \neq \varphi^*$, then there is an interior solution that maximizes (38) and ensures $\mathbb{E}[\pi|\hat{\theta}_i] > 0$. This interior solution is defined by Equation (39). We find that, when $\varphi > \varphi^*$, the expected volume of distributed water defined in (39) is less than $q_L^*(\mathbb{E}[\theta])$ defined in (42). If a local authority interests its budgets on the maintenance of the quality, then it tends to raise the water price. By contrast, if a local authority interests consumers surplus, then it fixes the water price to just cover the marginal cost. By the unique water price defined in (40), we study the effects of consumers' sensitivity to the quality of water services on public managements.

3.3.1 Consumers sensitivity

By ex post average of estimation about the quality of water services, the water price fixed by a local authority can be rewritten as a function of the inverse elasticity of demand and the shadow cost of public funds. The water price is given by

$$\begin{aligned} \frac{\partial \mathbb{E}[L|\hat{\theta}_i]}{\partial q_L} &= P_L(q_L)(1 + \mathbb{E}[\theta]) + \varphi P_L'(q_L) \cdot q_L(1 + \mathbb{E}[\theta]) \\ &+ \varphi P_L(q_L)(1 + \mathbb{E}[\theta]) - (1 + \varphi)C_{q_L} = 0, \end{aligned} \quad (44)$$

then Equation (44) is arranged to be

$$\begin{aligned} (1 + \varphi) [P_L(q_L)(1 + \mathbb{E}[\theta]) - C_{q_L}] &= -\varphi P_L'(q_L) \cdot q_L(1 + \mathbb{E}[\theta]), \\ \frac{[P_L(q_L)(1 + \mathbb{E}[\theta]) - C_{q_L}]}{P_L(q_L)} &= -\frac{\varphi}{(1 + \varphi)} \frac{1}{\varepsilon_{P_L}} (1 + \mathbb{E}[\theta]). \end{aligned} \quad (45)$$

where $\varepsilon_P \equiv (\partial q_L / \partial P_L) / (q_L / P_L) < 0$ is the elasticity of demand for water consumption. Note that the difference between the water price and the marginal cost is inversely proportional to the elasticity of demand for water consumption; at the same time depends on ex post average estimation about the quality. As $C_{q_L} = (1 + \mathbb{E}[\theta])$, the marginal cost of managing water services is equivalent to the marginal value of information on the quality of water services. Equation (45) can be simplified and arranged to obtain

$$\begin{aligned} \frac{[P_L(q_L) - 1]}{P_L(q_L)} &= -\frac{\varphi}{(1 + \varphi)} \frac{1}{\varepsilon_{P_L}}, \\ P_L &= \frac{1}{1 + \frac{\varphi}{(1 + \varphi)} \frac{1}{\varepsilon_{P_L}}}. \end{aligned} \quad (46)$$

where $\frac{1}{\varepsilon_P} \in] -\frac{(1+\varphi)}{\varphi}, 0[$ for $\varphi > 0$. Equation (46) shows that a unique water price does not depend directly on the quality of the infrastructure. Thus, we analyze the relationship between Equation (40)

and Equation (46).

Using (39) and (40), we can obtain the inverse price elasticity of demand in maximization of problem (37),

$$\frac{1}{\varepsilon_{P_L}} = - \frac{(a-1)(1+\varphi)}{(a+1)\varphi+1}. \quad (47)$$

The price elasticity of demand for water consumption captures the fixed effects of water consumption in (40). It reflects that municipalities' demographic and geographical characteristics have positive effects on water consumption (Porcher, 2014). Henceforth, we rewrite (45) as

$$\begin{aligned} \frac{P_L - C_{q_L}}{P_L} &= \frac{(a-1)\varphi - (1+2\varphi)\mathbb{E}[\theta]}{(a+1)\varphi+1}, \\ &= - \frac{(a-1)(1+\varphi)}{(a+1)\varphi+1} \left[\frac{(a-1)\varphi + (1+2\varphi)\mathbb{E}[\theta]}{(a-1)(1+\varphi)} \right], \end{aligned}$$

by integrating (47), we obtain,

$$\frac{P_L - C_{q_L}}{P_L} = - \frac{1}{\varepsilon_{P_L}} \frac{\varphi}{1+\varphi} + \frac{1}{\varepsilon_{P_L}} \frac{(1+2\varphi)}{(a-1)(1+\varphi)} \mathbb{E}[\theta]. \quad (48)$$

- If $\varphi \neq \varphi^*$ and $\varphi > 0$, then Equation (48) represents that the Lerner index (or the price-marginal cost ration) is the sum of two terms. The first term is $\frac{\varphi}{1+\varphi}$ times the inverse elasticity of demand for water consumption. The second term is a weighted average estimation of the quality of the infrastructure. It represents the sensitivity of consumers to the quality. The difference between the water price and the marginal cost is as large as the absolute value of elasticity of demand is small. The consumer's sensitivity to the quality of water services is added to this difference. In this case, as long as consumers' sensitivity to the quality is strong, the water price is increasing.

For $1 < a < 2$, such as in urbanized and semi-urbanized areas with a weak choke price, consumers' sensitivity to the quality is strong enough that the marginal cost pricing is increasing. By contrast, for $a > 2$, such as in rural areas with a strong choke price, consumers' sensitivity to the quality is relative weak, then the marginal cost pricing is decreasing. For example, in their empirical analysis, Reynaud and Thomas (2005) show that the consumers in urbanized areas present a large sensitivity to the public management of water networks, which has a significant effect on the water price. In addition, the empirical investigation made by Porcher (2014) of water pricing in France also provides an evidence for our theoretical results.

Lemma 4. The quality of the infrastructure is overestimated, such that $\mathbb{E}[\theta] \in]0, \frac{(a-1)}{2}[$. When $\varphi \neq \varphi^*$ and $\varphi > 0$, the expected volume of distributed water is $q_L = \frac{(a-1)(1+\varphi)}{b(1+\mathbb{E}[\theta])(1+2\varphi)}$. The water price

captures consumers' sensitivity to the quality and is defined by the Lerner index as

$$\begin{aligned} \lim_{\mathbb{E}[\theta] \rightarrow 0} \frac{P_L - C_{qL}}{P_L} &= -\frac{\varphi}{1 + \varphi} \frac{1}{\varepsilon_{P_L}}, \\ P_L &= \frac{1}{1 + \frac{\varphi}{1 + \varphi} \frac{1}{\varepsilon_{P_L}}}. \end{aligned} \quad (49)$$

$$\begin{aligned} \lim_{\mathbb{E}[\theta] \rightarrow \frac{(a-1)}{2}} \frac{P_L - C_{qL}}{P_L} &= \frac{1}{2(1 + \varphi)} \frac{1}{\varepsilon_{P_L}}, \\ P_L &= \frac{(a + 1)}{2 - \frac{1}{1 + \varphi} \frac{1}{\varepsilon_{P_L}}}. \end{aligned} \quad (50)$$

Proof. See Appendix.

A local authority can set up the water price as in (49) when it has approximately complete information about the quality. This price is as high as the elasticity price of demand is small ($\frac{1}{\varepsilon_{P_L}} < 0$) and the shadow price of public funds is rising. By Lemma 4, we observe that the water price in (49) is the same as in (46). In (46), the water price is defined without considering consumers' sensitivity to the quality, and it is fixed for all possible overestimation of the quality. Nevertheless, in (49), the water price integrates consumers' sensitivity to the quality. A high sensitivity to the quality of the infrastructure enables the local authority to enhance the water services, but a low-level of water price hold by a local authority cannot cover the high-level marginal cost. Then, it raises the shadow price of public funds which is in turn added to the water price.

Moreover, we remark that, the marginal cost of maintenance of good quality is lower in areas with a small choke price ($a \in]1, 2[$) than in areas with a strong choke price ($a \geq 2$). However, if consumers' sensitivity to the good quality becomes powerful in areas with $a \in]1, 2[$, then the water price in these areas is largely increasing. These results can explain why urbanized areas in France experience increased fixed fees, which are linked to public investments in renewal water networks.

- If $\varphi = \varphi^*$ and $\varphi^* \neq 0$, then we return back to solutions defined in (42) and (43). However, if $\varphi^* = 0$, this means that $\mathbb{E}[\theta] = 0$ and $\varphi = 0$, then we have

$$q_L = \frac{(a - 1)}{b}, \quad (51)$$

and

$$P_L = 1. \quad (52)$$

Equation (52) shows that the water price is equal to the marginal cost only when there is an approximate complete information about the quality of the infrastructure.

- If $\varphi = 0$, but $\varphi^* \neq 0$, then we find a solution with respect to the Kuhn-Tucker complementary slackness condition. This means that a local authority does not put any social weight on its profits when ex post average estimation of the quality is $\mathbb{E}[\theta] \in]0, \frac{(a-1)}{2}[$. In this case, the expected volume

of distributed water becomes

$$q_L(\mathbb{E}[\theta]) = \frac{(a-1)}{b(1+\mathbb{E}[\theta])}. \quad (53)$$

Considering consumers' sensitivity to the quality, Equation (48) is simplified as

$$\frac{P_L - C_{qL}}{P_L} = \frac{1}{\varepsilon_{P_L}} \frac{1}{(a-1)} \mathbb{E}[\theta], \quad (54)$$

where $\frac{1}{\varepsilon_{P_L}} < 0$. For $a \in]1, 2[$, consumers' sensitivity to the quality is high, whereas for $a \geq 2$, consumers' sensitivity is small. Thus, from Equation (54), we obtain

$$\lim_{\mathbb{E}[\theta] \rightarrow 0} \frac{P_L - C_{qL}}{P_L} = \lim_{\mathbb{E}[\theta] \rightarrow 0} \left[\frac{1}{\varepsilon_{P_L}} \frac{1}{(a-1)} \mathbb{E}[\theta] \right],$$

$$P_L = C_{qL}. \quad (55)$$

$$\lim_{\mathbb{E}[\theta] \rightarrow \frac{(a-1)}{2}} \frac{P_L - C_{qL}}{P_L} = \lim_{\mathbb{E}[\theta] \rightarrow \frac{(a-1)}{2}} \left[\frac{1}{\varepsilon_{P_L}} \frac{1}{(a-1)} \mathbb{E}[\theta] \right],$$

$$P_L = \frac{(a+1)}{2 - \frac{1}{\varepsilon_{P_L}}}. \quad (56)$$

The cases of $(\varphi = \varphi^*)$ and $(\varphi = 0, \varphi^* \neq 0)$ lead us to the following results.

Lemma 5. The quality of the infrastructure is overestimated, such that $\mathbb{E}[\theta] \in]0, \frac{(a-1)}{2}[$. For $\varphi = 0$, $t = 1$, a local authority undertakes the entire costs. The expected volume of distributed water is $q_L(\mathbb{E}[\theta]) = \frac{(a-1)}{b(1+\mathbb{E}[\theta])}$. When a local authority has complete information about the quality, it keeps a unique marginal water pricing $P_L = 1$, and the expected volume of distributed water is $q_L = \frac{(a-1)}{b}$. Otherwise, a local authority sets up the water price depending on the choke price a and the elasticity price of demand ε_{P_L} : $P_L = \frac{(a+1)}{2 - \frac{1}{\varepsilon_{P_L}}}$.

Proof. See Appendix.

By Lemma 5, the marginal water pricing generates the less distortion for consumers with a low choke price than for consumers with a high choke price. But a low marginal price does not automatically lead to increase water consumption. Even though the expected volume of distributed water q_L is increasing with the fixed effects of water consumption, this raising volume is restrained by an overestimation of the quality of the infrastructure. For example, increased fixed effects of water consumption and decreased marginal prices have not a significant effect on water consumption in urbanized areas (see Porcher, 2014).

3.3.2 Shadow costs of public funds

Recall that when $\varphi \neq 0$, the marginal cost of managing water services is equivalent to the marginal value of information on the quality of water services. Thus, disclosed information allows a local authority to learn about the price elasticity of demand for water consumption ε_P , and the municipality's demographic and geographical characteristics a . In this case, the shadow cost of public funds may be expressed in

terms of ε_P and a , that is given by equalling Equation (40) to Equation (46),

$$\begin{aligned}\frac{(a+1)\varphi+1}{1+2\varphi} &= \frac{1}{1+\frac{\varphi}{1+\varphi}\frac{1}{\varepsilon_{PL}}}, \\ \varphi &= -\frac{1+\varepsilon_{PL}(a-1)}{\varepsilon_{PL}(a-1)+(a+1)}.\end{aligned}\tag{57}$$

When $\varphi \geq \varphi^*$, and $\mathbb{E}[\theta] \in]0, \frac{(a-1)}{2}[$, we find that $\varepsilon_{PL} \leq -\frac{(1+\mathbb{E}[\theta])}{a-(1+\mathbb{E}[\theta])}$. Hence,

$$\begin{cases} \varepsilon_{PL} \subset \left(-\frac{(a+1)}{(a-1)}, -\frac{1}{(a-1)}\right), \text{ if } 1 < a < 2, \\ \varepsilon_{PL} \subset \left(-1, -\frac{1}{(a-1)}\right), \text{ if } a \geq 2. \end{cases}\tag{58}$$

According to different levels of choke price, when consumers have different price elasticity of demand for water consumption, a local authority can take into account redistribution concerns. Therefore, the taxation by regulation is not distortive if the good quality of water services can be maintained, even improved in order to reserve water resources by detecting and reducing the possibilities of water leaks.

Proposition 5. A local authority and the operator estimate the quality of the infrastructure *without bias*, when the quality is overestimated, $\mathbb{E}[\theta] \in]0, \frac{(a-1)}{2}[$, the local authority keeps the management of water services. As $\varphi \geq \varphi^*$ is viewed as the shadow cost of public funds, $\{q_L(\mathbb{E}[\theta]), P_L\}$ given in (39) and (40), and $\{\varphi^*(\mathbb{E}[\theta]), q_L^*(\mathbb{E}[\theta]), P_L^*(\mathbb{E}[\theta])\}$ defined in (41), (42) and (43) are feasible and maximizes the expected social welfare function (37) subject to the local authority's budget constraint. The Lerner index allows a local authority to make aware of consumer's sensitivity to the quality of water services. It sets up the water price depending both on the choke price and the elasticity price of demand for water consumption.

We illustrate the results of Proposition 5 in Table 3. The different decision-makings of public management depend on ex post average estimation of the quality of the infrastructure, the choke price and consumers' sensitivity to the quality. Moreover, Table 3 supplies an interesting evidence that disclosed information can improve a local authority's decision-makings. Under complete information disclosure about the quality of the infrastructure, a local authority can know the elasticity price of demand. In this case, if the local authority is a utilitarian preoccupying the interests of consumers, then it sets up a unique water price, and does not put any weight on its operational profits. Otherwise, the water price is increasing in the shadow cost of public funds. By contrast, under the overestimation of the quality, the expected volume of distributed water depends on the level of overestimation. Then, the water price fixed by a local authority captures consumers' sensitivity to the quality through the choke price and the elasticity price of demand. In this case, if a local authority preoccupies the interests of consumers, then the water price becomes lower when the elasticity price of demand is more inelastic. Otherwise, the water price is increasing in the shadow cost of public funds because consumers pay for the maintenance of the good quality.

To get a more intuitive understanding the role of information disclosure, first, we provide an analysis to show how the precision of information impacts the average estimation about the quality. Then, a numerical example is used to compare the results drawn from the different estimation level.

4 Information precision

Observing the delegation mechanism $\{\lambda^*(\mathbb{E}[\theta]), q(\mathbb{E}[\theta]), P(\mathbb{E}[\theta])\}$ and the public management $\{q_L(\mathbb{E}[\theta]), P_L\}$, $\{\varphi^*(\mathbb{E}[\theta]), q_L^*(\mathbb{E}[\theta]), P_L^*(\mathbb{E}[\theta])\}$, the expected volume of distributed water depend on the average estimation about the quality of the infrastructure. In particular, in the delegation mechanism, a local authority can adjuster its public-policy choice variable which is linked to the average estimation. In public management, a local authority raises its revenue to cover the cost through the shadow price of public funds, which depends also on the estimation of the quality. We analyze how the precision of information impacts the expected volume of distributed water.

4.1 Information precision

Let we denote $Z(\mathbb{E}[\theta]) = 1 + \mathbb{E}[\theta]$ in equations (27), (32), and (39). We refer to $Z(\mathbb{E}[\theta])$ as information rent depending linearly on ex post average estimation of the quality. Moreover, by assumption 4, $\mathbb{E}[\theta] = \mu_\theta$, we can write

$$Z(\mu_\theta) = 1 + \mu_\theta. \quad (59)$$

By the conditions $\mathbb{E}[\theta] \in] - 1, \frac{(a-1)}{2}[$ and $a > 1$, the linear function $Z(\mu_\theta)$ is increasing in μ_θ . Further, the quality of the infrastructure θ is normally distributed in $\Theta = [\theta^-, \theta^+]$, the density probability $f(\theta)$ is continuous differentiable in $\Theta = [\theta^-, \theta^+]$, and the curve of the density probability $f(\theta)$ is continuous and positive at $\theta^- < \mu_\theta < \theta^+$. Since the average estimation of the quality is $\mathbb{E}[\theta] = \mu_\theta$, it varies in $] - 1, \frac{(a-1)}{2}[\subset [\theta^-, \theta^+]$. Further, the density probability $f(\theta)$ intends to be maximum at μ_θ , as $f(\mu_\theta) = \frac{1}{\sqrt{2\pi}\sigma_\theta} = \frac{\sqrt{\tau_\theta}}{\sqrt{2\pi}}$.

No matter when $\mathbb{E}[\theta] = \mu_\theta$, the line of the function $Z(\mu_\theta)$ and the curve of $f(\theta)$ can intersect at the maximum of $f(\theta)$. We may have at most a tangent point between these two curves at μ_θ . The possibility that the tangent occurs, depends on the variability of the precision of information about the quality of the infrastructure. For example, in Figure 7, the line of the function $Z(\mu_\theta)$ crosses respectively the maximum of $f(\theta)$ at $(\mu_\theta = -0.33, \sigma = 0.6)$ and $(\mu_\theta = 0, \sigma = 0.4)$. When the precision of signals reaches $\tau_\theta \equiv \frac{1}{0.272}$, we find a tangent point between these two curves at $\mu_\theta = 0.5$.

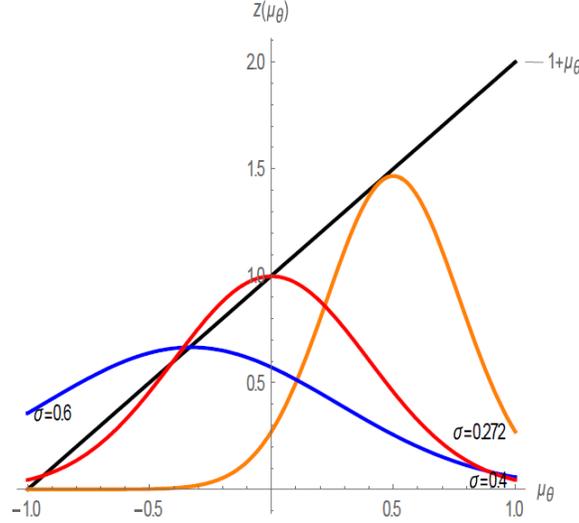


Figure 7 – The relationships between information rent $Z(\mu_\theta)$ and varying degrees of precision $\tau_\theta \equiv \frac{1}{\sigma}$ of signal.

By Figure 7, we can determine the threshold value of the precision of estimation, either under which the quality will be underestimated, or beyond which the quality will be overestimated. Henceforth, we have the equation of the tangent that is

$$Z(\mu_\theta) = 1 + \mu_\theta = f(\mu_\theta) = \frac{\sqrt{\tau_\theta}}{\sqrt{2\pi}}. \quad (60)$$

Equation (60) yields

$$\mu_\theta = \frac{\sqrt{\tau_\theta}}{\sqrt{2\pi}} - 1. \quad (61)$$

Lemma 6. The expected quality $\mathbb{E}[\theta] = \mu_\theta$ varies in $] -1, \frac{(a-1)}{2} [$,

- i) when $\sqrt{2\pi} < \sqrt{\tau_\theta} < \frac{(a+1)}{2} \sqrt{2\pi}$, then $0 < \mathbb{E}[\theta] < \frac{(a-1)}{2}$, a local authority and the operator overestimate the quality of water services;
- ii) when $0 < \sqrt{\tau_\theta} < \sqrt{2\pi}$, then $-1 < \mathbb{E}[\theta] < 0$, a local authority and the operator underestimate the service quality;
- iii) when $\sqrt{\tau_\theta} = \sqrt{2\pi}$, then $\mathbb{E}[\theta] = 0$, a local authority and the operator benefit from a complete information about the service quality.

Proof. See Appendix.

By Lemma 6, ex post average estimation of the quality is increasing in the precision of information. The economic thinking behind this result is that when both a local authority and the operator have more precision of information about the quality of water services, they increase their expected estimation, otherwise, it is the reverse.

In the case of overestimation, a local authority reduces the expected volume of distributed water, but it raises the price of water through the shadow costs of public funds. In the case of underestimation, a local authority may increase the expected volume of distributed water. At the same time, it decreases the public-policy choice variable in order to keep the water price unchanged, even to reduce it. If both a local authority and the operator have enough precision of information about the quality, then they can benefit from a situation of complete information. In this case, there will be the optimal expected volume of distributed water.

Moreover, we can respectively determine the gap between the optimal expected volume when $\mathbb{E}[\theta] = 0$, and the expected volume when $\mathbb{E}[\theta] \neq 0$. We remark that there is a discontinuity in the optimal expected volume with respect to the level of estimation of the quality. Substituting $1 + \mathbb{E}[\theta] = \frac{\sqrt{\tau_\theta}}{\sqrt{2\pi}}$ in Equations (27), (32) and (39), we have

■ when $-1 < \mathbb{E}[\theta] < 0$, Equation (27) and (32) become

$$\begin{cases} q(\mathbb{E}[\theta] \neq 0) = \frac{a\sqrt{2\pi} - \sqrt{\tau_\theta}}{2b\sqrt{\tau_\theta}}, & \text{for } 1 < a < 2, \\ q(\mathbb{E}[\theta] \neq 0) = \frac{\sqrt{2\pi}(a-1)}{b\sqrt{\tau_\theta}}, & \text{for } a > 1. \end{cases} \quad (62)$$

■ when $\mathbb{E}[\theta] = 0$, Equation (27) and (32) are given by

$$\begin{cases} q^*(\mathbb{E}[\theta] = 0) = \frac{(a-1)}{2b}, & \text{for } 1 < a < 2, \\ q^*(\mathbb{E}[\theta] = 0) = \frac{(a-1)}{b}, & \text{for } a > 2. \end{cases} \quad (63)$$

■ when $0 < \mathbb{E}[\theta] < \frac{(a-1)}{2}$, Equation (39) is written as

$$q_L(\mathbb{E}[\theta] \neq 0) = \frac{\sqrt{2\pi}(a-1)(1+\varphi)}{b\sqrt{\tau_\theta}(1+2\varphi)}, \quad \text{for } a > 1. \quad (64)$$

■ when $\mathbb{E}[\theta] = 0$, and $\varphi > \varphi^*$, Equation (39) becomes

$$q_L^*(\mathbb{E}[\theta] = 0) = \frac{(a-1)(1+\varphi)}{b(1+2\varphi)}, \quad \text{for } a > 1. \quad (65)$$

According to the level of estimation of the quality, the expected volume of water leaks can be measured by the difference between the expected volume with complete information ($\mathbb{E}[\theta] = 0$) and that with estimation ($\mathbb{E}[\theta] \neq 0$), such that

$$\begin{cases} q^*(\mathbb{E}[\theta] = 0) - q(\mathbb{E}[\theta] \neq 0) = \frac{a}{2b} \left(1 - \frac{\sqrt{2\pi}}{\sqrt{\tau_\theta}}\right), & \text{when } -1 < \mathbb{E}[\theta] < 0, \text{ for } 1 < a < 2, \\ q^*(\mathbb{E}[\theta] = 0) - q(\mathbb{E}[\theta] \neq 0) = \frac{(a-1)}{b} \left(1 - \frac{\sqrt{2\pi}}{\sqrt{\tau_\theta}}\right), & \text{when } -1 < \mathbb{E}[\theta] < 0, \text{ for } a \geq 2, \\ q_L^*(\mathbb{E}[\theta] = 0) - q_L(\mathbb{E}[\theta] \neq 0) = \frac{(a-1)(1+\varphi)}{b(1+2\varphi)} \left(1 - \frac{\sqrt{2\pi}}{\sqrt{\tau_\theta}}\right), & \text{when } 0 < \mathbb{E}[\theta] < \frac{(a-1)}{2}, \text{ for } a > 1. \end{cases} \quad (66)$$

Although a local authority delegates the management of water services to the operator, it tolerates more level of water leaks in areas with a high choke price than in areas with a small choke price. We

observe the same thing when a local authority keeps the public management of water services.

Under the delegation contract, the operator improves the quality of the infrastructure with the public intervention. As long as the quality of the infrastructure is revealed during the contract, the volume of water leaks can be considerably reduced. But, there are future water price increases. Under the public management, it is better for a local authority to have complete information about the quality of the infrastructure. According to the choke price and consumers' sensitivity to the quality, a local authority may leave some level of water leaks in order to keep a low-level of water price. We find that, in areas with a small choke price, the expected volume of distributed water under the public management q_L^* is higher than under the delegation contract q^* . On the contrary, in areas with a high choke price, a local authority is indifferent between contract-out and public management of water networks, because it has the same expected volume of distributed water. However, the water price of public management is lower than that of delegation contract. It might be the reason that under public management, the price of water is hold at a low-level while the quality of the infrastructure is less improved than under private management.

The volume gap determined by (66) can be considered as the expected level of water leaks tolerated by a local authority in the distributed water. This volume of water leaks is tightly linked to the precision of information. The relationship between the expected volume gap and the precision of information can be summarized as follows,

$$\left\{ \begin{array}{ll} q^* < q, & \text{if } 0 < \sqrt{\tau\theta} < \sqrt{2\pi}, \\ & \text{and } -1 < \mathbb{E}[\theta] < 0 : \text{underestimation.} \\ q^* = q, \text{ and } q_L^* = q_L, & \text{if } \sqrt{\tau\theta} = \sqrt{2\pi} : \text{complete information.} \\ q_L^* > q_L, & \text{if } \sqrt{2\pi} < \sqrt{\tau\theta} < \frac{(a+1)}{2}\sqrt{2\pi}, \\ & \text{and } 0 < \mathbb{E}[\theta] < \frac{(a-1)}{2} : \text{overestimation.} \end{array} \right. \quad (67)$$

Proof. See Appendix.

From the viewpoint of informational rent, a local authority can extract more water leaks from the operator as the quality of the infrastructure is improved. However, if the quality is estimated to be better than it might seem, then it is a cost efficient operator that wins the delegation, and the water price increases. This is not favorable to the consumers. Hence, the local authority allows a level of water leaks to the operator in order to reduce the price. The expected volume of distributed water increases enough to reach the optimal volume.²¹ A local authority draws some profits from the operator during the adjustments of the water price towards the optimal level. As a result, the operator has not any incentives to improve the quality of the infrastructure. The local authority prefers to keep the management of such water services.

If the quality is estimated to be worse than it might seem, then the expected volume of distributed water increases. As the consumers pay more for the volume of distributed water because of water leaks,

²¹Both the optimal level of the volume and the water price are measured under the complete information about the quality of the infrastructure.

it is not beneficial to the consumers. The local authority reduces the level of water leaks tolerated in the water distribution, but the water price is adjusted to be high through the policy instrument. Even though the expected volume of distributed water decreases, a cost efficient operator benefits from water leaks and an increase in the water price. As a result, the local authority gives up some information rent to this operator to the detriment of consumers' surplus. The operator can be incited to improve the quality of the infrastructure.

Too much precision of information may create a dilemma, in which the operator does not have any incentives to improve the quality. This result is similar to Martimort and Sand-Zantman (2006), which showed the positive relationship between low-powered incentives and infrastructure quality. But our paper provides evidence that information disclosure reduces the stakes a local authority and the operator have in delegation decisions, then reduces the extent of false transparency.

4.2 Numerical example

Now, we analyze an example of one municipality, in which there is a small choke price $a \in]1, 2[$. Under our assumptions, we consider that $\mathbb{E}[\theta] = 0$, a local authority and the operator benefit from a complete information about the quality of the infrastructure. In this setting, the local authority prefers to keep the public management in order to avoid an excessive price of water due to the public intervention. Assuming that $\varphi > 0$, we have

$$q_L^* = \frac{(a-1)(1+\varphi)}{b(1+2\varphi)}, P_L^* = \frac{(a+1)\varphi+1}{1+2\varphi}, \pi_L^* = \frac{(a-1)^2\varphi(1+\varphi)}{b(1+2\varphi)^2},$$

$$SC_L^* = \frac{(a-1)^2(1+\varphi)^2}{2b(1+2\varphi)^2}, W_L^* = \frac{(a-1)^2(1+\varphi)(1+3\varphi)}{2b(1+2\varphi)^2}.$$

Note that, for the shadow price of public funds $\varphi > 0$, the marginal cost $C_{q_L}^* = 1$ and $P_L^* > C_{q_L}^*$. This result comes from the fact that the optimal regulatory price depends on the local authority's estimation about the quality. Since the water price P_L^* is generally strictly higher than the marginal cost $C_{q_L}^*$, and the local authority is implied to know the elasticity price of demand for water consumption, the optimal regulated price may be higher than the unregulated monopoly price determined by the condition $MR = MC$. As a local authority undertakes the entire cost of managing the water services, its social objective is subject to the budget constraint. The shadow costs of public funds are less distortive for consumers with low choke prices than for consumers with high choke prices. The local authority can experience a unique marginal water price by taking into account the choke prices and the elasticity price of demand, which are different from one municipality to the other. In this case, the local authority may generate the higher social welfare than if it overestimates the quality of the infrastructure.

Further, for the shadow cost of public funds $\varphi = 0$, we find the situation of regulated natural monopoly such that $P_L^* = C_{q_L}^*$. The social welfare is equal to the consumer surplus.

However, if we suppose that $\mathbb{E}[\theta] \neq 0$, then in the first case, $\mathbb{E}[\theta] = \frac{1}{4}$. In other words, a local authority and the operator overestimate the quality. Hence, the local authority decides to keep the

public management. Restricting the choke price to be $a \in]\frac{6}{4}, 2[$, we find

$$q_L = \frac{4(a-1)(1+\varphi)}{5b(1+2\varphi)}, P_L = \frac{(a+1)\varphi+1}{1+2\varphi}, \pi_L = \frac{[2\varphi(2a-3)-1](a-1)(1+\varphi)}{5b(1+2\varphi)^2},$$

$$SC_L = \frac{2(a-1)^2(1+\varphi)^2}{5b(1+2\varphi)^2}, W_L = \frac{(a-1)(1+\varphi)[2(a-1)(1+\varphi)+2\varphi(2a-3)-1]}{5b(1+2\varphi)^2}.$$

In this case, the marginal cost $C_{qL} = \frac{5}{4}$, and $P_L > C_{qL}$. The unique water price P_L is higher than the marginal cost. Though the quality is overestimated, the local authority may set up the same water price as in the situation of complete information. But it raises the water price to cover its cost linking to the maintenance or the improvement of the quality, when there is a high-level consumers' sensitivity to the quality in areas with the choke price $a \in]\frac{6}{4}, 2[$. The expected volume of distributed water can be reduced, but the social welfare is reduced with respect to the optimal level. Indeed, if the local authority reduces the water leaks as the same time as holds a low-level water price, then the marginal cost becomes so important that the local authority must raise the shadow price of public funds φ . Hence, an increase in φ generates the losses in the consumers surplus.

In the second case, we assume that $\mathbb{E}[\theta] = -\frac{1}{4}$, and the choke price $a \in]1, 2[$. A local authority and the operator underestimate the quality. Then, we find $\lambda^* = 2(a - \frac{3}{4})$, and obtain:

$$q = \frac{4a-3}{6b}, P = \frac{a}{2} + \frac{3}{8}, \pi = \frac{(4a-3)^2}{48b}, SC = \frac{(4a-3)^2}{96b}, W = \frac{(4a-3)^2(2a-1)}{48b}.$$

Note that the marginal cost is $C_q(\mathbb{E}[\theta] = -\frac{1}{4}) = \frac{3}{4}$, and $P > C_q$. Since a local authority gives incentives to the operator winning the delegation, it adjusts the public-policy choice variable λ to make the water price cover the marginal cost. Such adjustment requires the local authority to undertake some costs in improving the quality of the infrastructure. Moreover, even though the local authority tolerates a positive level of water leaks to the operator, the water price increases with the choke price. Finally, the operator receiving the delegation does not undertake more costs, and it benefits from not only a high water price but also a certain amount of water leaks. The operator's profit π is larger than the optimal profit π_L^* . Nevertheless, the consumer surplus is reduced on the reason that the local authority gives up informational rent to the operator. We summarize these three special cases in Table 4 for $a \in]1, 2[$.

In our simple model, on the basis of the private estimation structure $\hat{\theta}_i$ made by operator i , if both a local authority and the operator estimate the quality of water networks without bias, then the local authority always tolerates a level of water leakages in order to keep the governance of delegation contracts. This level of water leakages depends on the precision of information about the quality. So, the expected volume of distributed water relies on the average estimation of the quality, which becomes a posterior common knowledge. The precision of information tends to affect the level of this common knowledge. On the one hand, a local authority overestimates the service quality when it has the access to more precision of disclosed information. On the other hand, a local authority underestimates the service quality if it has less precision of disclosed information. The gap between the overestimation and the underestimation can be captured by the tolerated volume of water leakages. Since the tolerated volume of water leakages

varies with the precision, it may be considered as a kind of informational rent, which a local authority would like to extract from the operator as the service quality improves. Moreover, a local authority adjusts the public-policy choice variable according to the average estimation of the service quality. In this view, the expected volume of distributed water, the price and the realized profits are drawn not only from the estimated service quality, but also from the public-policy choice variable.

Table 4 lists results of different levels of the average estimation when we focus on the choke price in one municipality that is $a \in]1, 2[$, and the most important observations we could make in this model is the following: a local authority delegates the management of the water networks to the operator when the service quality is underestimated due to a lack of information precision, and a local authority must already share the cost. By contrast, when the service quality is overestimated because of more information precision, a local authority keeps the management of water networks. By taking into account the consumer's sensitivity to the quality of water services, a local authority can set up a unique water price depending on the elasticity price of demand and the fixed effects of water consumption presented by the choke price.

5 Conclusion

Our contribution is to analyze how a local authority optimally decides to contract out or manage itself water services, when the quality of the infrastructure is uncertain. We examine information disclosure in the design of delegation. There is information asymmetry about the cost, and the efforts of improving the quality between a local authority and a potential operator (public or private).

The quality of the infrastructure can be revealed by the public and private signals. The revelation of quality affects the expected volume of distributed water, in which a local authority decides to tolerate some level of water leaks. Information asymmetry arises from both before and after the delegation process. We neglect the cost-reducing incentives and the operator's efforts in this paper. We simply focus on ex post average estimation about the quality of the infrastructure. By taking account of the fundamental motives and the coordination motives largely studied in the "Beauty Contest" literature, we assume that the private revised estimation perfectly converges to the public revised estimation. In others words, a local authority and a potential operator have the same ex post average estimation about the quality.

From these perspectives, we obtain three primary results. First, under the perfect precision of estimation, the optimal regulated volume of distributed water does not include the volume of water leaks. Then, the lack of information precision generates an underestimation of the quality of the infrastructure, whereas too much precision of information yields an overestimation of the quality. Finally, the expected volume of water leaks is engaged in the delegation contracts setting as information rent that a local authority gives up to the operator.

We also extend our analysis to the public management. Since the quality of the infrastructure is overestimated better than it should be, a local authority tends to keep the public management. We

find that, in water price settings, the marginal cost of managing water services is equivalent to the marginal value of information on the quality. Disclosed information allows the local authority to consider consumers' sensitivity to the quality when it sets up the water price.

By our assumption of unbiased estimation, our result shows that a local authority faces a trade-off between information rent extraction and a low-level water price, depending on information precision. The precision of public and private estimation leads a local authority to mitigate informational distortion in delegation contract settings, in water price settings of public management. However, our results may be changed by the fact that the public and private estimation are biased. This issue will be analyzed in future work, where we take into account the competition motives due to information acquisition.

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6 Appendix

Proof of Lemma 2:

$$\begin{aligned}
\frac{\partial \mathbb{E} [W(q, \tilde{\theta}, \tilde{\theta}_i) | \hat{\theta}_i]}{\partial q} &= \left[P(q(\tilde{\theta} | \hat{\theta}_i))(1 + \mathbb{E} [\tilde{\theta} | \hat{\theta}_i]) - a(1 + \mathbb{E} [\tilde{\theta}_i | \hat{\theta}_i]) + 2bq(1 + \mathbb{E} [\tilde{\theta} | \hat{\theta}_i])(1 + \mathbb{E} [\tilde{\theta}_i | \hat{\theta}_i]) \right. \\
&\quad \left. + \lambda \left\{ a(1 + \mathbb{E} [\tilde{\theta}_i | \hat{\theta}_i]) - 2bq(1 + \mathbb{E} [\tilde{\theta} | \hat{\theta}_i])(1 + \mathbb{E} [\tilde{\theta}_i | \hat{\theta}_i]) - (1 + \mathbb{E} [\tilde{\theta}_i | \hat{\theta}_i]) \right\} \right] = 0 \\
&= \left[(a - b(1 + \mathbb{E} [\tilde{\theta} | \hat{\theta}_i])q)(1 + \mathbb{E} [\tilde{\theta} | \hat{\theta}_i]) - a(1 + \mathbb{E} [\tilde{\theta}_i | \hat{\theta}_i]) + 2bq(1 + \mathbb{E} [\tilde{\theta} | \hat{\theta}_i])(1 + \mathbb{E} [\tilde{\theta}_i | \hat{\theta}_i]) \right. \\
&\quad \left. + a\lambda(1 + \mathbb{E} [\tilde{\theta}_i | \hat{\theta}_i]) - \lambda 2bq(1 + \mathbb{E} [\tilde{\theta} | \hat{\theta}_i])(1 + \mathbb{E} [\tilde{\theta}_i | \hat{\theta}_i]) - \lambda(1 + \mathbb{E} [\tilde{\theta}_i | \hat{\theta}_i]) \right] = 0.
\end{aligned} \tag{A.1}$$

This yields Equations (10) and (11) in the text. It is easy to verify that the second order conditions are satisfied if $\frac{1}{2} < \lambda \leq 1$ and $\mu_\theta > -1$:

$$\frac{\partial^2 \mathbb{E} [W(q, \tilde{\theta}, \tilde{\theta}_i) | \hat{\theta}_i]}{\partial q^2} = -b(1 + \mathbb{E} [\tilde{\theta} | \hat{\theta}_i])^2 + 2b(1 - \lambda)(1 + \mathbb{E} [\tilde{\theta} | \hat{\theta}_i])(1 + \mathbb{E} [\tilde{\theta}_i | \hat{\theta}_i]) \leq 0 \tag{A.2}$$

This yields,

$$\lambda \geq 1 - \frac{(1 + \mathbb{E} [\tilde{\theta} | \hat{\theta}_i])}{2(1 + \mathbb{E} [\tilde{\theta}_i | \hat{\theta}_i])}. \tag{A.3}$$

Under Assumption 4, we obtain

$$\lambda \geq \frac{1}{2}. \tag{A.4}$$

Further, since

$$1 - \frac{(1 + \mathbb{E} [\tilde{\theta} | \hat{\theta}_i])}{2(1 + \mathbb{E} [\tilde{\theta}_i | \hat{\theta}_i])} = \frac{1}{2} + \frac{\mathbb{E} [\Delta \theta_i | \hat{\theta}_i]}{2(1 + \mathbb{E} [\tilde{\theta}_i | \hat{\theta}_i])} \tag{A.5}$$

and

$$\frac{1}{2} + \frac{\mathbb{E} [\Delta \theta_i | \hat{\theta}_i]}{2(1 + \mathbb{E} [\tilde{\theta}_i | \hat{\theta}_i])} \leq 1, \tag{A.6}$$

then,

$$1 + \mathbb{E} \left[\tilde{\theta} | \hat{\theta}_i \right] \geq 0, \quad (\text{A.7})$$

It follows that

$$\mathbb{E}[\theta] \geq -1. \quad (\text{A.8})$$

In addition, as $\mathbb{E} \left[\tilde{\theta} | \hat{\theta}_i \right]$ and $\mathbb{E} \left[\tilde{\theta}_i | \hat{\theta}_i \right]$ are random variables, we find that, for $\frac{a}{a+1} < \lambda \leq 1$ and $a > 1 + \frac{2\mathbb{E}[\Delta\theta_i | \hat{\theta}_i]}{1 + \mathbb{E}[\tilde{\theta}_i | \hat{\theta}_i]}$,

$$\frac{\partial q}{\partial \mathbb{E} \left[\tilde{\theta} | \hat{\theta}_i \right]} > 0, \quad \frac{\partial^2 q}{\partial \mathbb{E} \left[\tilde{\theta} | \hat{\theta}_i \right]^2} > 0, \quad (\text{A.9})$$

$$\frac{\partial q}{\partial \mathbb{E} \left[\tilde{\theta}_i | \hat{\theta}_i \right]} < 0, \quad \frac{\partial^2 q}{\partial \mathbb{E} \left[\tilde{\theta}_i | \hat{\theta}_i \right]^2} < 0. \quad (\text{A.10})$$

The volume of distributed water is increasing and convex in the random variable $\mathbb{E} \left[\tilde{\theta} | \hat{\theta}_i \right]$. Hence, according to Jensen's Inequality Theorem, $\mathbb{E} \left[q \left(\mathbb{E}[\tilde{\theta} | \hat{\theta}_i] \right) \right] > q \left(\mathbb{E} \left[\mathbb{E}[\tilde{\theta} | \hat{\theta}_i] \right] \right)$. Nevertheless, we show that the volume of distributed water is decreasing and concave in the random variable $\mathbb{E} \left[\tilde{\theta}_i | \hat{\theta}_i \right]$, then $\mathbb{E} \left[q \left(\mathbb{E} \left[\tilde{\theta}_i | \hat{\theta}_i \right] \right) \right] < q \left(\mathbb{E} \left[\mathbb{E} \left[\tilde{\theta}_i | \hat{\theta}_i \right] \right] \right)$. One may verify that the expected price and volume are positive under our assumptions.

Proof of Proposition 1:

Under conditions $\mathbb{E}[\theta] \in]-1, +\infty[$, and $\lambda \in]\frac{a}{a+1}, 1]$, for $a > 1$, $\varphi \in [0, 1]$, $t \in [0, 1]$, we prove:

$$\frac{\partial q}{\partial \varphi} = \frac{-(a-1)(1-t)}{b(1+\mathbb{E}[\theta])(2\lambda-1)^2}, \quad \text{and} \quad \frac{\partial^2 q}{\partial \varphi^2} = \frac{4(a-1)(1-t)^2}{b(1+\mathbb{E}[\theta])(2\lambda-1)^3} > 0. \quad (\text{A.11})$$

$$\frac{\partial q}{\partial t} = \frac{-(a-1)(1-\varphi)}{b(1+\mathbb{E}[\theta])(2\lambda-1)^2}, \quad \text{and} \quad \frac{\partial^2 q}{\partial t^2} = \frac{4(a-1)(1-\varphi)^2}{b(1+\mathbb{E}[\theta])(2\lambda-1)^3} > 0. \quad (\text{A.12})$$

In addition, we can prove the cross effects between the social weight φ , and the marginal transfer t on the regulated volume:

$$\frac{\partial^2 q}{\partial \varphi \partial t} = \frac{\partial^2 q}{\partial t \partial \varphi} = \frac{(a-1)[1+2(1-t)(1-\varphi)]}{b(1+\mathbb{E}[\theta])(2\lambda-1)^3} > 0; \quad (\text{A.13})$$

Observing the conditions A.11 to A.13, we can check conditions under which the regulated volume in (12) is convex. Let H denote the Hessian of $q(\mathbb{E}[\theta])$:

$$H = \begin{pmatrix} H(1,1) = \frac{\partial^2 q}{\partial \varphi^2} & H(1,2) = \frac{\partial^2 q}{\partial t \partial \varphi} \\ H(2,1) = \frac{\partial^2 q}{\partial \varphi \partial t} & H(2,2) = \frac{\partial^2 q}{\partial t^2} \end{pmatrix} = \begin{pmatrix} 4(1-t)^2 & [1+2(1-t)(1-\varphi)] \\ [1+2(1-t)(1-\varphi)] & 4(1-\varphi)^2 \end{pmatrix} \left(\frac{(a-1)}{b(1+\mathbb{E}[\theta])(2\lambda-1)^3} \right)$$

The expected volume in (12) is minimum on φ and t if and only if the Hessian matrix H is positive

definite. In our case, we need to verify whether the naturally ordered principal minors of the matrix alternate in sign:

- the first naturally ordered principal minor is positive:

$$(4(1-t)^2) \left(\frac{(a-1)}{b(1+\mathbb{E}[\theta])(2\lambda-1)^3} \right) > 0 \Rightarrow \lambda > \frac{1}{2}$$

- the second naturally ordered principal minor is positive, $\det H' > 0$, but,

$$|H| = [4(1-t)(1-\varphi)]^2 - [1+2(1-t)(1-\varphi)]^2 > 0 \Rightarrow (1-t)(1-\varphi) > \frac{1}{2}$$

Since both condition are not satisfied, $(t, \varphi) = (1, 1)$ can not allowing the expected volume of distributed water to attend its minimum. However, we can check that for $t = 1$, and $\varphi \in [0, 1)$, or for $\varphi = 1$, and $t \in [0, 1)$, the expected volume of distributed can be minimum on $\lambda = [t + \varphi(1-t)] = 1$, which depends only on the average estimation about the quality of the infrastructure:

$$q(\mathbb{E}[\theta]) = \frac{(a-1)}{b(1+\mathbb{E}[\theta])} = \begin{cases} \frac{(a-1)}{b} < \frac{(a-1)}{b(1+\mathbb{E}[\theta])}, & \text{if } \mathbb{E}[\theta] \in]-1, 0[, \\ \frac{(a-1)}{b} & \mathbb{E}[\theta] = 0, \\ \frac{(a-1)}{b} > \frac{(a-1)}{b(1+\mathbb{E}[\theta])}, & \text{if } \mathbb{E}[\theta] \in]0, +\infty[. \end{cases} \quad (\text{A.14})$$

Proof of Lemma 2 and Lemma 3:

We also check the cross effects between the social weight φ and the marginal transfer t on the water price: under conditions $\mathbb{E}[\theta] \in]-1, +\infty[$, and $\lambda \in]\frac{a}{a+1}, 1]$, for $a > 1$, $\varphi \in [0, 1]$, $t \in [0, 1]$:

$$\frac{\partial^2 P}{\partial \varphi \partial t} = \frac{\partial^2 P}{\partial t \partial \varphi} = \frac{-(a-1)[1+2(1-t)(1-\varphi)]}{(2\lambda-1)^3} < 0. \quad (\text{A.15})$$

The first cross effect indicates that a higher social weigh strictly decreases the marginal effect of transfer on the water price, while the second cross effect indicates that an increased marginal transfer strictly reduces the effect of a higher social weight on the water price. Both cross effects can explain the fact that a high λ increases the water price at a decreasing rate.

Verifying the Hessian Matrix H , $(t, \varphi) = (1, 1)$ can not allowing the water price to attend its maximum. Nevertheless, we check that for $t = 1$, and $\varphi \in [0, 1)$ or for $\varphi = 1$, and $t \in [0, 1)$, the water price can be maximum on $\lambda = [t + \varphi(1-t)] = 1$, in other words, $P = 1$.

Proof of Proposition 2:

By substituting Equation (12) and (13), the operator's expected profit can be computed as:

$$\begin{aligned}
\pi(P, q) &= Pq - C(q) \\
&= \left[\frac{(a+1)\lambda - a}{(2\lambda - 1)} - (1 + \mathbb{E}[\theta]) \right] \left[\frac{(a-1)\lambda}{b(1 + \mathbb{E}[\theta])(2\lambda - 1)} \right] \\
&= \frac{(a-1)\lambda [(a+1)\lambda - a - (2\lambda - 1)(1 + \mathbb{E}[\theta])]}{b(1 + \mathbb{E}[\theta])(2\lambda - 1)^2},
\end{aligned} \tag{A.16}$$

where $\mathbb{E}[\theta] > -1$, $\forall a \in R$, $a > 1$, and $\frac{a}{a+1} < \lambda \leq 1$.

Ensuring that the operator's profit in (A.16) that $\pi(P, q) \geq 0$, we make the third term of dividend $[(a+1)\lambda - a - (2\lambda - 1)(1 + \mathbb{E}[\theta])] \geq 0$, we get the condition of λ :

$$\frac{a - (1 + \mathbb{E}[\theta])}{(a+1) - 2(1 + \mathbb{E}[\theta])} \leq \lambda \leq 1. \tag{A.17}$$

From (A.17), by comparing $\frac{a - (1 + \mathbb{E}[\theta])}{(a+1) - 2(1 + \mathbb{E}[\theta])}$ and $\frac{a}{a+1}$, we obtain the conditions of the public-policy choice variables:

- when $-1 < \mathbb{E}[\theta] \leq 0$, then $\frac{a - (1 + \mathbb{E}[\theta])}{(a+1) - 2(1 + \mathbb{E}[\theta])} \leq \lambda \leq 1$;
- when $0 < \mathbb{E}[\theta] < \frac{(a-1)}{2}$, then $\lambda = \frac{a - (1 + \mathbb{E}[\theta])}{(a+1) - 2(1 + \mathbb{E}[\theta])}$, but $\lim_{\mathbb{E}[\theta] \rightarrow 0} \lambda = 1$.

Therefore, $\frac{a - (1 + \mathbb{E}[\theta])}{(a+1) - 2(1 + \mathbb{E}[\theta])} \leq \lambda < 1$ is the condition allowing the water price to cover the marginal cost, when the quality of the infrastructure is underestimated $-1 < \mathbb{E}[\theta] < 0$.

Moreover,

$$\frac{\partial \pi}{\partial \mathbb{E}[\theta]} = \frac{-(a-1)\lambda [(a+1)\lambda - a]}{b(1 + \mathbb{E}[\theta])^2 (2\lambda - 1)^2}, \tag{A.18}$$

Since $\frac{a - (1 + \mathbb{E}[\theta])}{(a+1) - 2(1 + \mathbb{E}[\theta])} \leq \lambda < 1$, we have $(a+1)\lambda - a > 0$. Then $\frac{\partial \pi}{\partial \mathbb{E}[\theta]} < 0$, π is decreasing in $\mathbb{E}[\theta]$. In others words,

- when $-1 < \mathbb{E}[\theta] < 0$, and $\frac{a - (1 + \mathbb{E}[\theta])}{(a+1) - 2(1 + \mathbb{E}[\theta])} \leq \lambda \leq 1$, the operator's profit π is decreasing in $\mathbb{E}[\theta]$ and it is positive;
- when $0 \leq \mathbb{E}[\theta] < \frac{(a-1)}{2}$, then $\lambda = \frac{a - (1 + \mathbb{E}[\theta])}{(a+1) - 2(1 + \mathbb{E}[\theta])}$, but $\lim_{\mathbb{E}[\theta] \rightarrow 0} \lambda = 1$, the operator's profit π is decreasing in $\mathbb{E}[\theta]$ to be negative.

Further,

$$\frac{\partial^2 \pi}{\partial^2 \mathbb{E}[\theta]} = \frac{2(a-1)\lambda [(a+1)\lambda - a]}{b[2\lambda - 1]^2 (1 + \mathbb{E}[\theta])^3}, \tag{A.19}$$

As $\frac{a - (1 + \mathbb{E}[\theta])}{(a+1) - 2(1 + \mathbb{E}[\theta])} \leq \lambda < 1$, we get $2(a-1)\lambda [(a+1)\lambda - a] > 0$. So $\frac{\partial^2 \pi}{\partial^2 \mathbb{E}[\theta]} > 0$, π is convex in $\mathbb{E}[\theta]$. In others words,

- when $-1 < \mathbb{E}[\theta] < 0$, and $\frac{a - (1 + \mathbb{E}[\theta])}{(a+1) - 2(1 + \mathbb{E}[\theta])} \leq \lambda < 1$, the operator's profit π is convex in $\mathbb{E}[\theta]$,
- when $0 \leq \mathbb{E}[\theta] < \frac{(a-1)}{2}$, then $\lambda = \frac{a - (1 + \mathbb{E}[\theta])}{(a+1) - 2(1 + \mathbb{E}[\theta])}$, but $\lim_{\mathbb{E}[\theta] \rightarrow 0} \lambda = 1$, the operator's profit π is convex in $\mathbb{E}[\theta]$,

- when $\lim_{\mathbb{E}[\theta] \rightarrow 0} \lambda = 1$, and $\lambda_{min} = \frac{a-(1+\mathbb{E}[\theta])}{(a+1)-2(1+\mathbb{E}[\theta])}$ allowing the water price to cover the marginal operational cost if and only if $-1 < \mathbb{E}[\theta] < 0$.

These are the proofs in Proposition 2.

The operator's profit results from the expected estimation about the quality of water services, the changing in the shadow price of public funds, and the changing in the marginal transfer. We begin to restrict $-1 < \mathbb{E}[\theta] < 0$ and we analyze the relationship between the operator's profit and the evolution of public-policy variables $\lambda \in (\frac{a-(1+\mathbb{E}[\theta])}{(a+1)-2(1+\mathbb{E}[\theta])}, 1)$.

Proof of Proposition 3:

1. i)

$$\frac{\partial \pi}{\partial \lambda} = \frac{(a-1)[2\lambda\mathbb{E}[\theta] + (a-(1+\mathbb{E}[\theta]))]}{b(1+\mathbb{E}[\theta])(2\lambda-1)^3}, \quad (\text{A.20})$$

where $\mathbb{E}[\theta] > -1, \forall a \in R, a > 1$, and $\frac{a-(1+\mathbb{E}[\theta])}{(a+1)-2(1+\mathbb{E}[\theta])} \leq \lambda < 1$.

- For $-1 < \mathbb{E}[\theta] < -(a-1)$ and $1 < a < 2$, when $\frac{a-(1+\mathbb{E}[\theta])}{(a+1)-2(1+\mathbb{E}[\theta])} \leq \lambda < \frac{(1+\mathbb{E}[\theta])-a}{2\mathbb{E}[\theta]}$, the operator's profit π is increasing in the evolution of λ ;
- For $-1 < \mathbb{E}[\theta] < -(a-1)$ and $1 < a < 2$, when $\frac{(1+\mathbb{E}[\theta])-a}{2\mathbb{E}[\theta]} \leq \lambda < 1$, the operator's profit π is decreasing in the evolution of λ .
- For $-1 < \mathbb{E}[\theta] < 0$ and $a > 2$, when $\lambda = 1$, the local authority ensures the operator's profit $\pi = \frac{(a-1)}{b(1+\mathbb{E}[\theta])} - \frac{(a-1)}{b} > 0$ for $-1 < \mathbb{E}[\theta] < 0$ and sets a unique water price $P = 1$.

2. ii).

$$\begin{aligned} \frac{\partial^2 \pi}{\partial \lambda^2} &= \frac{\partial}{\partial \lambda} \left(\frac{(a-1)[2\lambda\mathbb{E}[\theta] + (a-(1+\mathbb{E}[\theta]))]}{b(1+\mathbb{E}[\theta])(2\lambda-1)^3} \right) \\ &= \frac{-(a-1)[4\lambda\mathbb{E}[\theta] - 2\mathbb{E}[\theta] + 3(a-1)]}{b(1+\mathbb{E}[\theta])(2\lambda-1)^4}, \end{aligned} \quad (\text{A.21})$$

where $\mathbb{E}[\theta] > -1, \forall a \in R, a > 1$, and $\frac{a-(1+\mathbb{E}[\theta])}{(a+1)-2(1+\mathbb{E}[\theta])} \leq \lambda < 1$.

In addition, when $-1 < \mathbb{E}[\theta] < -(a-1)$ and $1 < a < 2$, we compute

$$\begin{aligned} &\left[\frac{a-(1+\mathbb{E}[\theta])}{(a+1)-2(1+\mathbb{E}[\theta])} \right] - \left[\frac{(1+\mathbb{E}[\theta])-a}{2\mathbb{E}[\theta]} \right] \\ &= -(a-1)[a+(1+\mathbb{E}[\theta])] < 0. \end{aligned} \quad (\text{A.22})$$

- For $-1 < \mathbb{E}[\theta] < -(a-1)$ and $1 < a < 2$, when $\frac{a-(1+\mathbb{E}[\theta])}{(a+1)-2(1+\mathbb{E}[\theta])} \leq \lambda < \frac{(1+\mathbb{E}[\theta])-a}{2\mathbb{E}[\theta]}$, the operator's profit π is concave in the evolution of λ ;
- For $-1 < \mathbb{E}[\theta] < -(a-1)$ and $1 < a < 2$, when $\frac{(1+\mathbb{E}[\theta])-a}{2\mathbb{E}[\theta]} \leq \lambda < 1$, the operator's profit π is concave in the evolution of λ ;
- For $-1 < \mathbb{E}[\theta] < -(a-1)$ and $1 < a < 2$, when $\lambda^* = \frac{(1+\mathbb{E}[\theta])-a}{2\mathbb{E}[\theta]}$, the operator's profit will be maximum.

Summarizing the conditions from (A.21) to (A.22): when $-1 < \mathbb{E}[\theta] < -(a-1)$ and $1 < a < 2$, $\frac{a-(1+\mathbb{E}[\theta])}{(a+1)-2(1+\mathbb{E}[\theta])} \leq \lambda < 1$, we observe that:

- The operator's profit π is positive;
- The operator's profit π is decreasing and convex in $\mathbb{E}[\theta]$;
- When $-1 < \mathbb{E}[\theta] < -(a-1)$ and $1 < a < 2$, and $\frac{a-(1+\mathbb{E}[\theta])}{(a+1)-2(1+\mathbb{E}[\theta])} \leq \lambda < \frac{(1+\mathbb{E}[\theta])-a}{2\mathbb{E}[\theta]}$, the operator's profit π is increasing and concave in λ . Meanwhile, when $\frac{(1+\mathbb{E}[\theta])-a}{2\mathbb{E}[\theta]} \leq \lambda < 1$, the operator's profit π is decreasing and concave in λ .
- When $\lambda^* = \frac{(1+\mathbb{E}[\theta])-a}{2\mathbb{E}[\theta]}$, the operator's profit is maximum at $-1 < \mathbb{E}[\theta] < -(a-1)$ for $1 < a < 2$.
- When $a > 2$, for $-1 < \mathbb{E}[\theta] < 0$, the optimal public-policy is to set up $\lambda = 1$ in order to ensuring the positive operator's profit with a unique water price.

Conditions from (A.21) to (A.22) also give the proofs for Proposition 4.

Proof of Lemma 4 and Lemma 5:

1. Proof of Lemma 4

By using Equation (46) in the paper, we look at the water price when the estimation of the service quality tends to be zero, in other words, a local authority and the operator have nearly complete information about the quality. In addition, we look at the water price when the quality is overestimated. Therefore,

$$\frac{P_L - C_{qL}}{P_L} = -\frac{1}{\varepsilon_{P_L}} \frac{\varphi}{1+\varphi} + \frac{1}{\varepsilon_{P_L}} \frac{(1+2\varphi)}{(a-1)(1+\varphi)} \mathbb{E}[\theta], \quad (\text{A.23})$$

$$\lim_{\mathbb{E}[\theta] \rightarrow 0} \frac{P_L - C_{qL}}{P_L} = \lim_{\mathbb{E}[\theta] \rightarrow 0} \left[-\frac{1}{\varepsilon_P} \frac{\varphi}{1+\varphi} + \frac{1}{\varepsilon_P} \frac{(1+2\varphi)}{(a-1)(1+\varphi)} \mathbb{E}[\theta] \right], \quad (\text{A.24})$$

$$\lim_{\mathbb{E}[\theta] \rightarrow 0} P_L \left(1 + \frac{1}{\varepsilon_{P_L}} \frac{\varphi}{1+\varphi} \right) = \lim_{\mathbb{E}[\theta] \rightarrow 0} C_{qL}, \quad (\text{A.25})$$

$$P_L = \frac{1}{1 + \frac{1}{\varepsilon_{P_L}} \frac{\varphi}{1+\varphi}}. \quad (\text{A.26})$$

and

$$\lim_{\mathbb{E}[\theta] \rightarrow \frac{(a-1)}{2}} \frac{P_L - C_{qL}}{P_L} = \lim_{\mathbb{E}[\theta] \rightarrow \frac{(a-1)}{2}} \left[-\frac{1}{\varepsilon_{P_L}} \frac{\varphi}{1+\varphi} + \frac{1}{\varepsilon_{P_L}} \frac{(1+2\varphi)}{(a-1)(1+\varphi)} \mathbb{E}[\theta] \right], \quad (\text{A.27})$$

$$\lim_{\mathbb{E}[\theta] \rightarrow \frac{(a-1)}{2}} P_L \left[1 + \frac{1}{\varepsilon_{P_L}} \frac{\varphi}{1+\varphi} - \frac{1}{\varepsilon_{P_L}} \frac{(1+2\varphi)}{(a-1)(1+\varphi)} \mathbb{E}[\theta] \right] = \lim_{\mathbb{E}[\theta] \rightarrow \frac{(a-1)}{2}} C_{qL}, \quad (\text{A.28})$$

$$P_L = \frac{(a+1)}{2 - \frac{1}{1+\varphi} \frac{1}{\varepsilon_{P_L}}}. \quad (\text{A.29})$$

2. Proof of Lemma 5

When the shadow price of public funds does not take any value, such that $\varphi = 0$, Equation (34) becomes,

$$\frac{P_L - C_{qL}}{P_L} = \frac{1}{\varepsilon_{P_L}} \frac{1}{(a-1)} \mathbb{E}[\theta]. \quad (\text{A.30})$$

This is Equation (40) in the paper.

We now look at the water price when the estimation of the service quality $E[\theta]$ tends to be zero, it means that a local authority and the operator have nearly complete information about the quality of water services. In addition, we look at the water price when the quality is overestimated. Therefore,

$$\lim_{\mathbb{E}[\theta] \rightarrow 0} \frac{P_L - C_{qL}}{P_L} = \lim_{\mathbb{E}[\theta] \rightarrow 0} \left[\frac{1}{\varepsilon_{P_L}} \frac{1}{(a-1)} \mathbb{E}[\theta] \right], \quad (\text{A.31})$$

$$P_L = C_{qL} = 1. \quad (\text{A.32})$$

and,

$$\lim_{\mathbb{E}[\theta] \rightarrow \frac{(a-1)}{2}} \frac{P_L - C_{qL}}{P_L} = \lim_{\mathbb{E}[\theta] \rightarrow \frac{(a-1)}{2}} \left[\frac{1}{\varepsilon_{P_L}} \frac{1}{(a-1)} \mathbb{E}[\theta] \right], \quad (\text{A.33})$$

$$\lim_{\mathbb{E}[\theta] \rightarrow \frac{(a-1)}{2}} P_L \left[1 - \frac{1}{2} \frac{1}{\varepsilon_{P_L}} \right] = \lim_{\mathbb{E}[\theta] \rightarrow \frac{(a-1)}{2}} C_{qL}, \quad (\text{A.34})$$

$$P_L \left[1 - \frac{1}{2} \frac{1}{\varepsilon_{P_L}} \right] = 1 + \frac{(a-1)}{2}, \quad (\text{A.35})$$

$$P_L = \frac{(a+1)}{2 - \frac{1}{\varepsilon_{P_L}}}. \quad (\text{A.36})$$

Proof of Lemma 6 :

$$Z(\mathbb{E}[\theta] = \mu_\theta) = 1 + \mu_\theta = f(\mu_\theta) = \frac{1}{\sqrt{2\pi} \sigma_\theta} = \frac{\sqrt{\tau_\theta}}{\sqrt{2\pi}}, \quad (\text{A.37})$$

then,

$$\mu_\theta = \frac{\sqrt{\tau_\theta}}{\sqrt{2\pi}} - 1, \quad (\text{A.38})$$

so, we have,

$$\frac{\partial \mu_\theta}{\partial \tau_\theta} = \frac{1}{2\sqrt{2\pi\tau_\theta}} > 0, \text{ and } \frac{\partial^2 \mu_\theta}{\partial^2 \tau_\theta} = -\frac{1}{4\sqrt{2\pi} \sqrt[3]{\tau_\theta^2}} < 0. \quad (\text{A.39})$$

(A.37) shows that the expected estimation (valuation) about the quality of service is increasing in the precision of information. We integrate $1 + \mathbb{E}[\theta] = \frac{\sqrt{\tau_\theta}}{\sqrt{2\pi}}$ in equations (27), (32), and (39).

First, we find the expected volume of water leaks, when the quality of water services is underestimated. By using Equation (27), if a local authority and the operator have the complete information about the quality of water services, then,

- We obtain that $q^*(\mathbb{E}[\theta] = 0) = \frac{(a-1)}{2b}$, in particular, for the fixed effects of water consumption $1 < a < 2$,
- We have also that $q^*(\mathbb{E}[\theta] = 0) = \frac{(a-1)}{b}$, in particular, for the fixed effects of water consumption

$a \geq 2$,

■ We remark that $q^*(\mathbb{E}[\theta] = 0) = \frac{(a-1)}{b} > q^*(\mathbb{E}[\theta] = 0) = \frac{(a-1)}{2b}$

By using Equation (27), if the local authority and the operator underestimate the quality of the infrastructure, $\mathbb{E}[\theta] \in]-1, 0[$, then we can substitute $1 + \mathbb{E}[\theta] = \frac{\sqrt{\tau_\theta}}{\sqrt{2\pi}}$ in the expected volume equation, $q(\mathbb{E}[\theta] \neq 0) = \frac{a-(1+\mathbb{E}[\theta])}{2b(1+\mathbb{E}[\theta])} = \frac{a-\frac{\sqrt{\tau_\theta}}{\sqrt{2\pi}}}{2b\frac{\sqrt{\tau_\theta}}{\sqrt{2\pi}}}$ for $a \in]1, 2[$, and $q(\mathbb{E}[\theta] \neq 0) = \frac{(a-1)}{b(1+\mathbb{E}[\theta])} = \frac{(a-1)}{b\frac{\sqrt{\tau_\theta}}{\sqrt{2\pi}}}$ for $a \geq 2$:

■ We obtain that $q^*(\mathbb{E}[\theta] \neq 0) = \frac{a\sqrt{2\pi}-\sqrt{\tau_\theta}}{2b\sqrt{\tau_\theta}}$, in particular, for the fixed effects of water consumption $1 < a < 2$,

■ We have also that $q^*(\mathbb{E}[\theta] \neq 0) = \frac{\sqrt{2\pi}(a-1)}{b\sqrt{\tau_\theta}}$, in particular, for the fixed effects of water consumption $a \geq 2$.

The expected volume of water leakages is measured by the gap between the expected volume obtained with complete information and that obtained with underestimation of the service quality, when $\mathbb{E}[\theta] \in]-1, 0[$, so we obtain,

$$\begin{aligned} & q^*(\mathbb{E}[\theta] = 0) - q(\mathbb{E}[\theta] \neq 0) \\ &= \begin{cases} \frac{(a-1)}{2b} - \frac{a\sqrt{2\pi}-\sqrt{\tau_\theta}}{2b\sqrt{\tau_\theta}} & \text{for } 1 < a < 2, \\ \frac{(a-1)}{b} - \frac{\sqrt{2\pi}(a-1)}{b\sqrt{\tau_\theta}} & \text{for } a \geq 2, \end{cases} \end{aligned} \quad (\text{A.40})$$

$$\begin{aligned} &= \begin{cases} \frac{a(\sqrt{\tau_\theta}-\sqrt{2\pi})}{2b\sqrt{\tau_\theta}} & \text{for } 1 < a < 2, \\ \frac{(a-1)(\sqrt{\tau_\theta}-\sqrt{2\pi})}{b\sqrt{\tau_\theta}} & \text{for } a \geq 2. \end{cases} \end{aligned} \quad (\text{A.41})$$

$$q^*(\mathbb{E}[\theta] = 0) < q(\mathbb{E}[\theta] \neq 0) \quad \text{for } 0 < \sqrt{\tau_\theta} < \sqrt{2\pi} : \quad \text{underestimation}, \quad (\text{A.42})$$

$$q^*(\mathbb{E}[\theta] = 0) = q(\mathbb{E}[\theta] \neq 0) \quad \text{for } \sqrt{\tau_\theta} = \sqrt{2\pi}. \quad (\text{A.43})$$

We remark that the expected volume of water leaks in areas with the high-level choke price ($a \geq 2$) is less important than with the low-level choke price ($1 < a < 2$).

Second, we find the expected volume of water leaks, when the quality of the infrastructure is overestimated:

By using Equation (39), if a local authority and the operator have the complete information about the quality of water services, then we have,

$$q_L^*(\mathbb{E}[\theta] = 0) = \frac{(a-1)(1+\varphi)}{b(1+2\varphi)} \quad \text{for } a > 1. \quad (\text{A.44})$$

If the local authority and the operator overestimate the quality of water service, $\mathbb{E}[\theta] \in]0, \frac{(a-1)}{2}[$, then

we can substitute $1 + E[\theta] = \frac{\sqrt{\tau\theta}}{\sqrt{2\pi}}$ in the expected volume equation,

$$\begin{aligned}
q_L(\mathbb{E}[\theta] \neq 0) &= \frac{(a-1)(1+\varphi)}{b(1+\mathbb{E}[\theta])(1+2\varphi)} \\
&= \frac{(a-1)(1+\varphi)}{b\frac{\sqrt{\tau\theta}}{\sqrt{2\pi}}(1+2\varphi)} \\
&= \frac{\sqrt{2\pi}(a-1)(1+\varphi)}{b\sqrt{\tau\theta}(1+2\varphi)} \quad \text{for } a > 1.
\end{aligned} \tag{A.45}$$

The expected volume of water leaks is measured by the difference between the expected volume with the complete information and that with the overestimation of the service quality,

$$\begin{aligned}
& q_L^*(\mathbb{E}[\theta] = 0) - q_L(\mathbb{E}[\theta] \neq 0) \\
&= \frac{(a-1)(1+\varphi)}{b(1+2\varphi)} - \frac{\sqrt{2\pi}(a-1)(1+\varphi)}{b\sqrt{\tau\theta}(1+2\varphi)} \\
&= \frac{(a-1)(1+\varphi)}{b(1+2\varphi)} \left(1 - \frac{\sqrt{2\pi}}{\sqrt{\tau\theta}}\right) \quad \text{for } a > 1.
\end{aligned} \tag{A.46}$$

Hence,

$$\begin{cases} q_L^*(\mathbb{E}[\theta] = 0) > q_L(\mathbb{E}[\theta] \neq 0) \text{ for } \sqrt{2\pi} < \sqrt{\tau\theta} < \frac{(\alpha+1)}{2}\sqrt{2\pi} : \text{overestimation,} \\ q_L^*(\mathbb{E}[\theta] = 0) = q_L(\mathbb{E}[\theta] \neq 0) \text{ for } \sqrt{\tau\theta} = \sqrt{2\pi}. \end{cases} \tag{A.47}$$

Tables

Table 1

Table 2

Table 2 – Delegation contracts for ex post average estimation of the service quality: $-1 < \mathbb{E}[\theta] < 0$

a	λ	the expected volume and water price
$1 < a < 2$	$\lambda^* = \frac{1+\mathbb{E}[\theta]-a}{2\mathbb{E}[\theta]}$	$q = \frac{a-(1+\mathbb{E}[\theta])}{2b(1+\mathbb{E}[\theta])}, P = \frac{a+(1+\mathbb{E}[\theta])}{2}$
$a \geq 2$	$\lambda^* = 1$	$q = \frac{(a-1)}{b(1+\mathbb{E}[\theta])}, P = 1$

Table 1 – Our Model and Related Literature

Information revealing	Costs	The quality of infrastructure	The quality index	Regulation by contracts
Private information	Boyer and Garcia (2008) Garcia and Thomas (2001, 2003) Garcia and Reynaud (2004) Porcher (2014, 2017) Reynaud and Thomas (2013)	Garcia and Thomas (2003) Martimort and Sand-Zantman (2006) Cavaliere et al. (2017)	Canneva and Garcia (2010)	Martimort and Sand-Zantman (2006) Garcia and Thomas (2003) Canneva and Garcia (2010) Desrieux et al. (2013)
Public information			Cousin and Taugourdeau (2016)	
Public and Private information		Reynaud and Thomas (2005)	Destandau and Garcia (2014) Our model	Our model

Table 3

Table 3 – Public management for ex post average estimation of the service quality: $0 \leq \mathbb{E}[\theta] < \frac{(a-1)}{2}$, $a > 1$

	φ	the expected volume and water price
$\mathbb{E}[\theta] = 0$	$\varphi > \varphi^*$	$q_L^* = \frac{(a-1)(1+\varphi)}{b(1+2\varphi)}$, $P_L^* = \frac{1}{1+\frac{\varphi}{1+\varphi} \frac{1}{\varepsilon_{P_L}}}$
	$\varphi = 0$	$q_L^* = \frac{(a-1)}{b}$, $P_L^* = 1$
$0 < \mathbb{E}[\theta] < \frac{(a-1)}{2}$	$\varphi > \varphi^*$	$q_L = \frac{(a-1)(1+\varphi)}{b(1+\mathbb{E}[\theta])(1+2\varphi)}$, $P_L = \frac{(a-1)}{2-\frac{1}{1+\varphi} \frac{1}{\varepsilon_{P_L}}}$
	$\varphi = 0$	$q_L = \frac{(a-1)}{b(1+\mathbb{E}[\theta])}$, $P_L = \frac{(a-1)}{2-\frac{1}{\varepsilon_{P_L}}}$

Table 4

Table 4 – The numerical applications

	$\mathbb{E}[\theta] = -\frac{1}{4}$ $1 < a < \frac{5}{4}$	$\mathbb{E}[\theta] = 0$ $1 < a < 2$	$\mathbb{E}[\theta] = \frac{1}{4}$ $\frac{3}{2} < a < 2$	Comparisons for $a \in (1, 2)$
Public choice variable	$\lambda = 2(a - \frac{3}{4})$	$\varphi > 0$	$\varphi > \frac{1}{2(2a-3)}$	
Regulated price	$P = \frac{a}{2} + \frac{3}{8}$	$P_L^* = \frac{(a+1)\varphi+1}{1+2\varphi}$ $(P_L^* \rightarrow \frac{1}{1+\frac{\varphi}{1+\varphi} \frac{1}{\varepsilon_{P_L}}})$	$P_L = \frac{(a+1)\varphi+1}{1+2\varphi}$ $(P_L \rightarrow \frac{(a+1)}{2-\frac{1}{1+\varphi} \frac{1}{\varepsilon_{P_L}}})$	$P > P_L^*$ $P_L^* \leq P_L$
Regulated volume	$q = \frac{4a-3}{6b}$	$q_L^* = \frac{(a-1)(1+\varphi)}{b(1+2\varphi)}$	$q_L = \frac{4(a-1)(1+\varphi)}{5b(1+2\varphi)}$	$q > q_L^*$ $q_L^* > q_L$
Profit	$\pi = \frac{(4a-3)^2}{48b}$	$\pi_L^* = \frac{(a-1)^2\varphi(1+\varphi)}{b(1+2\varphi)^2}$	$\pi_L = \frac{[2\varphi(2a-3)-1](a-1)(1+\varphi)}{5b(1+2\varphi)^2}$	$\pi > \pi_L^*$ $\pi_L^* > \pi_L$
Consumer surplus net	$SC = \frac{(4a-3)^2}{96b}$	$SC_L^* = \frac{(a-1)^2(1+\varphi)^2}{2b(1+2\varphi)^2}$	$SC_L = \frac{2(a-1)^2(1+\varphi)^2}{5b(1+2\varphi)^2}$	$SC < SC_L^*$ $SC_L^* > SC_L$
Social welfare	$W = \frac{(4a-3)^2(2a-1)}{48b}$	$W_L^* = \frac{(a-1)^2(1+\varphi)(1+3\varphi)}{2b(1+2\varphi)^2}$	$W_L = \frac{(a-1)(1+\varphi)[2(a-1)(1+\varphi)+2\varphi(2a-3)-1]}{5b(1+2\varphi)^2}$	$W > W_L^*$ $W_L^* > W_L$
Marginal cost	$C_q = \frac{3}{4}$	$C_{qL}^* = 1$	$C_{qL} = \frac{5}{4}$	$C_q < C_{qL}^* < C_{qL}$
	$P > C_q$	$P_L^* > C_{qL}^*$	$P_L > C_{qL}$	

Carrots, Sticks, and Water Public Services: the precision of disclosed information and delegation contracts

Early and Preliminary Version

Abstract

This paper analyzes optimal contractual shape of delegation contracts, when biased estimation about the quality of water services emerges between local authorities and potential service providers. We find that the conflict between the coordination motive and the competition motive result in two types of distortions: strategic distortion and informational distortion. To this end, we consider the precision of disclosure through the relative precision of public and private signals. Strategic distortions lead the potential service providers to deviate from two Separating Bayesian Equilibria. Informational distortion is associated with both information learning and the misleading estimation. Further, we show that these distortions can be mitigated by an increase in the precision of public signal. In addition, local authorities may adjust its public-policy instruments in order to limit the informational rent that it may concede to the operator.

KEYWORDS. Service Quality, Asymmetric Information, Estimation, Signal, Disclosure, Delegation Contracts, Strategic complementarity, Strategic substitutability.

JEL CODES. L33, L51, D82, D83.

1 Introduction

Information revealing contracts are largely applied to regulate water utilities. Revelation of costs and incentives to invest are a major concern for local authorities (henceforth “regulators”). In the water sector, the efficient governance under a contracting-out scheme is constrained by the increasing trend of water price and the potential decrease of the quality of water services. This problem is linked to the lack of transparency about the performance and the efforts of service providers. Transparency is not just measured by the quantity of information available. It can be also assessed by the relative degree of control over that information between the principal and agent concerning what it can be used to draw benefits from the principal-agent relationship.

In the water sector, the quality of the service is one of a set of indicators to measure the performance of drinking water networks. It is uncertain to both regulators and operators at the time of the delegation. Under public management, public operator withholds some information about the existing quality of drinking water networks to its advantage in delegation decisions. Under delegated management, a private operator does not reveal the information about the quality in order to continue to manager water services through renegotiation. Both situations are largely analyzed in the literature of Public-private partnerships (See Chong et al., 2006; Desrieux et al., 2013; Hoppe and Schmitz, 2013; Iossa and Martimort, 2016). Moreover, the quality of water services becomes an indicator to be examined in the empirical literature of cost revelation and water prices efficiency (See Boyer and Garcia, 2008; Destandau and Garcia, 2014; Garcia and Reynaud, 2004; Garcia and Thomas, 2003, 2001; Porcher, 2014, 2017; Reynaud and Thomas, 2005). In a closely related paper, Martimort and Sand-Zantman (2006) consider a risk-averse principal holding information about the quality of infrastructure. They ask whether a contract can signal the quality to a risk-neutral agent. They found that principals prefer to keep the public management of high-quality infrastructures.

While in Martimort and Sand-Zantman (2006) the principal does not disclose any information before contracting. In our paper, we consider disclosure in delegation of water services. Regulators are assumed to publish a quality index in response to operators’ disperse information. To our knowledge, information disclosure in delegation contracts has not been considered before.

We analyze how the precision of disclosure about the quality of water services affects the optimal shape of delegation contracts. We firstly assume that the quality is a random variable representing a state of the world unknown at the time of delegation. It can be estimated by local authorities and operators through disclosed information. Regulators collect and publish data about water networks. Any operator may observe these data to decide whether or not to acquire additional information. Our model covers three distinctive features: (1) asymmetric information in revised estimation about the service quality, which is presented by biased estimations between local authorities and operators; (2) information acquisition influences operators’ strategies in choosing the contracts on the basis of revised estimation; and (3) the precision of public and private estimation affect the choice of contracts.

We find that an operator who freely learns from others’ disclosed information rather than acquiring

costly information may mislead the delegation process by misguiding a local authority in the definition of the contract. This reduces the efficiency of the process since the regulator may tolerate some level of water leakages, which yields a large part of operating profits from the operator through the transfer designed in the contract. In this case, the delegation contract only covers an operator's ex post operational costs. Through it, a local authority extracts ex post participation rents due to the misleading estimation by giving an operator some incentives to improve the quality of water services.

In order to present some intuitions behind our findings, we describe some features of our screening contracts and the rents left to the operator. For instance, in the selection process, the regulator prefers that the operator's revised private estimation converges towards the revised public estimation. When the operator reports its revised private estimation without acquiring any information, the proposed contract can generate a high level profit. Since this contract depends not only on the precision of public and private signals, but also is influenced by information acquisition, then there are strategic distortion and informational distortion in choosing the contract.

Informational distortion arises from the fact that the regulator and an operator are influenced by the misleading estimation. They are misguided to make decision. Then, we find two types of strategic distortion: strategic complementarity and strategic substitutability. Such distortion mainly results from conflicts among three motives (See Morris and Shin, 2002; Cornand and Heinemann, 2008; Cornand and Ferreira, 2017): A fundamental motive, a coordination motive and a competition motive. A fundamental motive enables operators to predict and fit an exogenous fundamental value, which is considered the quality of water services in our model. A coordination motive gives incentives to operators to rely more on their revised private estimation about the quality. A competition motive induces operators to benefit from their strategic behaviors in the delegation process. Both strategic distortion and informational distortion make operators deviate from two Separating Bayesian Equilibria in order to obtain information rents. Hence, information rents can be composed of two parts: information rents linked to strategic distortion, and ex post participation rents linked to the misleading estimation about the quality of water infrastructure. Moreover, strategic distortion and informational distortion depend on the relative precision of public and private signals, and the relative overall precision of signal (See Angeletos and Pavan, 2004, 2007).

If the precision of public signal is high, then the competition motive dominates the coordination motive. Even though an operator is influenced by others' misleading information deriving from signals conveyed by correlation coefficient between operators' private information, it is worth to rely more on the precise public estimation and less on the private estimation. The operator deviates from one Separating Bayesian Equilibrium by coordinating towards the average public estimation. This makes the operator's action strategic substitute, when other operators rely more on their private estimation. Therefore, the operator can obtain information rents that depend on the average estimation and ex post participation rents that are due to the misleading estimation. The regulator thus faces a trade-off between increasing ex post participation rents and reducing information rents.

If the precision of public signal is low, then the coordination motive dominates the competition motive. Following other operators who put great weights on their idiosyncratic estimation, an operator may deviate from the second equilibrium by relying more on its own idiosyncratic estimation. On this view, the coordination motive makes an operator aligner its strategic decision with others. This leads the operator's action strategic complement. There is so great weights on operators' idiosyncratic estimation that the value of correlation coefficient across operators' private precision becomes high. However, a high value of correlation coefficient plays a role of public information, i.e. signals about the state of infrastructure quality. In consequence, there is an increase in the precision of public estimation that can lower information rents and ex post participation rents left to the operator. Therefore, both strategic and informational distortions are limited by improved precision of public estimation.

The precision of public and private signals renders the delegation transparent. Despite asymmetric information in the revised estimation, the mechanism of revelation reduces the control over the information. When regulators do not have precise public information, they can take advantage of both a high weight on idiosyncratic signal, and a high value of correlation coefficient across operators' precise private signals, which allows regulators to improve the relative precision of public estimation. Operators benefit from the precise private signal to adjust their strategies in information learning, and thus in choosing a contract. According to the relative precision of public and private signals, an operator, who does not acquire any information, switches between public learning (under coordination motive) and private learning (under competition motive). If the operator accepts the contract, then it draws some level of information rents from its decision-making strategy. At the same time, it profits from the misleading estimation by obtaining some ex post participation rents measured as the expected volume of water leakages tolerated by regulators in the delegation contract.

An increase in the precision of public estimation induces regulators to adjust the public-policy variables and the marginal transfer. The more volume of water leakages tolerated in the contract, the more transfer is important. Consequently, regulators extract ex post participation rents to make the operator improve the quality. We obtain the effects "Carrots and Sticks" generated by the contracting process.

Finally, this paper contributes to two main strands of literature. First, it extends the revelation of cost and/or effort by a regulation contract (See Garcia and Thomas, 2001; Elnaboulsi, 2001, 2009; Martimort and Sand-Zantman, 2006) to the theoretical and empirical analyses about water leakages considered as a key indicator of the service quality in the water sector. These analyses are provided by Garcia and Thomas (2003); Garcia and Reynaud (2004), Reynaud and Thomas (2005), Elnaboulsi (2009), Destandau and Garcia (2014), Porcher (2014, 2015, 2017) and Cavaliere et al. (2017). Regulators and operators are constrained by the volume of water distribution, in which the level of water leakages affects water prices, and hence the performance of managing water services.

Second, this paper belongs to a growing literature about the social value of public information initiated by Morris and Shin (2002), highlighting the conflicts between the fundamental and the coordination motives. Angeletos and Pavan (2004, 2007) and Hellwig and Veldkamp (2009) show that an increase in

the precision of public information can reduce these conflicts if information can be efficiently used. By combining with the competition motive, Vives (2008, 2011, 2014, 2017) and Myatt and Wallace (2012, 2015) merge the fundamental and coordination motives to show that the public information is socially desirable in market games. Referring to their findings, our model combines disclosed public information with the private information by using an informative signal, in which a weight is put on the idiosyncratic information. This informative signal measures the strategic value of information and is the common knowledge to both local authorities and operators. Further, it extends the analysis of Auriol and Laffont (1992), in which they apply a stochastic information structure to the revelation of cost in monopoly regulation by contracts. Our analysis, however, is similar to that of Bergemann et al. (2015). While the authors focus on the weight put on public signal, we are interested in the correlation between public signal and private signal. We observe that the regulator can improve public precision by learning from the correlation of private precision. Greater precision of public estimation can mitigate the negative effects of competition motive on the coordination motive. Meanwhile, by inferring from the correlation of private precision, potential service providers take their strategic decisions in the choice of delegation contracts. Few papers focus on the effects of precision of disclosed information about the quality of water infrastructure, when public water services are regulated by the delegation contracts. The objective of our paper is to fill this gap. We try to obtain the optimal expected volume of water distribution regulated by delegation contracts, depending on the precision of disclosure.

The paper proceeds as follows. Section 2 describes the set-up of model. Section 3 analyzes the information structure. Section 4 and Section 5 contribute to analyze the contract structures by comparing public precision to private precision. Section 6 concludes.

2 The General Model

Our model is in line with Baron and Myerson (1982). The regulator may delegate the public water services to a potential service provider (the operator hereafter). The state of the infrastructure $\theta \in \Theta \equiv [\theta^l, \theta^h]$ is not known with certainty by all parties. The regulator has some estimation about the quality based on published data (e.g., annual reports or other statistics). It publishes its assessments through a quality index $\tilde{\theta} \in \Theta$, to which we refer as the public signal. It is a mandatory disclosure mechanism that gives an open access to all operators to learn about the state of the infrastructure before participating in the delegation process. An operator has a private information about the quality, which is $\tilde{\theta}_i \in \Theta$ based on the public signal. We assume that any operator has an additional information that can not be observed by the regulator.

We consider two stages during the negotiation phase. In the first stage, operators choose the precision of private information. There are thus two kinds of operators if we do not take into account the cost of choosing the precision. One keeps its prior private precision, while the other decides to enhance its private precision by acquiring some information. In the second stage, operators observe public and private signals and choose their actions. In the second stage, the private precision of an operator who

does not acquire information can be affected by the others. This is different from the assumption of Morris and Shin (2002) that all agents have equal precision of private information in the second-stage game.

Information acquisition depends on an operator's *ex ante* beliefs about θ . Let $\hat{\theta}_i$ be operators' *ex ante* beliefs combining the private estimation with the public estimation. If an operator chooses to acquire information, then it tends to misreport its private information conditional on $\hat{\theta}_i$. If an operator does not acquire information, then it reveals correctly its private information conditional on $\hat{\theta}_i$. We investigate hereafter the effects of the correlation between private signals on operators' strategic behavior in choosing the delegation contracts.

2.1 Water demand

The demand function is known by both the regulator and operators. It is linear and given by:

$$P(q(\tilde{\theta})) = a - b(1 + \tilde{\theta})q, a > 0, b > 0. \quad (2.1)$$

where P denotes the water price fixed at the beginning of the delegation, a and b are strictly positive parameters and assumed to be known by all parties. We refer to the terms in the demand function (2.1), a and b as the choke price and the demand slop, respectively. Note that, the volume q depends on the random variable $\tilde{\theta}$. The regulator fixes the water price based on its own estimation of the quality of water mains. This price-setting signifies that the regulator can update the water price according to its precision of estimation about the quality of water mains.

Consumers' willingness-to-pay depend on the public estimation, and is given by:

$$V(q(\tilde{\theta})) = \int_0^{q(\tilde{\theta})} P(u) du. \quad (2.2)$$

Consumers pay the price for a given volume of water $q(\tilde{\theta}_i)$ consumed, which depends on the operator's private estimation. This yields the following consumers' surplus:

$$SC(q(\tilde{\theta}), q(\tilde{\theta}_i)) = V(q(\tilde{\theta})) - P(q(\tilde{\theta})) q(\tilde{\theta}_i). \quad (2.3)$$

2.2 Water services

We consider that an operator, either public or private, has a linear cost function $C_i(q(\tilde{\theta}_i))$, which depends on the private estimation of the quality $\tilde{\theta}_i$:¹

$$C_i(q, \tilde{\theta}_i) = (c + \tilde{\theta}_i)q \quad \text{if } q > 0, \quad \text{and} \quad C(0, \tilde{\theta}_i) = 0, \quad (2.4)$$

¹This cost function follows Weitzman (1978, pp.684). In this case, the operating cost function depends on the private estimation of the quality.

where $C_q \equiv \frac{\partial C}{\partial q} > 0$, $C_{\tilde{\theta}_i} \equiv \frac{\partial C}{\partial \tilde{\theta}_i} \equiv q > 0$, $C_{q\tilde{\theta}_i} \equiv \frac{\partial^2 C}{\partial q \partial \tilde{\theta}_i} \equiv 1 > 0$, and $C_{\tilde{\theta}_i q} \equiv \frac{\partial^2 C}{\partial \tilde{\theta}_i \partial q} \equiv 1 > 0$. These conditions ensure that different operators have indifference curves which cross each other at most once.

At this stage, we assume that for a given volume of water, the cost of water production is publicly observable. The marginal cost of water provision is normalized to one and so $c = 1$. Our analysis focuses on the shocks of the quality. They generate *ex post* operational costs for the operator, such as network maintenance and financing of existing and future water infrastructure. It is worth noting that the total average operational cost, ATC_i , has the same structure as the marginal operational cost MC_i , which is a linear function of the operator's private estimation, such that $ATC_i \equiv MC_i = (1 + \tilde{\theta}_i)$.

The regulator and operators are assumed to be risk-neutral. An operator, who manage the water networks under a delegation contract, does expose itself to the shocks on the network state. The regulator shares the profit of operating the water network with the operator, so it bears the same shock as the operator through the volume of water distributed. Martimort and Sand-Zantman (2006) show that a risk-averse local government bears more the financial risk than a risk-neutral operator in the water industry if the quality of water infrastructure increases. They consider that the regulator is privately informed about the quality of the infrastructure, and it increases the share of the operational risk it bears so as to signal the quality of the infrastructure to the uninformed operator. In our analysis, both the regulator and the operator are imperfectly informed about the quality of water mains. The better the quality of the network, the less the share of the state shock born by the regulator.

The profit drawn from the activity of distributing drinking water distribution can be decomposed into two parts: a part that is paid to the operator and a part that is paid to the municipality to reimburse its investments. We impose the accounting convention that the regulator receives the entire profit from services and gives back a fraction $(1 - t)$ of it to the operator. Our transfer function takes the form:

$$T_i(\pi_i) = -t\pi_i(q, \tilde{\theta}, \tilde{\theta}_i), \quad \text{where } t \in [0, 1]. \quad (2.5)$$

where the fraction $t \in [0, 1]$ represents the marginal transfer. It determines the operator's marginal sharing of profits. $T_i(\pi_i)$ depends proportionally on the operator's realized profit $\pi_i(\tilde{\theta}, \tilde{\theta}_i)$. Thereby, the operator's payoff function is:

$$U_i(q, \tilde{\theta}, \tilde{\theta}_i, t) = \pi_i(q, \tilde{\theta}, \tilde{\theta}_i) + T_i(\pi_i) = (1 - t) \left[P(q(\tilde{\theta}))q(\tilde{\theta}_i) - C_i(q(\tilde{\theta}_i)) \right]. \quad (2.6)$$

2.3 Social welfare

We assume that the regulator integrates the gains to consumers, its part of profits and a weighted payoff of the operator in its objective. Specially, we assume that the regulator puts a weight $\varphi \in [0, 1]$ on the

payoff function of the operator, so the regulator's objective is:

$$\begin{aligned} W(q, \tilde{\theta}, \tilde{\theta}_i, t, \varphi) &= SC(q, \tilde{\theta}, \tilde{\theta}_i) + t\pi_i(q, \tilde{\theta}, \tilde{\theta}_i) + \varphi U_i(q, \tilde{\theta}, \tilde{\theta}_i, t) \\ &= SC(q, \tilde{\theta}, \tilde{\theta}_i) + [t + \varphi(1-t)]\pi_i(q, \tilde{\theta}, \tilde{\theta}_i). \end{aligned} \quad (2.7)$$

where we denote $\lambda = [t + \varphi(1-t)]$, satisfying $\lambda \in]0, 1]$. It represents the public-policy variable that the regulator faces in order to make trade-off between rent extraction and incentive.

Up to now, we have described a standard regulation model. If the regulator and operators were to know θ with certainty, and hence $\tilde{\theta} \equiv \tilde{\theta}_i$, then the regulator chooses a volume of water distribution so as to maximize social welfare subject to the operator's breakeven constraint:

$$Max_{q(\theta)} \{V(q(\theta)) - P(q(\theta))q(\theta) + \lambda(P(q(\theta))q(\theta) - C_i(q(\theta)))\} \quad (2.8)$$

subject to

$$P(q(\theta))q(\theta) \geq C_i(q(\theta)) \quad (2.9)$$

Letting $\nu \geq 0$ denote the shadow price of constraint (2.9), the optimal price and volume of water satisfy:

$$\frac{P(q^*(\theta)) - C'(q^*(\theta))}{P(q^*(\theta))} = -\frac{[1 - (\lambda + \nu)]}{(\lambda + \nu)} \frac{1}{\xi(q^*(\theta))} \quad (2.10)$$

$$q^*(\theta) = \frac{(a-1)}{b(1+\theta)} \quad (2.11)$$

where $\lambda + \nu \in [0, 1]$, and $\xi(q^*(\theta))$ is the elasticity of water demand. $q^*(\theta)$ is the regulated full information volume level depending the state of the quality.

Note that, the shadow price ν is higher than λ . Since $\nu > 0$, the social welfare reaches a maximum when the operator's breakeven constraint is saturated at $q^*(\theta)$ defined in (2.11). The optimal price is given by "the Lerner index" in (2.10), and it rules out transfers from the regulator to the operator. The regulator must compensate the operator for costly water services by allowing higher price, so the price in general exceed marginal costs. It is straightforward that the price-marginal cost ratio depends directly on the state of the quality θ .

Under incomplete information, incentives constraints must be added in the regulator's program when operators receives a pair of public and private signals. We investigate how public and private signals about the quality of water mains affect this regulation.

3 The Information Structure

3.1 Public and private signals

The quality state of water infrastructure, θ is assumed to be distributed normally with $\theta \sim N(\mu_\theta, \sigma_\theta^2)$. Let's denote the precision of information $\tau_\theta \equiv \frac{1}{\sigma_\theta^2}$. The regulator discloses its signal through a *quality index* given by:

$$\tilde{\theta} = \theta + \eta, \tilde{\theta} \sim N(\mu_\theta, \sigma_{\tilde{\theta}}^2). \quad (3.1)$$

The noise term η is normally distributed, independent of θ , with the mean 0 and variance σ_η^2 . The quality index is “public” in the sense that the actual estimation of $\tilde{\theta}$ is common knowledge to all parties. The accuracy of this index is presented by the precision $\tau_{\tilde{\theta}} \equiv \frac{1}{\sigma_{\tilde{\theta}}^2 + \sigma_\eta^2}$.

Following Myatt and Wallace (2012, 2015), we assume that a potential operator i has its own private signal given by:

$$\tilde{\theta}_i = \tilde{\theta} + \Delta\theta_i, \Delta\theta_i \sim N(0, \sigma_{\Delta\theta_i}^2). \quad (3.2)$$

The idiosyncratic signal $\Delta\theta_i$ is independent of θ and η , so that $\tilde{\theta}_i = \theta + \eta + \Delta\theta_i$. It is also independent of the aggregate shock $\tilde{\theta}$, and is identically and independently distributed across operators. The private signal is thus jointly normally distributed as $\tilde{\theta}_i \sim N(\mu_\theta, \sigma_{\tilde{\theta}_i}^2)$. Given the linearity structure adopted in this paper, we write the variance of the quality shock $\tilde{\theta}_i$:

$$\sigma_{\tilde{\theta}_i}^2 = \sigma_\theta^2 + \sigma_\eta^2 + \sigma_{\Delta\theta_i}^2. \quad (3.3)$$

Thus, the precision of the private signal is $\tau_{\tilde{\theta}_i} \equiv \frac{1}{\sigma_\theta^2 + \sigma_\eta^2 + \sigma_{\Delta\theta_i}^2}$, which reflects the overall accuracy of the estimation about the quality of networks.

Since $\mathbb{E}[\tilde{\theta}_i] = \mathbb{E}[\tilde{\theta}] = \mathbb{E}[\theta] \equiv \mu_\theta$, we assume that the average estimation of infrastructure is fixed as a target in the delegation process. We consider that private signals are symmetrically distributed around μ_θ , meaning that a same mass of operators has *ex ante* belief that the public signal $\tilde{\theta}$ is an overestimation or an underestimation of the true value of θ . The first ones naturally anticipate that operating the water network is less interesting than announced, and the second ones anticipate that operating the network is more interesting than announced.

The correlation $\rho_{\theta\theta}$ between any two operators' signals is given by:²

$$\rho_{\theta\theta} = \frac{\sigma_\theta^2}{\sigma_\theta^2 + \sigma_{\Delta\theta_i}^2} = \frac{\tau_{\Delta\theta_i}}{\tau_{\tilde{\theta}} + \tau_{\Delta\theta_i}}. \quad (3.4)$$

It measures the relative precision of the public signal. Under our assumptions, it is easy to show that the covariance between $\tilde{\theta}_i$ and $\tilde{\theta}_j$ is equal to the covariance between $\tilde{\theta}_i$ and the public signal $\tilde{\theta}$.

²For notational convenience, we omit part of the subscripts in the description of the moments, and thus write $\rho_{\theta\theta}$ instead of $\rho_{\theta_i\theta_j}$.

From the composition of estimation as presented by the correlation coefficient $\rho_{\theta\theta}$, we can draw the relation relative of public and private precision. First of all, when $\tau_{\tilde{\theta}} > \tau_{\Delta\theta_i}$, the correlation $\rho_{\theta\theta}$ varies in the interval $[0, \frac{1}{2}[$. It implies that operators receive idiosyncratic signals, which are imperfectly correlated, and each operator observes both the precise public signal and its own noisy private signal. Then, when $\tau_{\tilde{\theta}} < \tau_{\Delta\theta_i}$, the correlation $\rho_{\theta\theta} \in]\frac{1}{2}, 1]$. The private signals tend to be perfectly correlated and we are in a common-value model because of the precise idiosyncratic signal. It indicates that whatever is noisy the public signal, each operator can observe its signal with no measurement error if $\tau_{\Delta\theta_i} \equiv \infty$. Finally, when $\tau_{\tilde{\theta}} = \tau_{\Delta\theta_i}$, the correlation $\rho_{\theta\theta} = \frac{1}{2}$. In this case, we find that the precision of information about the state of the quality τ_{θ} depends on the dispersion between the idiosyncratic noise and the public noise. The smaller is the dispersion, the more precise is τ_{θ} .

3.2 A noisy common knowledge structure

Once the regulator discloses the public signal, an operator i decides whether to participate or not to the delegation process. If it does, then we assume that the operator sets *ex ante* its own signal $\hat{\theta}_i$ and reports it to the regulator. $\hat{\theta}_i$ is given by:

$$\hat{\theta}_i \equiv \tilde{\theta} + d\Delta\theta_i. \quad (3.5)$$

where $d \in [0, 1]$ represent a weight on the idiosyncratic estimation.³

$\hat{\theta}_i$ is assumed to be a *noisy common knowledge* for all parties. Even if the operator has superior information about the quality, it faces some residual uncertainty about its *ex post* operating costs. For the regulator, the uncertainty about the *ex post* operating costs linked to the quality may give rise to some variation in the quality levels and incentive schemes.

Based on $\hat{\theta}_i$, both the regulator and the operator revise their estimations. Thereby, the conditional expectation of the private signal is

$$\begin{aligned} \mathbb{E}[\tilde{\theta}_i|\hat{\theta}_i] &= \mathbb{E}[\tilde{\theta}|\hat{\theta}_i] + \mathbb{E}[\Delta\theta_i|\hat{\theta}_i] \\ &= \mu_{\theta} + \frac{\rho_{\theta\theta} + d(1 - \rho_{\theta\theta})}{\rho_{\theta\theta} + d^2(1 - \rho_{\theta\theta})} (\hat{\theta}_i - \mu_{\theta}). \end{aligned} \quad (3.6)$$

If an operator i does not acquire any additional information, then equation (3.6) can be decomposed into two parts. First of all, it is the conditional expectation of the public signal

$$\mathbb{E}[\tilde{\theta}|\hat{\theta}_i] = \mu_{\theta} + \frac{\rho_{\theta\theta}}{\rho_{\theta\theta} + d^2(1 - \rho_{\theta\theta})} (\hat{\theta}_i - \mu_{\theta}). \quad (3.7)$$

³An alternative normalization would assign a weight 1 to the idiosyncratic shock $\Delta\theta_i$ and $\frac{1}{(1-r)}$ to the aggregate shock $\tilde{\theta}$, as in Bergemann et al. (2015).

Then, we have the conditional expectation of the idiosyncratic signal

$$\mathbb{E}[\Delta\theta_i|\hat{\theta}_i] = \frac{d(1 - \rho_{\theta\theta})}{\rho_{\theta\theta} + d^2(1 - \rho_{\theta\theta})}(\hat{\theta}_i - \mu_\theta). \quad (3.8)$$

The above conditional expectation equations show that the correlation coefficient across any two private signals $\rho_{\theta\theta}$ and the parameter d play respectively a role in the updating process. To show that, we consider the following cases:

- We recall that if $\tau_{\tilde{\theta}} \geq \tau_{\Delta\theta_i}$, then $\rho_{\theta\theta} \in [0, \frac{1}{2}]$. The correlation coefficient across private signals is weak and each operator relies more on its idiosyncratic signal. Equation (3.8) shows that for any $d \in]0, 1[$, there exists a critical value $d = \sqrt{\frac{\rho_{\theta\theta}}{(1 - \rho_{\theta\theta})}}$ beyond which $\mathbb{E}[\Delta\theta_i|\hat{\theta}_i]$ is decreasing in d . It indicates that, a slight high correlation across the private signals due to a more weight put on the idiosyncratic signal can reduce ex post biased estimation $(\hat{\theta}_i - \mu_\theta)$. This effect is complemented by the revised public signal (see equation (3.7)). Hence, when the public signal is more precise than the private signal, ex post biased estimation is reduced in the conditional expectation of private signal. In particular, when $d = 1$, then equation (3.6) reduces to $\mathbb{E}[\tilde{\theta}_i|\hat{\theta}_i] = \hat{\theta}_i \equiv \tilde{\theta} + \Delta\theta_i \equiv \tilde{\theta}_i$. An operator can revise its private signal without bias, but holds its own idiosyncratic signal. Similarly, if $d = 0$, then the public signal is observed with certainty by both the regulator and the operator without bias, as $\mathbb{E}[\tilde{\theta}|\hat{\theta}_i] \equiv \mathbb{E}[\tilde{\theta}_i|\hat{\theta}_i] \equiv \tilde{\theta}$. But there remains residual uncertainty about the idiosyncratic signal $\Delta\theta_i$. As a consequence, even conditioning on the signal $\hat{\theta}_i$, an operator's revised private signal $\tilde{\theta}_i$ is not completely revealed to the regulator.
- When $\tau_{\tilde{\theta}} \leq \tau_{\Delta\theta_i}$, then $\rho_{\theta\theta} \in [\frac{1}{2}, 1]$. The correlation coefficient across private signals is increasing in a more precise idiosyncratic signal. Equation (3.8) shows that for any $d \in [0, 1]$, the revised idiosyncratic signal depends less on the ex post biased estimation. The intuition is that each operator puts more weight on the precise idiosyncratic signal in its signal $\hat{\theta}_i$, which, in turn, increases the correlation coefficient $\rho_{\theta\theta}$ measured as the common knowledge among all parties. For instance, if $d = 1$, then $\mathbb{E}[\Delta\theta_i|\hat{\theta}_i] \equiv (1 - \rho_{\theta\theta})(\hat{\theta}_i - \mu_\theta)$. In this case, if $\rho_{\theta\theta}$ increases, then the revised idiosyncratic signal is less biased. In particular, when $\rho_{\theta\theta} \rightarrow 1$, then $\mathbb{E}[\Delta\theta_i|\hat{\theta}_i] \equiv 0$. Conversely, there is more ex post biased estimation in the revised public signal because of the imprecise public signal (see equation (3.7)), so that $\mathbb{E}[\tilde{\theta}|\hat{\theta}_i] \equiv \mu_\theta + \rho_{\theta\theta}(\hat{\theta}_i - \mu_\theta)$. When $\rho_{\theta\theta} \rightarrow 1$, then $\mathbb{E}[\tilde{\theta}|\hat{\theta}_i] \equiv \hat{\theta}_i \equiv \tilde{\theta} + \Delta\theta_i$. It indicates that the revised public signal is influenced by the idiosyncratic signal. As a result, when $d = 1$ and $\rho_{\theta\theta} \rightarrow 1$, the revised private signal $\mathbb{E}[\tilde{\theta}_i|\hat{\theta}_i] \equiv \hat{\theta}_i \equiv \tilde{\theta}_i$. Even though it is not affected by the ex post biased estimation due to the precise idiosyncratic signal, an operator's revised private signal is not completely known by the regulator.
- For any $d \in]0, 1[$, if $\rho_{\theta\theta} = \frac{1}{2}$ (and equivalently $\tau_{\tilde{\theta}} = \tau_{\Delta\theta_i}$), then operators' idiosyncratic signals are imperfectly correlated. In this case, both revised public and private signals depend proportionally on the ex post biased estimation $(\hat{\theta}_i - \mathbb{E}[\hat{\theta}_i])$. If a high d is put on the idiosyncratic signal in $\hat{\theta}_i$, then the revised idiosyncratic signal depends more on the ex post biased estimation, whereas the revised public signal depends less on the ex post biased estimation. In addition, equation (3.6)

becomes $\mathbb{E}[\tilde{\theta}_i|\hat{\theta}_i] \equiv \mu_\theta + \frac{1+d}{1+d^2}(\hat{\theta}_i - \mu_\theta)$. Since $\tau_{\tilde{\theta}} = \tau_{\Delta\theta_i}$, an operator faces a trade-off between a more weight and a less weight put on its idiosyncratic estimation. Hence, the effects of ex post biased estimation on its revised private signal can be strengthened by a less weight $d \in]0, \sqrt{2} - 1]$, or be weakened by a more weight $d \in]\sqrt{2} - 1, 1]$.

The above analysis shows that there is some ex post biased estimation about the quality of water mains in revised public and private signals. Hence, an operator may have incentives to acquire additional information in order to increase its idiosyncratic estimation. In doing so, the operator tends to misreport its private estimation based on the signal $\hat{\theta}_i$ in the choice of the contracts. As a consequence, the regulator may inefficiently assign a delegation contract.

In following section, we illustrate this strategic behavior by considering that, $\mathbb{E}[\tilde{\tilde{\theta}}_i|\hat{\theta}_i]$, where $\tilde{\tilde{\theta}}_i = \tilde{\theta}_i + \Delta\theta_i^+$, is an operator's revised *over(under)-estimation* about the quality of water mains. After privately acquiring a bit of information presented by h_θ , which is imperfectly known by the regulator. Hence, the operator's amplified idiosyncratic estimation is assumed to be $\Delta\theta_i^+ \equiv \Delta\theta_i + h_\theta$. We assume that h_θ is a continuous random variable in $\Theta = [\theta^l, \theta^h]$ with a positive density function $g(h_\theta) > 0$, which is defined from a cumulative distribution function $G(h_\theta)$ in $\Theta = [\theta^l, \theta^h]$. Both $G(h_\theta)$ and $g(h_\theta)$ are continuous and at least twice differentiable in h_θ . In addition, this additional idiosyncratic information is independent of $\Delta\theta_i$.

We can now analyze how the precision of public and private signals affects the choice of delegation contracts for the case of $\mathbb{E}[\tilde{\tilde{\theta}}_i|\hat{\theta}_i] \neq \mathbb{E}[\tilde{\theta}_i|\hat{\theta}_i]$.

4 Contract Structures

4.1 Set up

In the negotiation stage of delegation process (Figure 1), the regulator cannot distinguish the type of idiosyncratic shock $\Delta\theta_i$ from $\Delta\theta_i^+$ in a potential operator's own signal $\hat{\theta}_i$. But, it can set up the average estimation of the quality of water mains μ_θ as a target in the proposition of delegation in order to avoid over (under)-estimation about the quality, and, hence to allocate inefficiently the contract.

Given the announced *ex ante* information $\hat{\theta}_i$ (the signal), an operator can correctly reports its revised private estimation $\mathbb{E}[\tilde{\theta}_i|\hat{\theta}_i]$, or incorrectly report its revised private estimation $\mathbb{E}[\tilde{\tilde{\theta}}_i|\hat{\theta}_i]$. We ask now which the mechanism the regulator can implement and push the operator to reveal correctly its revised private signal about the quality of the infrastructure.

On the basis of private signal $\hat{\theta}_i$ announced by operators, the regulator can offer a menu of contracts $\left\{ \left(q_i \left(\mathbb{E}[\tilde{\theta}_i|\hat{\theta}_i] \right), T_i \left(\mathbb{E}[\tilde{\theta}_i|\hat{\theta}_i] \right) \right), \left(q_i \left(\mathbb{E}[\tilde{\tilde{\theta}}_i|\hat{\theta}_i] \right), T_i \left(\mathbb{E}[\tilde{\tilde{\theta}}_i|\hat{\theta}_i] \right) \right) \right\}_{i=1}^n$, with $(\tilde{\theta}_i; \tilde{\tilde{\theta}}_i; \hat{\theta}_i) \in \Theta = [\theta^l, \theta^h]$. In these contracts proposal, the regulator offers a couple of expected volume of water distribution and expected transfer allocated to the operator who receives the delegation.⁴ In order to simplify the notation of index,

⁴In Laffont and Martimort (2002) (p48-50): Let M be the message space offered to the agent by a more general mechanism, conditionally on a given message $m \in M$ received from the agent, the principal requests a production level $q(m)$ and provides

we assume that $q_1(\mathbb{E}[\tilde{\theta}_i|\hat{\theta}_i]) \equiv q_1$, $T_1(\mathbb{E}[\tilde{\theta}_i|\hat{\theta}_i]) \equiv T_1$, and $q_2(\mathbb{E}[\tilde{\tilde{\theta}}_i|\hat{\theta}_i]) \equiv q_2$, $T_2(\mathbb{E}[\tilde{\tilde{\theta}}_i|\hat{\theta}_i]) \equiv T_2$. Thus, a menu of contracts is represented by $\{(q_1, T_1), (q_2, T_2)\}$.

Moreover, given the information structure available to all parties, the winner draws q_1 (or q_2) in order to maximize $\mathbb{E}[U_i(q_1)|\hat{\theta}_i]$ (or $\mathbb{E}[U_i(q_2)|\hat{\theta}_i]$). Then, it receives an expected transfer T_1 (or T_2). The expected regulated price $P(q_1) \equiv P_1$ (or $P(q_2) \equiv P_2$) is fixed by the regulator in the negotiation phase of delegation contracts.⁵

Finally, given the signal $\hat{\theta}_i$, the expected social welfare function is now written as:

$$\mathbb{E}[W(q_1, q_2)|\hat{\theta}_i] = \omega \{SC(q_1) + \lambda\pi(q_1)\} + (1 - \omega) \{SC(q_2) + \lambda\pi(q_2)\}, \quad (4.1)$$

where the parameter $\omega \in [0, 1]$ is the probability that an operator announces $\mathbb{E}[\tilde{\theta}_i|\hat{\theta}_i]$ and chooses $\{q_1, T_1\}$, and $(1 - \omega)$ is the probability that an operator announces $\mathbb{E}[\tilde{\tilde{\theta}}_i|\hat{\theta}_i]$ and choose $\{q_2, T_2\}$. The regulator hopes that an operator type $(\mathbb{E}[\tilde{\theta}_i|\hat{\theta}_i])$ selects $\{q_1, T_1\}$, and an operator type $(\mathbb{E}[\tilde{\tilde{\theta}}_i|\hat{\theta}_i])$ selects instead $\{q_2, T_2\}$. Since the expected social welfare function depends proportionally on expected profits, we focus our analysis on an operator's the expected profit function.

By accepting a given price depending on the revised public signal, the expected volume of distributed water by a potential operator depends on the conditional expectation of its private signal. As the marginal cost of water provision is normalized to one, it is the shock of the quality that generates the operational costs for an operator.⁶ For instance, Porcher (2014) notes that, in the water industry, marginal cost depends first of all on the age of the plant more than on the volumetric charge. Hence, for a given volume of water distribution, an operator's operational costs are directly linked to the conditional expectation of its private signal. Let's define $\pi_1(\mathbb{E}[\tilde{\theta}_i|\hat{\theta}_i])$ to be the conditional expected payoff of an operator who has $\mathbb{E}[\tilde{\theta}_i|\hat{\theta}_i]$ and reports it correctly, whereas $\pi_2(\mathbb{E}[\tilde{\tilde{\theta}}_i|\hat{\theta}_i])$ to be the conditional expected payoff of an operator who has $\mathbb{E}[\tilde{\tilde{\theta}}_i|\hat{\theta}_i]$ and reports it correctly:

$$\pi_1(\mathbb{E}[\tilde{\theta}_i|\hat{\theta}_i]) = [a - b(1 + \mathbb{E}[\tilde{\theta}_i|\hat{\theta}_i])q_1] (1 + \mathbb{E}[\tilde{\theta}_i|\hat{\theta}_i])q_1 - (1 + \mathbb{E}[\tilde{\theta}_i|\hat{\theta}_i])q_1, \quad (4.2)$$

$$\pi_2(\mathbb{E}[\tilde{\tilde{\theta}}_i|\hat{\theta}_i]) = [a - b(1 + \mathbb{E}[\tilde{\tilde{\theta}}_i|\hat{\theta}_i])q_2] (1 + \mathbb{E}[\tilde{\tilde{\theta}}_i|\hat{\theta}_i])q_2 - (1 + \mathbb{E}[\tilde{\tilde{\theta}}_i|\hat{\theta}_i])q_2. \quad (4.3)$$

The biased signals about the quality of water mains are introduced to the negotiation phase in the second stage of delegation process represented in Figure 1.

a corresponding payment $t(m)$. Here, we denote $\mathbb{E}[\tilde{\theta}_i|\hat{\theta}_i]$ as an operator i 's revised private signal of the quality of water infrastructure.

⁵Normality of random variables means that prices and quantities can be negative with positive probability. The probability of this event can be controlled, if necessary, by an appropriate choice of means and variances (Vives (2008)). We use the key property of Gaussian distribution that conditional expectations are linear.

⁶The quality of water mains includes maintaining, improving, renewing, and even innovating the networks of mains.

Table 1: Expected private estimation linked to information acquisition

Overestimate the bad quality	Underestimate the bad quality	Converge estimation	Overestimate the good quality	Underestimate the good quality
$-1 < \theta^l \leq h_\theta < \mu_\theta < 0$	$-1 < \theta^l \leq \mu_\theta < h_\theta$	$h_\theta = \mu_\theta$	$0 < \mu_\theta < h_\theta \leq \theta^h$	$h_\theta < \mu_\theta \leq \theta^h$
$\mathbb{E}[h_\theta] = \mu_\theta - g(h_\theta^*)(\mu_\theta - h_\theta)(1 + \mu_\theta)$	$\mathbb{E}[h_\theta] = \mu_\theta + g(h_\theta^*)(h_\theta - \mu_\theta)(1 + \mu_\theta)$	$\mathbb{E}[h_\theta] = \mu_\theta$	$\mathbb{E}[h_\theta] = \mu_\theta + g(h_\theta^*)(h_\theta - \mu_\theta)(1 + \mu_\theta)$	$\mathbb{E}[h_\theta] = \mu_\theta - g(h_\theta^*)(\mu_\theta - h_\theta)(1 + \mu_\theta)$
$\mathbb{E}[h_\theta] < 0$	$\mathbb{E}[h_\theta] > 0$	$sgn(\mathbb{E}[h_\theta]) = sgn(\mu_\theta)$	$\mathbb{E}[h_\theta] > 0$	$\mathbb{E}[h_\theta] < 0$

■ See Appendix

In Table 1, we characterize the effects of additional information h_θ on the revised private estimation of an operator. Compared to the prior common knowledge about the quality of water mains μ_θ , some additional information leads the operator to overestimate or underestimate the quality. We find that $\mathbb{E}[h_\theta]$ imposes a negative effect on the revised private signal when the operator overestimates the bad quality or underestimates the good quality, so that $\mathbb{E}[h_\theta] < 0$. Conversely, $\mathbb{E}[h_\theta]$ imposes a positive effect on the revised private signal when the operator overestimates the good quality or underestimates the bad quality, and we find $\mathbb{E}[h_\theta] > 0$. In particular, the operator may have some additional information that converges with the prior common knowledge. In this case, for a given precision of signal, the operator's revised signal relies more on the average estimation about the quality, and, hence, $\mathbb{E}[\tilde{\theta}_i|\hat{\theta}_i] \equiv 2\mu_\theta + \frac{d\tau_{\tilde{\theta}} + \tau_{\Delta\theta_i}}{d^2\tau_{\tilde{\theta}} + \tau_{\Delta\theta_i}} [\hat{\theta}_i - \mathbb{E}[\hat{\theta}_i]]$. We ask how $\mathbb{E}[h_\theta]$ can affect the expected volume and price of water in the negotiation stage if an operator honestly reports its revised estimation.

4.2.2 Truthful reports

- Maximizing the expected profits. If an operator involves in the negotiation phase of delegation, then by maximizing its conditional expected profits, it may truthfully signal its revised estimation $\mathbb{E}[\tilde{\theta}_i|\hat{\theta}_i]$ or $\mathbb{E}[\tilde{\theta}_i|\hat{\theta}_i]$ to the regulator. Its expected volume of water to be distributed can be written:⁹

$$q_1 \left(\mathbb{E}[\tilde{\theta}_i|\hat{\theta}_i] \right) \equiv q_2 \left(\mathbb{E}[\tilde{\theta}_i|\hat{\theta}_i] \right) \equiv \frac{a - 1}{2b(1 + \mathbb{E}[\tilde{\theta}_i|\hat{\theta}_i])}, \quad (4.4)$$

both of them depend on the revised public estimation about the quality of water mains.

- Average cost pricing. We recall that the expected marginal cost equals the expected average total cost. They are affine functions of an operator's conditional expectation of the private signal, as $\mathbb{E}[MC_i|\hat{\theta}_i] = \mathbb{E}[ATC_i|\hat{\theta}_i] = (1 + \mathbb{E}[\tilde{\theta}_i|\hat{\theta}_i])$, or $\mathbb{E}[MC_i|\hat{\theta}_i] = \mathbb{E}[ATC_i|\hat{\theta}_i] = (1 + \mathbb{E}[\tilde{\theta}_i|\hat{\theta}_i])$. If the regulator can make an operator report honestly its revised private estimation in the negotiation, then it imposes the public policy that the expected price equals the expected average total operational cost (and equivalently equals the expected marginal operational cost), it is known as "average cost pricing".¹⁰ For an operator

⁹Let's define q_1 as the expected volume maximizing an operator's profit when it announces $\mathbb{E}[\tilde{\theta}_i|\hat{\theta}_i]$, and q_2 as the expected volume maximizing an operator's profit when it announces $\mathbb{E}[\tilde{\theta}_i|\hat{\theta}_i]$.

¹⁰Let's denote q_1^* as the expected volume of water distribution in equilibrium of the regulation when an operator has $\mathbb{E}[\tilde{\theta}_i|\hat{\theta}_i]$, and q_2^* as the expected volume of the equilibrium when an operator has $\mathbb{E}[\tilde{\theta}_i|\hat{\theta}_i]$.

who reports $\mathbb{E}[\tilde{\theta}_i|\hat{\theta}_i]$, the expected volume of water distribution in equilibrium of the regulation is

$$q_1^* \left(\mathbb{E}[\tilde{\theta}_i|\hat{\theta}_i]; \mathbb{E}[\tilde{\theta}|\hat{\theta}_i] \right) = \frac{a - (1 + \mathbb{E}[\tilde{\theta}_i|\hat{\theta}_i])}{b(1 + \mathbb{E}[\tilde{\theta}|\hat{\theta}_i])}, \quad (4.5)$$

and for an operator who reports $\mathbb{E}[\tilde{\theta}_i|\hat{\theta}_i]$, the expected volume of water distribution in equilibrium is

$$\begin{aligned} q_2^* \left(\mathbb{E}[\tilde{\theta}_i|\hat{\theta}_i]; \mathbb{E}[\tilde{\theta}|\hat{\theta}_i] \right) &= \frac{a - (1 + \mathbb{E}[\tilde{\theta}_i|\hat{\theta}_i])}{b(1 + \mathbb{E}[\tilde{\theta}|\hat{\theta}_i])} \\ &= q_1^* - \frac{\mathbb{E}[h_\theta]}{b(1 + \mathbb{E}[\tilde{\theta}|\hat{\theta}_i])}. \end{aligned} \quad (4.6)$$

Since $\mathbb{E}[\tilde{\theta}_i|\hat{\theta}_i] \neq \mathbb{E}[\tilde{\theta}|\hat{\theta}_i]$, an operator misleads its revised estimation about the quality of water mains due to additional information $\mathbb{E}[h_\theta]$. By comparing (4.6) to (4.5), for a given revised public estimation, if an operator acquires some information $\mathbb{E}[h_\theta]$ about the quality of water services, then there are three possibilities (see Table1). First of all, when the bad quality of water services is overestimated, or the good quality is underestimated, then $\mathbb{E}[h_\theta] < 0$ and q_2^* is higher than q_1^* . Then, when the bad quality of water services is underestimated, or the good quality is overestimated, then $\mathbb{E}[h_\theta] > 0$ and q_2^* is lower than q_1^* . Finally, even with information acquisition, the operator's estimation converges to the average estimation, such that $h_\theta \equiv \mu_\theta$, then q_2^* depends on both the average estimation and the precision of information. Therefore, the expected water prices are given by

$$P_1^* \left(\mathbb{E}[\tilde{\theta}_i|\hat{\theta}_i] \right) = 1 + \mathbb{E}[\tilde{\theta}_i|\hat{\theta}_i], \quad (4.7)$$

$$P_2^* \left(\mathbb{E}[\tilde{\theta}_i|\hat{\theta}_i] \right) = 1 + \mathbb{E}[\tilde{\theta}_i|\hat{\theta}_i] = P_1^* + \mathbb{E}[h_\theta]. \quad (4.8)$$

Equation (4.8) shows that the price depends both on an operator's private revised estimation and its acquired information $\mathbb{E}[h_\theta]$. When the precision of private estimation is given, the operator who acquires the information, may ask for a high water price. Indeed, some additional information leads the operator to evaluate a high marginal operational cost incurred by improving or maintaining the quality.

In a nutshell, information acquisition can lead an operator to over(under)-estimate the quality. For the same precision of information, the operator signals its revised estimation linked to information acquisition to the regulator. Both underestimating the bad quality and overestimating the good quality reduce the volume of water distribution. However, the water price rises. Indeed, the volume that is consumed by users is considerably less than the total volume put into the networks. If the regulator tolerates few of water leakages in the distribution networks due to the operator's misleading estimation about the quality, then the operator may negotiate a high water price in order to cover the operational cost of improving the networks.

On the contrary, if the operator overestimates the bad quality or underestimates the good quality, and signals its mistaken estimation to the regulator, then the latter authorizes a level of water leakages in the water distribution networks. Thus, the water price may decrease. It is reasonable to think that

the operator's operational cost is low enough to make the regulator reduce the price. Finally, even if the operator acquires information, its revised estimation converges to the average estimation about the quality. Therefore, we find that the level of water leakages depends both on the precision of information and the average estimation about the quality of the networks.

We investigate how does the precision of information and information acquisition affect the expected volume and price of water?

4.2.3 Information precision in truthful reports

In order to analyze the effects of information precision on the truthful reports, we need the following definition.

Definition 1. For noisy information structure $d \in [0, 1]$, $\delta_1 = \frac{\tau_{\Delta\theta_i}}{d^2\tau_{\hat{\theta}} + \tau_{\Delta\theta_i}}$ is the relative precision of private signal, $\delta_2 = \frac{d\tau_{\hat{\theta}}}{d^2\tau_{\hat{\theta}} + \tau_{\Delta\theta_i}}$ is the relative precision of public signal, and $\delta = \frac{d\tau_{\hat{\theta}} + \tau_{\Delta\theta_i}}{d^2\tau_{\hat{\theta}} + \tau_{\Delta\theta_i}}$ the relative precision of total signal.

From definition 1, we characterize the expected volume and price of water defined by the above two kinds of truthful reports. In the first case, equation (4.4) can be rewritten:

$$q_1(\delta_1) \equiv q_2(\delta_1) = \frac{(a-1)}{2b[1 + (1-\delta_1)\mu_\theta + \delta_1\hat{\theta}_i]}. \quad (4.9)$$

This yields

$$P_1 \equiv P_2 = \frac{a+1}{2}. \quad (4.10)$$

We recall that from (4.4) the expected volume of distributed water only depends on the conditional expectation of public signal. Equation (4.9) shows that the expected volume is decreasing with the relative precision of private signal δ_1 , and with the average estimation μ_θ . The more precise are the public and private signals, the less is the volume of leaks tolerated in the networks. In particular, for a given precision of private signal, if the operator's revised private estimation converges to the average estimation, and, hence, $[\hat{\theta}_i - \mathbb{E}[\hat{\theta}_i]] \equiv 0$, then we find the case of benchmark in which the expected volume depends only on μ_θ . However, compared to the expected volume under the complete information (see equation (2.11)), the volume under incomplete information is reduced because the revised estimation is influenced by the idiosyncratic noise.

Further, the expected water price is increasing with the choke price $a > 1$. This is similar to a two-part tariff. On the one side, each customer must pay a fixed charge corresponding to provisions for capital stock renewal and debt service. On the other side, a marginal tariff corresponds to operating expenses of the volumetric charge. The latter is linked to the quality in our model and represented by a , which is strongly affected by the geographic and demographic characters of one municipality. The operator can always renegotiate the water price, though the volume of water distribution is high or low. In addition, this price is higher than the price under complete information. As a result, an operator has not any incentive to reduce costs.

In the second case, since the regulation policy equals the expected water prices to the expected average total operational cost, the expected volume of water distribution depends both on the precision of information and the information acquired by an operator. Equations (4.5) and (4.6) are respectively rewritten:

$$q_1^*(\delta, \delta_1) = \frac{a - (1 + (1 - \delta)\mu_\theta + \delta\hat{\theta}_i)}{b(1 + (1 - \delta_1)\mu_\theta + \delta_1\hat{\theta}_i)}, \quad (4.11)$$

and

$$q_2^*(\delta, \delta_1, \mathbb{E}[h_\theta]) = \frac{a - (1 + (1 - \delta)\mu_\theta + \delta\hat{\theta}_i) - \mathbb{E}[h_\theta]}{b(1 + (1 - \delta_1)\mu_\theta + \delta_1\hat{\theta}_i)}. \quad (4.12)$$

Thus, the expected water prices are given:

$$P_1^*(\delta) = 1 + (1 - \delta)\mu_\theta + \delta\hat{\theta}_i, \quad (4.13)$$

and

$$P_2^*(\delta, \mathbb{E}[h_\theta]) = (1 + \mathbb{E}[h_\theta]) + (1 - \delta)\mu_\theta + \delta\hat{\theta}_i. \quad (4.14)$$

Under the regulation policy, we find that the expected volume and price are influenced only by the relative precision of signals if there is not any additional information (see equations (4.11) and (4.13)). Otherwise, they are also influenced by the average of information acquisition $\mathbb{E}[h_\theta]$ (see equations (4.12) and (4.14)). Now, we respectively analyze the effects of the precision of signals without and with information acquisition on the regulation policy.

4.2.4 The precision of signals without information acquisition

We focus on the case of “average cost pricing” regulation. In equations (4.11) and (4.13), when an operator signals correctly $\mathbb{E}[\tilde{\theta}_i|\hat{\theta}_i]$, the expected volume depends both on the relative total precision δ , and on the relative precision of private signal δ_1 . The precision of information is exogenous, and $\delta > \delta_1$ because of the relative precision of public signal.

Proposition 1 . For any $d \in [0, 1]$, and if the correlation coefficient $\rho_{\theta\theta} = \frac{1}{2}$, under precise public and private signals, then the regulator can assign accurately the expected volume and sets reasonably the expected water price:

$$q_1^* = \frac{a - (1 + \mu_\theta)}{b(1 + \mu_\theta)}, P_1^* = 1 + \mu_\theta \quad (4.15)$$

The expected volume and water price are linear functions of the ex post average estimation of the quality of water mains, as $\mu_\theta > -1$. The regulator may delegate the management as long as the quality is estimated to be bad. Otherwise, if the quality is estimated to be good, then it can manage itself the service in order to keep water prices at a low-level. Now we analyze when it is favorable for an operator

to participate the delegation process by announcing correctly its revised private estimation.

If the correlation of coefficient across private signals is $\rho_{\theta\theta} \geq \frac{1}{2}$, then the expected volume and price of water defined in (4.15) can deviate from μ_θ because of either $\tau_{\Delta\theta_i} > \tau_{\hat{\theta}}$ or $\tau_{\hat{\theta}} < \tau_{\Delta\theta_i}$. Thus, the regulator may inefficiently allocate the volume to an operator and set the price. This leads us to the following main results in Table 2.

Table 2: The precision of estimation without information acquisition

	δ_1	δ	q_1^*	P_1^*	$var(q_1^*)$	$var(P_1^*)$
$\tau_{\hat{\theta}} \equiv \tau_{\Delta\theta_i} \rightarrow +\infty$	0	0	$\frac{a-(1+\mu_\theta)}{b(1+\mu_\theta)}$	$(1+\mu_\theta)$	0	0
$\tau_{\Delta\theta_i} > \tau_{\hat{\theta}}$	1	1	$\frac{a-(1+\hat{\theta}_i)}{b(1+\hat{\theta}_i)}$	$(1+\hat{\theta}_i)$	$(\frac{a}{b})^2 \frac{\rho_{\theta\theta} + d^2(1-\rho_{\theta\theta})}{(1+\mu_\theta)^4 \rho_{\theta\theta} \tau_{\hat{\theta}}}$	$\frac{\rho_{\theta\theta} + d^2(1-\rho_{\theta\theta})}{\rho_{\theta\theta} \tau_{\hat{\theta}}}$
$\tau_{\hat{\theta}} > \tau_{\Delta\theta_i}$	0	$\frac{1}{d}$	$\frac{a-1}{b(1+\mu_\theta)} - \frac{1}{b(1+\mu_\theta)} \hat{\theta}_i$	$1 + \tilde{\theta}_i$	$\frac{1}{b^2(1+\mu_\theta)^2} \left(\frac{1}{(1-\rho_{\theta\theta})\tau_{\Delta\theta_i}} \right)$	$\frac{1}{(1-\rho_{\theta\theta})\tau_{\Delta\theta_i}}$
$\tau_{\hat{\theta}} \equiv \tau_{\Delta\theta_i} \rightarrow 0$	$\frac{1}{1+d^2}$	$\frac{1+d}{1+d^2}$	$\frac{(1+d^2)[a-(1+\mu_\theta)]-(1+d)[\hat{\theta}_i-\mu_\theta]}{b[(1+d^2)(1+\mu_\theta)+[\hat{\theta}_i-\mu_\theta]}$	$(1+\mu_\theta) + \frac{1+d}{1+d^2} [\hat{\theta}_i - \mu_\theta]$	$\frac{\tau_{\Delta\theta_i}(1+d^2)[a-(1+\mu_\theta)]^2+(1+d)^2}{b^2(1+d^2)^2[(1+\mu_\theta)]^4\tau_{\Delta\theta_i}^2}$	$\frac{(1+d)^2}{(1+d^2)\tau_{\Delta\theta_i}}$

Proposition 2. For a given precision of public signal, if there is an increase in the precision of idiosyncratic estimation, so that $\tau_{\Delta\theta_i} > \tau_{\hat{\theta}}$ and $\rho_{\theta\theta} \in]\frac{1}{2}, 1]$, then the relative precision of private signal is:

$\lim_{\tau_{\Delta\theta_i} \rightarrow +\infty} \delta_1 = 1$, and the relative total precision is: $\lim_{\tau_{\Delta\theta_i} \rightarrow +\infty} \delta = 1$. The dispersion of the expected volume is:

$$var(q_1^*) = \left(\frac{a}{b}\right)^2 \frac{\rho_{\theta\theta} + d^2(1-\rho_{\theta\theta})}{(1+\mu_\theta)^4 \rho_{\theta\theta} \tau_{\hat{\theta}}}, \quad (4.16)$$

and the dispersion of the expected water price is:

$$var(P_1^*) = \frac{\rho_{\theta\theta} + d^2(1-\rho_{\theta\theta})}{\rho_{\theta\theta} \tau_{\hat{\theta}}}. \quad (4.17)$$

■ See Appendix.

The first part of Proposition 2 says that an increase in the precision of the idiosyncratic signal improves either the precision of private signal δ_1 or the total precision δ . In this case, a precise $\hat{\theta}_i$ sends more information to the regulator. Moreover, the precision of idiosyncratic signal increases the correlation coefficient across operators' private signals, so that $\rho_{\theta\theta} \rightarrow 1$. If an operator reports correctly its revised private estimation, then the regulator can learn more about the quality through $\hat{\theta}_i$ and $\rho_{\theta\theta}$. Therefore, from proposition 2, the expected volume of water distribution decreases with δ_1 and δ in equations (4.11), whereas the expected water price is increasing in δ in equation (4.13).

The second part of Proposition 2 states that the precision of the idiosyncratic signal makes the expected volume and price deviate from the average estimation because an operator relies more on its idiosyncratic signal in $\hat{\theta}_i$. It is worth noting that the expected volume and price depends proportionally on the dispersion of $\hat{\theta}_i$ measured $[\hat{\theta}_i - \mu_\theta]$. And equation (4.16) and (4.17) indicate that the dispersion of

the expected volume and of the price is increasing in $d \in [0, 1]$. The regulator may inaccurately estimate the volume of water distribution, and thus the water price.

However, these dispersion can be reduced by the correlation coefficient $\rho_{\theta\theta}$, the precision of public signal $\tau_{\hat{\theta}}$. Firstly, if $\rho_{\theta\theta}$ approaches 1, for a given precision of public signal, then the dispersion of the expected volume and price is decreasing in a high value of $\rho_{\theta\theta}$. Then, the precision of public signal depends on the amount of ex post information the regulator has on the quality of water mains. When learning from $\hat{\theta}_i$ and $\rho_{\theta\theta}$, the regulator can estimate more accurately the expected volume and water price in the negotiation with an operator.

Proposition 3. For a given precision of private signal, if there is an increase in the precision of public signal, so that $\tau_{\hat{\theta}} > \tau_{\Delta\theta_i}$ and $\rho_{\theta\theta} \in [0, \frac{1}{2}[$, then the relative precision of private signal is: $\lim_{\tau_{\hat{\theta}} \rightarrow +\infty} \delta_1 = 0$, and the relative total precision is: $\lim_{\tau_{\hat{\theta}} \rightarrow +\infty} \delta = \frac{1}{d}$. The dispersion of the expected volume is:

$$\text{var}(q_1^*) = \frac{1}{b^2(1 + \mu_\theta)^2(1 - \rho_{\theta\theta})\tau_{\Delta\hat{\theta}_i}}, \quad (4.18)$$

and the dispersion of the expected water price is:

$$\text{var}(P_1^*) = \frac{1}{(1 - \rho_{\theta\theta})\tau_{\Delta\hat{\theta}_i}}. \quad (4.19)$$

■ See Appendix.

The first part of Proposition 3 states that if the public signal is precise, then the relative total precision about the quality δ increases with the information structure d in the signal $\hat{\theta}_i$. Though the private signal is less precise than the public signal, a high weight $d \in]0, 1]$ put on the idiosyncratic signal makes $\hat{\theta}_i$ sends more noisy information to the regulator. In this case, from equation (4.11), we find that the expected volume of water distribution is decreasing in the average estimation $\mu_\theta > -1$, but the expected water prices are increasing in the average estimation μ_θ .

Moreover, when $\tau_{\Delta\theta_i} < \tau_{\hat{\theta}}$ and $\rho_{\theta\theta} \in [0, \frac{1}{2}[$, the expected volume depends also negatively on the private signal, and the expected water price becomes a linear function of the private signal. Hence, the second part of Proposition 3 indicates that the dispersion of the expected volume and price increases with the correlation coefficient $\rho_{\theta\theta} \in [0, \frac{1}{2}[$. In fact, there is less correlation across the private signals. Even though the total precision of signals increases, the regulator cannot observe with certainty the precision of idiosyncratic signal through $\rho_{\theta\theta}$. Hence, the regulator is influenced by the noisy idiosyncratic information and cannot accurately assign the expected volume and fix the price.

However, equation (4.18) and (4.19) show that these dispersion can be reduced by an increase in the precision of the idiosyncratic signal. The precise idiosyncratic signal makes each operator rely more on its own private signal than the precise public signal. Thus, the signal $\hat{\theta}_i$ can send less noisy information and the regulator improve its revised public estimation.

Now we consider that both public and private signals are imprecise, so that $\tau_{\Delta\theta_i} = \tau_{\hat{\theta}} \rightarrow 0$, $\rho_{\theta\theta} = \frac{1}{2}$. An operator can choose to report its revised estimation by putting some weight on its idiosyncratic signal

in $\hat{\theta}_i$. But, this strengthens the ex post biased estimation $[\hat{\theta}_i - \mu_\theta]$ (see Table 2). The regulator can be led to inaccurately allocate the expected volume of water and set the price. It is quite clear from Table 2 that the dispersion of the volume and the price is increasing with the imprecise signals and d .

We observe that without information acquisition, an operator participates in the delegation process when it has more precise private estimation than the public estimation about the quality of water mains. Needing more precise private estimation gives incentives to an operator to acquire additional information. However, additional information may misguide the operator's inference about the fundamental - the quality of the networks. It takes an operator away from its correct prior mean in its revised private estimation. Therefore, we need to investigate the effects the precision of disclosure may have on information acquisition.

4.2.5 The precision of estimation with information acquisition

Through information acquisition, an operator can choose to report its misleading revised estimation to the regulator. Equations (4.12) and (4.14) show that information acquisition affects the expected volume and price of water. We recall that from Table 1 an operator tends to over(under)-estimate the bad quality or over(under)-estimate the good quality. These misleading estimations lead us to the following respective mains results.

Table 3: The precision of estimation with information acquisition

	Overestimation of the bad quality or Underestimation of the good quality $\mathbb{E}[h_\theta] < 0$			
	δ_1	δ	$q_2^*(\delta, \delta_1, \mathbb{E}[h_\theta])$	$P_2^*(\delta, \delta_1, \mathbb{E}[h_\theta])$
$\tau_{\Delta\theta_i} \rightarrow +\infty$ $\tau_{\hat{\theta}} \rightarrow 0$	1	1	$\frac{a-(1+\hat{\theta}_i)-\mathbb{E}[h_\theta]}{b(1+\hat{\theta}_i)} > q_1^*$	$(1 + \hat{\theta}_i) + \mathbb{E}[h_\theta] < P_1^*$
$\tau_{\Delta\theta_i} \rightarrow +\infty$ $\tau_{\hat{\theta}} \rightarrow +\infty$	0	0	$\frac{a-(1+\mu_\theta)-\mathbb{E}[h_\theta]}{b(1+\mu_\theta)} > q_1^*$	$(1 + \mu_\theta) + \mathbb{E}[h_\theta] < P_1^*$
$\tau_{\Delta\theta_i} \rightarrow 0$ $\tau_{\hat{\theta}} \rightarrow 0$	$\frac{1}{1+d^2}$	$\frac{1+d}{1+d^2}$	$\frac{(1+d^2)[a-(1+\mu_\theta)]-(1+d)[\hat{\theta}_i-\mu_\theta]-\mathbb{E}[h_\theta]}{b[(1+d^2)(1+\mu_\theta)+[\hat{\theta}_i-\mu_\theta]]} > q_1^*$	$(1 + \mu_\theta) + \frac{1+d}{1+d^2} [\hat{\theta}_i - \mu_\theta] + \mathbb{E}[h_\theta] < P_1^*$
$\tau_{\Delta\theta_i} \rightarrow 0$ $\tau_{\hat{\theta}} \rightarrow +\infty$	0	$\frac{1}{d}$	$\frac{a-(1+\tilde{\theta}_i)-\mathbb{E}[h_\theta]}{b(1+\mu_\theta)} > q_1^*$	$(1 + \tilde{\theta}_i) + \mathbb{E}[h_\theta] < P_1^*$

Table 3 shows that whatever are precise the public and private signals, if an operator overestimates the bad quality or underestimates the good quality ($\mathbb{E}[h_\theta] < 0$), then this misleading estimation imposes a negative effect on the revised private signal sent to the regulator. Hence, the expected volume of

distributed water assigned to the operator is higher than if it had not acquired any information. Thus, the expected prices are reduced.

By contrast, if an operator underestimates the bad quality or overestimates the good quality ($\mathbb{E}[h_\theta] > 0$), then this misleading estimation imposes a positive effect on the revised private signal to the regulator. Therefore, the expected volume assigned to the operator becomes lower than if it had not acquired any information, and the prices increase. In this case, the different volumes and the prices of water are illustrated in the following Table 4.

Table 4: The precision of estimation with information acquisition

	Underestimation of the bad quality or Overestimation of the good quality $\mathbb{E}[h_\theta] > 0$			
	δ_1	δ	$q_2^*(\delta, \delta_1, \mathbb{E}[h_\theta])$	$P_2^*(\delta, \delta_1, \mathbb{E}[h_\theta])$
$\tau_{\Delta\theta_i} \rightarrow +\infty$ $\tau_{\tilde{\theta}} \rightarrow 0$	1	1	$\frac{a-(1+\tilde{\theta}_i)-\mathbb{E}[h_\theta]}{b(1+\tilde{\theta}_i)} < q_1^*$	$(1 + \tilde{\theta}_i) + \mathbb{E}[h_\theta] > P_1^*$
$\tau_{\Delta\theta_i} \rightarrow +\infty$ $\tau_{\tilde{\theta}} \rightarrow +\infty$	0	0	$\frac{a-(1+\mu_\theta)-\mathbb{E}[h_\theta]}{b(1+\mu_\theta)} < q_1^*$	$(1 + \mu_\theta) + \mathbb{E}[h_\theta] > P_1^*$
$\tau_{\Delta\theta_i} \rightarrow 0$ $\tau_{\tilde{\theta}} \rightarrow 0$	$\frac{1}{1+d^2}$	$\frac{1+d}{1+d^2}$	$\frac{(1+d^2)[a-(1+\mu_\theta)]-(1+d)[\tilde{\theta}_i-\mu_\theta]-\mathbb{E}[h_\theta]}{b[(1+d^2)(1+\mu_\theta)+[\tilde{\theta}_i-\mu_\theta]]} < q_1^*$	$(1 + \mu_\theta) + \frac{1+d}{1+d^2} [\tilde{\theta}_i - \mu_\theta] + \mathbb{E}[h_\theta] > P_1^*$
$\tau_{\Delta\theta_i} \rightarrow 0$ $\tau_{\tilde{\theta}} \rightarrow +\infty$	0	$\frac{1}{d}$	$\frac{a-(1+\tilde{\theta}_i)-\mathbb{E}[h_\theta]}{b(1+\mu_\theta)} < q_1^*$	$(1 + \tilde{\theta}_i) + \mathbb{E}[h_\theta] > P_1^*$

Comparing the different expected volumes and prices of water with respect to the precision of public and private signals in Table 3 and Table 4, we reach the following result.

Proposition 4 . An increase in the precision of private or public signal can weaken the effects of additional information on the ex post biased estimation. For a given weight $d \in]0, 1]$ put on the idiosyncratic signal by an operator, whatever is the misleading estimation $\mathbb{E}[h_\theta] \leq 0$ the regulator can assign the different level of the expected volume,

$$q_2^*\{\tau_{\Delta\theta_i} > \tau_{\tilde{\theta}}\} < q_2^*\{\tau_{\tilde{\theta}} \equiv \tau_{\Delta\theta_i} \rightarrow 0\} < q_2^*\{\tau_{\tilde{\theta}} > \tau_{\Delta\theta_i}\} < q_2^*\{\tau_{\tilde{\theta}} \equiv \tau_{\Delta\theta_i} \rightarrow +\infty\}, \quad (4.20)$$

and price,

$$P_2^*\{\tau_{\tilde{\theta}} \equiv \tau_{\Delta\theta_i} \rightarrow 0\} > P_2^*\{\tau_{\Delta\theta_i} > \tau_{\tilde{\theta}}\} > P_2^*\{\tau_{\tilde{\theta}} > \tau_{\Delta\theta_i}\} > P_2^*\{\tau_{\tilde{\theta}} \equiv \tau_{\Delta\theta_i} \rightarrow +\infty\}. \quad (4.21)$$

■ See Appendix.

Through the signal $\hat{\theta}_i$, the misleading estimations reported by an operator may strengthen the ex post biased estimation $[\hat{\theta}_i - \mu_\theta]$. The regulator thus tolerates a level of water leakages in the expected volume of distributed water. By contrast, when the misleading estimation may attenuate the ex post biased estimation, then the regulator reduces the tolerated water leakages in the expected volume. In addition, with a considerable volume of distributed water, the marginal operational cost linking to the maintenance of the network of mains is low enough to lead the regulator to reduce the prices. Nevertheless, with a restricted volume of distributed water, the prices augment in order to cover the cost of improving the quality of the networks.

The expected volume and prices are affected not only by the precision of signals, but also by the mean of additional information. We recall that on the basis of the signal $\hat{\theta}_i$, an operator's additional information is independent of its prior private signal. Hence, the correlation coefficient $\rho_{\theta\theta}$ measures also the relative contribution of the additional information to an operator's private signal. It is given by:

$$\rho_{\theta\theta} = \frac{\sigma_{\tilde{\theta}}^2 + (\mathbb{E}[h_\theta])^2}{\sigma_{\tilde{\theta}}^2 + \sigma_{\Delta\theta_i}^2}, \quad (4.22)$$

and the relation relative precision of public and private signal is given by:

$$\frac{\tau_{\tilde{\theta}}}{\tau_{\Delta\theta_i}} = \frac{(1 - \rho_{\theta\theta})}{(\rho_{\theta\theta} - \tau_{\Delta\theta_i} (\mathbb{E}[h_\theta])^2)}, \quad (4.23)$$

where the mean of additional information depends on the precision of idiosyncratic signal, as $\mathbb{E}[h_\theta] \in] - \sqrt{\frac{1}{\tau_{\Delta\theta_i}}}, \sqrt{\frac{1}{\tau_{\Delta\theta_i}}} [$.

When $\rho_{\theta\theta} \in] \frac{1}{2} + \frac{1}{2}\tau_{\Delta\theta_i} (\mathbb{E}[h_\theta])^2, 1 [$, we note that $\tau_{\Delta\theta_i} > \tau_{\tilde{\theta}}$. In the limit case, as $\tau_{\Delta\theta_i} \rightarrow +\infty$, we find that $\mathbb{E}[h_\theta] \rightarrow 0$. The more precise private signal is, the less additional information is acquired by an operator. In addition, the coefficient correlation plays a role of public information, from which the regulator can learn about the quality of water infrastructure. In addition, the precise idiosyncratic signal may weaken the effect of misleading estimation on the beliefs of the regulator. As a result, the expected volume can be reduced to the lowest level, as $q_2^* = \frac{a - (1 + \hat{\theta}_i) - \mathbb{E}[h_\theta]}{b(1 + \hat{\theta}_i)}$, and the expected water price is negotiated to be a high level, as $P_2^* = (1 + \hat{\theta}_i) + \mathbb{E}[h_\theta]$. But, this price is lower than the price set in the case that both public and private signals are noisy.

Moreover, when $\rho_{\theta\theta} \in] 0, \frac{1}{2} + \frac{1}{2}\tau_{\Delta\theta_i} (\mathbb{E}[h_\theta])^2 [$, we have that $\tau_{\tilde{\theta}} > \tau_{\Delta\theta_i}$. If $\tau_{\Delta\theta_i} \rightarrow 0$, then $\mathbb{E}[h_\theta] \in] -\infty, +\infty [$. An operator tends to acquire information in order to increase the precision of private signal. But, some additional information may increase the ex post biased estimation, as $[\tilde{\theta}_i - \mathbb{E}[\tilde{\theta}_i]]$ because the regulator is influenced by the operator's misleading estimation when learning from the imperfect correlation coefficient. Even with the precise public signal, the regulator may be misguided to tolerate a level of water leakages in the volume of distributed water, and to fix low prices.

Furthermore, when $\rho_{\theta\theta} = \frac{1}{2} + \frac{1}{2}\tau_{\Delta\theta_i} (\mathbb{E}[h_\theta])^2$, we obtain that $\tau_{\tilde{\theta}} = \tau_{\Delta\theta_i}$. If $\tau_{\tilde{\theta}} = \tau_{\Delta\theta_i} \rightarrow +\infty$, then through $\rho_{\theta\theta}$, a small amount of additional information can take both the regulator and an operator away from their correct prior average estimation. In other words, information acquisition generates

a negative effect on the precision of public and private signals. Hence, there is the highest level of volume, as $q_2^* = \frac{a-(1+\mu_\theta)-\mathbb{E}[h_\theta]}{b(1+\mu_\theta)}$ depending on $\mathbb{E}[h_\theta] \leq 0$. Symmetrically, if $\tau_{\hat{\theta}} = \tau_{\Delta\theta_i} \rightarrow 0$, then the more information an operator acquires, the more misleading estimation it makes. The ex post biased estimation $[\hat{\theta}_i - \mathbb{E}[\hat{\theta}_i]]$ increases enough to make the regulator inaccurately to estimate the quality of water mains. As a consequence, the regulator assigns a high level of the volume and prices.

In the regulation case, whether an operator acquires additional information or not, it participates in the delegation as long as $\tau_{\Delta\theta_i} > \tau_{\hat{\theta}}$. Through the weight d , and the coefficient correlation $\rho_{\theta\theta}$, precise private estimation attenuate the ex post biased estimation $[\hat{\theta}_i - \mathbb{E}[\hat{\theta}_i]]$. Hence, the regulator can assign correctly the expected volume to the operator, and the price of water is negotiated and fixed at the beginning of delegation. When $\tau_{\Delta\theta_i} \leq \tau_{\hat{\theta}}$, the regulator delegates the management of water services by tolerating a level of water leakages in the distributed water. If an operator does not acquire information, then it faces a low price. By contrast, if an operator acquires additional information, then it can negotiate a high price with the regulator.

4.3 Contracts with Information Structures

When an operator reports honestly its revised estimation about the quality, the regulator applies the regulation policy on the basis of revised public and private signals. An operator can decide whether or not to participate in the delegation with respect to its precise private signal. The regulator tends to adjust its regulation policy according to the precise public signal. Combined with information structure, information acquisition can affect the expected volume and prices of water defined in the contracts. As long as the additional information acquired by an operator is truthfully announced to the regulator, the latter is able to maintain all types of operators at their zero status-quo profit level. However, this is no longer possible under incomplete information when an operator does not report honestly its additional information anymore.

From Figure 2, the regulation equilibrium B is preferred to A by operators. If the marginal operational cost curve of an operator is $1 + \mathbb{E}[\tilde{\theta}_i|\hat{\theta}_i]$,¹¹ and it passes through A' , then the operator obtains a positive payoff level instead of a zero payoff level at A . Indeed, for a given expected volume $q_1^*(1 + \mathbb{E}[\tilde{\theta}_i|\hat{\theta}_i])$, at A' , the operator can benefit from the same price as at the equilibrium B . The surface of triangle $A'CF$ is larger than that of triangle ADF due to informational rent measured by triangle $A'GB$. This informational rent is drawn from consumers surplus because of the misleading estimation $\mathbb{E}[h_\theta] > 0$.

If the marginal operational cost curve of an operator is $1 + \mathbb{E}[\tilde{\theta}_i|\hat{\theta}_i]$, and it passes through B' , then the pay off of the operator becomes smaller than it had been at B . For a given expected volume $q_2^*(1 + \mathbb{E}[\tilde{\theta}_i|\hat{\theta}_i])$, at B' , the operator does not reveal its additional information and accepts the same price as at the equilibrium A . The surface of triangle $B'DE$ is smaller than that of triangle BCE due to informational distortion measured by triangle $B'EA$. It is the informational rent that is given up by the

¹¹With $\mu_\theta \neq 0$, the conditional expectations, such as $\mathbb{E}[\tilde{\theta}_i|\hat{\theta}_i]$ and $\mathbb{E}[\tilde{\theta}_i|\hat{\theta}_i]$, are given by a convex combination of the signal $\hat{\theta}_i$ and prior mean μ_θ .

operator as soon as it misreports its marginal cost to the regulator.

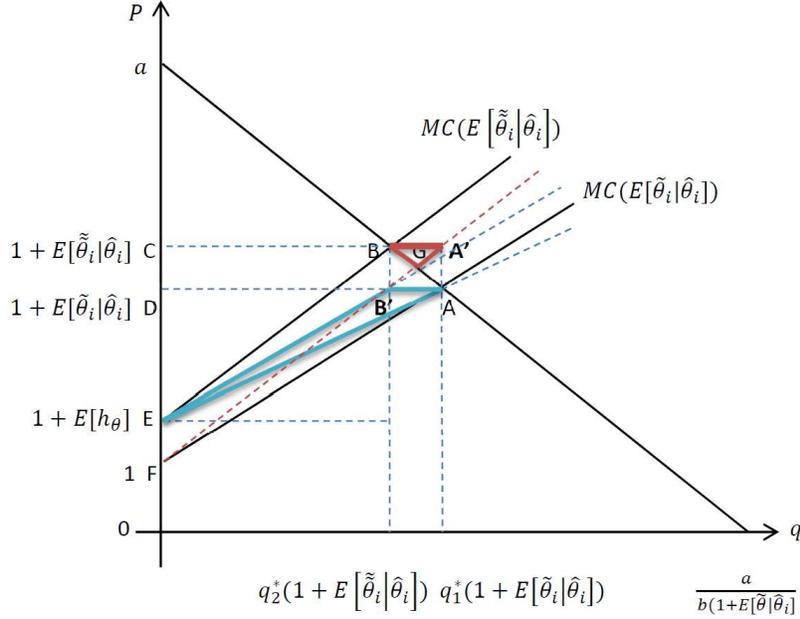


Figure 2: Truthful estimation revelation (A, B)

Hence, when the regulator cannot observe that an operator acquires information about the quality of water services, the truthful estimation revelation contracts (A, B) cannot be implemented under asymmetric information.

Now, under asymmetric information, we assume that $q_1(\mathbb{E}[\tilde{\theta}_i | \hat{\theta}_i]) \equiv \tilde{q}_1$, $T_1(\mathbb{E}[\tilde{\theta}_i | \hat{\theta}_i]) \equiv \tilde{T}_1$, and $q_2(\mathbb{E}[\tilde{\theta}_i | \hat{\theta}_i]) \equiv \tilde{q}_2$, $T_2(\mathbb{E}[\tilde{\theta}_i | \hat{\theta}_i]) \equiv \tilde{T}_2$. The menu of contracts $\left\{ \left(\tilde{q}_1, \tilde{T}_1 \right), \left(\tilde{q}_2, \tilde{T}_2 \right) \right\}$ corresponding to (A, B) is not incentive compatible. This leads to have definition 2:

Definition 2: For a given expected price depending on the revised public estimation, an operator has a revised estimate $\mathbb{E}[\tilde{\theta}_i | \hat{\theta}_i]$ and reports it truthfully if its expected profit $\tilde{\pi}_1 \left(\mathbb{E}[\tilde{\theta}_i | \hat{\theta}_i], \tilde{q}_1 \right)$ is weakly preferred to $\tilde{\pi}_1 \left(\mathbb{E}[\tilde{\theta}_i | \hat{\theta}_i], \tilde{q}_2 \right)$. An operator has a revised estimate $\mathbb{E}[\tilde{\theta}_i | \hat{\theta}_i]$ and reports it truthfully if its expected profit $\tilde{\pi}_2 \left(\mathbb{E}[\tilde{\theta}_i | \hat{\theta}_i], \tilde{q}_2 \right)$ is weakly preferred to $\tilde{\pi}_2 \left(\mathbb{E}[\tilde{\theta}_i | \hat{\theta}_i], \tilde{q}_1 \right)$. We define that the menu of contracts $\left\{ \left(\tilde{q}_1, \tilde{T}_1 \right), \left(\tilde{q}_2, \tilde{T}_2 \right) \right\}$ is incentive compatible.

Under revised private estimation conditional on the signal $\hat{\theta}_i$, the expected volume of water distributed by an operator satisfies the following Expected Incentive Compatibility Constraint (henceforth, “EIC”) with respect to definition 2

$$\begin{aligned} & \left[a - b \left(1 + \mathbb{E}[\tilde{\theta} | \hat{\theta}_i] \right) \tilde{q}_1 \right] \left(1 + \mathbb{E}[\tilde{\theta}_i | \hat{\theta}_i] \right) \tilde{q}_1 - \left(1 + \mathbb{E}[\tilde{\theta}_i | \hat{\theta}_i] \right) \tilde{q}_1 \\ & \geq \left[a - b \left(1 + \mathbb{E}[\tilde{\theta} | \hat{\theta}_i] \right) \tilde{q}_2 \right] \left(1 + \mathbb{E}[\tilde{\theta}_i | \hat{\theta}_i] \right) \tilde{q}_2 - \left(1 + \mathbb{E}[\tilde{\theta}_i | \hat{\theta}_i] \right) \tilde{q}_2. \end{aligned} \quad (4.24)$$

When an operator has more information about the quality than the regulator, it tends to misreport

its revised estimation about the marginal cost in order to get more profit. Equation (4.24) indicates that: when an operator has an expected operational cost $1 + \mathbb{E}[\tilde{\theta}_i|\hat{\theta}_i]$, for a given expected price fixed by the regulator, the volume of distributed water depends on its private revised signal $\mathbb{E}[\tilde{\theta}_i|\hat{\theta}_i]$, and the operational profit it gets is weakly higher than if it had reported $\mathbb{E}[\tilde{\theta}_i|\hat{\theta}_i]$. By contrast, when an operator has an expected operational cost $1 + \mathbb{E}[\tilde{\theta}_i|\hat{\theta}_i]$, by accepting the fixed expected price, the expected volume depends on $\mathbb{E}[\tilde{\theta}_i|\hat{\theta}_i]$, and the operational profit it gets is weakly higher than if it had reported $\mathbb{E}[\tilde{\theta}_i|\hat{\theta}_i]$. Indeed, an operator has two choices: it sends its revised private signal without acquiring information, or it sends its revised private signal with acquiring information. Expected Incentive Compatibility Constraint (4.24) can incite an operator to correctly report its choice.

Moreover, for a menu of contracts to be accepted, the regulator guarantees to an operator the non-null profits who announces its revised private estimation. Henceforth, we have Expected Individual Rationality Constraint (henceforth, “EIR”)

$$\begin{aligned} & \tilde{\pi}_2 \left(\mathbb{E}[\tilde{\theta}_i|\hat{\theta}_i], \tilde{q}_2 \right) = \\ & \left[a - b \left(1 + \mathbb{E}[\tilde{\theta}_i|\hat{\theta}_i] \right) \tilde{q}_2 \right] \left(1 + \mathbb{E}[\tilde{\theta}_i|\hat{\theta}_i] \right) \tilde{q}_2 - \left(1 + \mathbb{E}[\tilde{\theta}_i|\hat{\theta}_i] \right) \tilde{q}_2 \geq 0. \end{aligned} \quad (4.25)$$

A menu of contracts is incentive compatible if it satisfies the conditions from (4.24)–(4.25). In particular, from (4.25), we get

$$| \mathbb{E}[\tilde{\theta}_i|\hat{\theta}_i] - \mathbb{E}[\tilde{\theta}_i|\hat{\theta}_i] | (\tilde{q}_1 - \tilde{q}_2) \geq 0. \quad (4.26)$$

Since $| \mathbb{E}[\tilde{\theta}_i|\hat{\theta}_i] - \mathbb{E}[\tilde{\theta}_i|\hat{\theta}_i] | \equiv | \mathbb{E}[h_\theta] |$, from (4.26), we have $\tilde{q}_1 > \tilde{q}_2$. If (4.26) is hold, then from (4.24) to (4.26), we can obtain the inequality

$$\tilde{\pi}_1 \left(\mathbb{E}[\tilde{\theta}_i|\hat{\theta}_i], \tilde{q}_1 \right) \geq \tilde{\pi}_2 \left(\mathbb{E}[\tilde{\theta}_i|\hat{\theta}_i], \tilde{q}_2 \right) + \left(| \mathbb{E}[\tilde{\theta}_i|\hat{\theta}_i] - \mathbb{E}[\tilde{\theta}_i|\hat{\theta}_i] | \right) \tilde{q}_2. \quad (4.27)$$

By computing the benefit of any menu of contracts, the expected social welfare of the regulator in (4.1) can be rewritten in expected terms. There exists a probability $\omega \in [0, 1]$ that an operator may honestly choose the contract $\{ \tilde{q}_1, \tilde{T}_1 \}$, and a probability $(1 - \omega)$ that an operator may honestly choose the contract $\{ \tilde{q}_2, \tilde{T}_2 \}$. Therefore

$$\begin{aligned} & \underset{\{ \tilde{q}_1, \tilde{q}_2 \}}{\text{Maximum}} \left\{ \omega \left[SC(\tilde{q}_1) + \lambda \tilde{\pi}_1 \left(\mathbb{E}[\tilde{\theta}_i|\hat{\theta}_i], \tilde{q}_1 \right) \right] + (1 - \omega) \left[SC(\tilde{q}_2) + \lambda \tilde{\pi}_2 \left(\mathbb{E}[\tilde{\theta}_i|\hat{\theta}_i], \tilde{q}_2 \right) \right] \right\}, \\ & \text{subject to} \\ & (4.24)(EIC), \\ & (4.25)(EIR). \end{aligned} \quad (4.28)$$

Here, it is worth noting that using the constraints (4.24), and (4.25), we have

$$\begin{aligned} \left(|\mathbb{E}[\tilde{\theta}_i|\hat{\theta}_i] - \mathbb{E}[\tilde{\theta}_i|\hat{\theta}_i] | \right) \tilde{q}_2 &\leq \tilde{\pi}_1 \left(\mathbb{E}[\tilde{\theta}_i|\hat{\theta}_i], \tilde{q}_1 \right) - \tilde{\pi}_2 \left(\mathbb{E}[\tilde{\theta}_i|\hat{\theta}_i], \tilde{q}_2 \right) \\ &\leq \left(|\mathbb{E}[\tilde{\theta}_i|\hat{\theta}_i] - \mathbb{E}[\tilde{\theta}_i|\hat{\theta}_i] | \right) \tilde{q}_1. \end{aligned} \quad (4.29)$$

This is a simplified inequality structure in the framework of Baron and Myerson (1982). If we divide (4.29) by $\left(|\mathbb{E}[\tilde{\theta}_i|\hat{\theta}_i] - \mathbb{E}[\tilde{\theta}_i|\hat{\theta}_i] | \right)$ and take the limit as $\mathbb{E}[\tilde{\theta}_i|\hat{\theta}_i] \rightarrow \mathbb{E}[\tilde{\theta}_i|\hat{\theta}_i]$, we obtain

$$\tilde{\pi}'_1 \left(\mathbb{E}[\tilde{\theta}_i|\hat{\theta}_i], \tilde{q}_1 \right) = -\tilde{q}_1, \quad (4.30)$$

for almost all $\mathbb{E}[\tilde{\theta}_i|\hat{\theta}_i]$ in $\Theta = [\theta^l, \theta^h]$. A menu of contracts proposed by the regulator should enable an operator, who acquires information, to reach its status-quo profit level. If an operator does not acquire information, then this menu of contracts gives it incentives to participate in the delegation. Therefore, we analyze the effects of the precision of disclosure on the contract solutions.

4.3.1 Expected individual rationality constraint

Analyzing the Expected Individual Constraint $\tilde{\pi}_2 \left(\mathbb{E}[\tilde{\theta}_i|\hat{\theta}_i], \tilde{q}_2 \right) \geq 0$, we obtain the expected volume of distributed water as $\tilde{q}_2^* \leq \frac{a-1}{b(1+\mathbb{E}[\tilde{\theta}_i|\hat{\theta}_i])}$, where $a > 1$, and $0 < b < 1$. It is worth noting that for a given revised public estimation, this volume is higher than the expected volume obtained by maximizing the expected profit of an operator type $(\mathbb{E}[\tilde{\theta}_i|\hat{\theta}_i])$ under complete information. In fact, we find that the expected profit $\tilde{\pi}_2$ is increasing and concave in $\tilde{q}_2^* \in]0, \frac{a-1}{2b(1+\mathbb{E}[\tilde{\theta}_i|\hat{\theta}_i])}]$, but it is decreasing and concave in $\tilde{q}_2^* \in]\frac{a-1}{2b(1+\mathbb{E}[\tilde{\theta}_i|\hat{\theta}_i])}, \frac{a-1}{b(1+\mathbb{E}[\tilde{\theta}_i|\hat{\theta}_i])}]$.

In particular, $\tilde{q}_2^* = \frac{a-1}{b(1+\mathbb{E}[\tilde{\theta}_i|\hat{\theta}_i])}$ imposes an upper bound on the expected volume that gives incentives to an operator to announce its revised estimation $\mathbb{E}[\tilde{\theta}_i|\hat{\theta}_i]$.¹² Thus, we focus on investigating how the precision of estimation affects the expected volume chosen by an operator who acquires additional information.

We recall from definition 1 that $\mathbb{E}[\tilde{\theta}_i|\hat{\theta}_i] = d\delta_2\mu_\theta + \delta_1\hat{\theta}_i$. It yields $\tilde{q}_2^* = \frac{a-1}{b(1+d\delta_2\mu_\theta + \delta_1\hat{\theta}_i)}$. This expected volume depends inversely on δ_1, δ_2 , and information structure d . Since \tilde{q}_2^* decreases proportionally with $\hat{\theta}_i$ through δ_1 , the signal $\hat{\theta}_i$ influences an operator type $(\mathbb{E}[\tilde{\theta}_i|\hat{\theta}_i])$'s decision-making whether or not to participate to the delegation, and also its revised private estimation to enable the acceptance of contract. Thus, by according to the precision of signals, different expected volumes can be chosen by an operator type $(\mathbb{E}[\tilde{\theta}_i|\hat{\theta}_i])$ in the menu of contracts. Thus, the following Table 5 illustrates the effects of the precise signals on the expected volume assigned by the regulator. We observe two Bayesian Nash equilibria of the expected volume of distributed water.

¹²For an operator who does not acquire additional information, its expected volume of distributed water satisfies $\tilde{\pi}_1 \left(\mathbb{E}[\tilde{\theta}_i|\hat{\theta}_i], \tilde{q}_1^* \right) \geq 0$, and it is $\tilde{q}_1^* = \frac{a-1}{b(1+\mathbb{E}[\tilde{\theta}_i|\hat{\theta}_i])}$. We find that $\tilde{q}_1^* = \tilde{q}_2^*$.

Table 5: How the precision of estimation affects \tilde{q}_2^*

	$\tau_{\hat{\theta}} \rightarrow +\infty$	$\tau_{\hat{\theta}} \rightarrow 0$
$\tau_{\Delta\theta_i} \rightarrow +\infty$	$\frac{(a-1)}{b(1+\hat{\theta}_i)} ; \frac{(a-1)}{b(1+\mu_\theta)}$	$\frac{(a-1)}{b(1+\hat{\theta}_i)} ; \frac{(a-1)}{b(1+\hat{\theta}_i)}$
$\tau_{\Delta\theta_i} \rightarrow 0$	$\frac{(a-1)}{b(1+\mu_\theta)} ; \frac{(a-1)}{b(1+\mu_\theta)}$	$\frac{(a-1)}{b(1+\mu_\theta)} ; \frac{(a-1)}{b(1+\hat{\theta}_i)}$

Proposition 5 . When $\tau_{\hat{\theta}} > \tau_{\Delta\theta_i}$, the expected volume of Bayesian Nash equilibrium satisfying individual rationality constraint is $\tilde{q}_2^* = \frac{(a-1)}{b(1+\mu_\theta)}$. When $\tau_{\Delta\theta_i} > \tau_{\hat{\theta}}$, the expected volume of Bayesian Nash equilibrium satisfying individual rationality constraint is $\tilde{q}_2^* = \frac{(a-1)}{b(1+\hat{\theta}_i)}$.

■ See Appendix.

The expected volume satisfying individual rationality constraint is in general affected by the precision of disclosure. With information acquisition, if the correlation coefficient across the private signals is $\rho_{\theta\theta} \in]0, \frac{1}{2} + \frac{1}{2}\tau_{\Delta\theta_i} (\mathbb{E}[h_\theta])^2 [$, then we have $\tau_{\hat{\theta}} > \tau_{\Delta\theta_i}$. Though an operator acquires information, the idiosyncratic signal remains noisy and the relative precision of private signal $\delta_1 \rightarrow 0$. But, through $\rho_{\theta\theta}$ and the weight put on the idiosyncratic information d , the public estimation about the quality tends to be more precise, as the relative precision of public signal is $\delta_2 \rightarrow \frac{1}{d}$. The expected volume depends only on prior average estimation μ_θ in equilibrium. Both the regulator and the operator do not deviate from this equilibrium. The operator finds it favorable to accept this expected volume, whatever is the state of the quality estimated by the regulator.

By contrast, if $\rho_{\theta\theta} \in]\frac{1}{2} + \frac{1}{2}\tau_{\Delta\theta_i} (\mathbb{E}[h_\theta])^2, 1[$, then we have $\tau_{\Delta\theta_i} > \tau_{\hat{\theta}}$. More additional information revealed by $\rho_{\theta\theta}$ makes the revised public estimation relatively imprecise, as $\delta_2 \rightarrow 0$. The regulator is taken away from its prior estimation μ_θ . The expected volume depends inversely on the signal $\hat{\theta}_i$ in equilibrium. Indeed, when there is an increase in the precision of idiosyncratic estimation due to information acquisition, as the relative precision of private signal $\delta_1 \rightarrow 1$. Thus, $\rho_{\theta\theta}$ becomes “the ex post common knowledge” sending more information to the regulator. In order to give incentives to an operator type $(\mathbb{E}[\tilde{\theta}_i|\hat{\theta}_i])$ to participate in the delegation process, the regulator assigns the expected volume according to the signal $\hat{\theta}_i$ announced by the operator.

Corollary 1. In Expected Individual Rationality Constraint, the expected volume of water leakage tolerated by the regulator varies with the ex post biased estimation, as $[\hat{\theta}_i - \mathbb{E}[\hat{\theta}_i]]$:

$$q^{loss} = \frac{(a-1)}{b} \left(\frac{[\hat{\theta}_i - \mathbb{E}[\hat{\theta}_i]]}{(1+\hat{\theta}_i)(1+\mu_\theta)} \right). \quad (4.31)$$

■ See Appendix.

An operator who revises its private estimation by acquiring additional information can be incited by this tolerated water leakage and participate in the delegation process. However, when the operator puts more weight d on the idiosyncratic estimation in its signal $\hat{\theta}_i$, the dispersion of water leakage is

increasingly dominated by the imprecise idiosyncratic signal:

$$\text{var} \left(q^{loss} \right) = \frac{(a-1)^2}{b^2(1+\mu_\theta)^4} \left[\frac{1}{\tau_{\hat{\theta}}} + d^2 \frac{1}{\tau_{\Delta\theta_i}} \right]. \quad (4.32)$$

The regulator can reduce this dispersion as long as there is an increase precision in the public signal.

4.3.2 The second-best solutions

Binding Constraints (4.25) and (4.27), and using Constraint (4.29), for a given $\lambda \in [0, 1]$, the regulator's problem (4.28) can be rewritten:

$$\max_{\{\tilde{q}_1, \tilde{q}_2\}} \omega [SC(\tilde{q}_1)] + (1-\omega) [SC(\tilde{q}_2)] + \omega \lambda \mathbb{E}[h_\theta] \tilde{q}_1. \quad (4.33)$$

The expected volume maximizing the regulator's problem is:

$$\tilde{q}_1 = \frac{a \left(\mathbb{E}[\Delta\theta_i | \hat{\theta}_i] - \frac{\lambda}{a} \mathbb{E}[h_\theta] \right)}{b(1 + \mathbb{E}[\tilde{\theta} | \hat{\theta}_i]) \left(1 + \mathbb{E}[\tilde{\theta}_i | \hat{\theta}_i] + \mathbb{E}[\Delta\theta_i | \hat{\theta}_i] \right)}, \quad (4.34)$$

$$\tilde{q}_2 = \frac{a \left(\mathbb{E}[\Delta\theta_i | \hat{\theta}_i] + \mathbb{E}[h_\theta] \right)}{b(1 + \mathbb{E}[\tilde{\theta} | \hat{\theta}_i]) \left(1 + \mathbb{E}[\tilde{\theta}_i | \hat{\theta}_i] + \mathbb{E}[\Delta\theta_i | \hat{\theta}_i] + \mathbb{E}[h_\theta] \right)}. \quad (4.35)$$

where $\mathbb{E}[h_\theta] = [\mu_\theta - g(h_\theta^*)(\mu_\theta - h_\theta)(1 + \mu_\theta)]$. Equations (4.34) and (4.35) depends both on the precision of signals and the misleading estimation. The fact that whether or not \tilde{q}_1 is higher than \tilde{q}_2 is linked to the sign of $\mathbb{E}[h_\theta]$. This misleading estimation may guide the regulator to overestimate the bad quality (underestimate the good quality), as $\mathbb{E}[h_\theta] < 0$. Hence, the regulator assigns a high expected volume to an operator who chooses \tilde{q}_1 , but a low expected volume to an operator if it chooses \tilde{q}_2 .

Since both the expectation of idiosyncratic and public signals are linear in prior estimation μ_θ , the relative precision of private signal δ_1 , and the relative precision of public signal δ_2 . We study the effects of an increase in the relative precision of private signal δ_1 on the expected volumes \tilde{q}_1 and \tilde{q}_2 . By integrating the relative precision of signals into equations (4.34) and (4.35), we have:

$$\tilde{q}_1 = \frac{a \left(\delta_2 \left[\hat{\theta}_i - \mu_\theta \right] - \frac{\lambda}{a} \mathbb{E}[h_\theta] \right)}{b \left[1 + (1 - \delta_1) \mu_\theta + \delta_1 \hat{\theta}_i \right] \left[1 + (1 - \delta) \mu_\theta + \delta \hat{\theta}_i + \delta_2 (\hat{\theta}_i - \mu_\theta) \right]}, \quad (4.36)$$

$$\tilde{q}_2 = \frac{a \left(\delta_2 \left[\hat{\theta}_i - \mu_\theta \right] + \mathbb{E}[h_\theta] \right)}{b \left[1 + (1 - \delta_1) \mu_\theta + \delta_1 \hat{\theta}_i \right] \left[1 + (1 - \delta) \mu_\theta + \delta \hat{\theta}_i + \delta_2 (\hat{\theta}_i - \mu_\theta) + \mathbb{E}[h_\theta] \right]}. \quad (4.37)$$

Proposition 6 . Let denote $k_1 = -\frac{\alpha}{\lambda} \delta_2$ as an operator's strategy, then $K_1 = (1 - k_1) \mu_\theta + k_1 \hat{\theta}_i$ is the Separating Bayesian Equilibrium. When the minimum average information acquisition is above the equilibrium, as $g(h_\theta^*) \geq \frac{1}{(\mu_\theta - h_\theta)(1 + \mu_\theta)} [K_1]$, the expected volume of distributed water in a contract is reducing in an increase precision of private signal.

■ See Appendix.

The regulator may be misguided by $\mathbb{E}[h_\theta]$ and authorizes operators for the different expected volume of distributed water. Nevertheless, for a given weighted precision of public signal $d^2\tau_{\hat{\theta}}$, an increase of idiosyncratic precision allows the regulator to restrict the expected volume. We find that $\frac{\partial \hat{q}_1}{\partial \delta_1} \leq 0$ and $\frac{\partial \hat{q}_2}{\partial \delta_1} \leq 0$, when the relationship between the average information acquisition and the precision of signal is:

$$\frac{1}{(\mu_\theta - h_\theta)(1 + \mu_\theta)} \left(\mu_\theta + \mathbb{E}[\Delta\theta_i | \hat{\theta}_i] \right) \geq g(h_\theta^*) \geq \frac{1}{(\mu_\theta - h_\theta)(1 + \mu_\theta)} [K_1], \quad (4.38)$$

where $K_1 = (1 + \frac{\alpha}{\lambda}\delta_2)\mu_\theta - \frac{\alpha}{\lambda}\delta_2\hat{\theta}_i$. The minimum average information acquisition is above the Separating Bayesian Equilibrium. An operator's strategy is $k_1 = -\frac{\alpha}{\lambda}\delta_2$, and it depends negatively on the relative precision of public signal.

If $\tau_{\Delta\theta_i} > \tau_{\hat{\theta}}$, then an increase of idiosyncratic precision lowers the relative precision of public signal δ_2 , but highers the relative precision of private signal δ_1 . A decrease in δ_2 makes an operator put less weight on the average estimation than that on its signal $\hat{\theta}_i$. Following other operators, an operator finds optimal to rely on its idiosyncratic estimation. This leads operator's actions to be *strategic complements*. As long as the average information acquisition is above the equilibrium, an operator is likely to learn from what other operators learn (Hellwig and Veldkamp, 2009) in order to raise its idiosyncratic precision. But, the ex post biased estimation $\left[\mu_\theta - \frac{\alpha}{\lambda}\mathbb{E}[\Delta\theta_i | \hat{\theta}_i] \right]$ is enlarged by information acquisition. A little more information misleads operators to believe that the quality of water infrastructure is worse than it had been estimated, such that $\mathbb{E}[h_\theta] < 0$. Therefore, there is the information rent represented by $-\frac{\lambda}{\alpha}\mathbb{E}[h_\theta]$. It is left to an operators who does not acquire information.

Moreover, the correlation coefficient across precise private estimation is $\rho_{\theta\theta} \in [\frac{1}{2} + \frac{1}{2}\tau_{\Delta\theta_i} (\mathbb{E}[h_\theta])^2, 1]$. Recall that a high value of $\rho_{\theta\theta}$ plays a role of public information, it signals the state of the quality to the regulator. The more precise is the relative private estimation, the higher is $\rho_{\theta\theta}$. Hence, the expected volume of distributed water assigned to an operator is reduced.

However, the regulator may increase the public choice variables λ in order to restrict the ex post biased estimation. By doing this, it raises the expected volume of water distribution chosen by an operator influenced by the misleading estimation. At the same time, it lowers the expected volume chosen by an operator who acquires additional information. In addition, through the parameter d , the total precision of signals δ approximates to one when $\rho_{\theta\theta} \rightarrow 1$. A high correlation coefficient across operators' private signals enables the overall estimation to be accurate. The parameter d can mitigate the negative effect of the coordination motive, which results from an excessive weight on the private signal under strategic complementarity. We now investigate how the parameter d affects the relative precision of total estimation.

Corollary 2. The maximal relative precision of total estimation:

$$\max_d \{\delta\} = \frac{\rho_{\theta\theta} + d(1 - \rho_{\theta\theta})}{\rho_{\theta\theta} + d^2(1 - \rho_{\theta\theta})}$$

is achieved by the parameter d :

$$d^* \equiv \underset{d}{\operatorname{argmax}}\{\delta\} = \frac{\sqrt{\rho_{\theta\theta}} - \rho_{\theta\theta}}{1 - \rho_{\theta\theta}} < \frac{1}{2}. \quad (4.39)$$

■ See Appendix.

Condition (4.39) shows that the relative precision of total estimation is maximized by the parameter $d^* \in]0, \frac{1}{2}[$. This means that idiosyncratic precision is high enough to enable an operator relies less on its idiosyncratic estimation when other operators acquire more information. Thus, the expected volume chosen by an operator increases in the relative of total estimation, as $\frac{\partial^2 \hat{q}_1}{\partial \delta \partial \delta_1} \geq 0$ and $\frac{\partial^2 \hat{q}_2}{\partial \delta \partial \delta_1} \geq 0$. We remark that in (4.38), the maximum average information acquisition is restricted by the fact that operator's actions become strategic substitutes.

Proposition 7. Let denote $k_2 = \frac{\alpha}{\lambda} \delta$ as an operator's strategy, then $K_2 = (1 - k_2)\mu_\theta + k_2 \hat{\theta}_i$ is the Separating Bayesian Equilibrium. When there is

$$g(h_\theta^*) \leq \frac{1}{(\mu_\theta - h_\theta)(1 + \mu_\theta)} \left(\left(1 + \frac{2a - \lambda}{a} \mu_\theta\right) + \frac{\lambda}{a} [K_2] \right), \quad (4.40)$$

the average information acquisition is under the equilibrium, the expected volume of water distribution in delegation contracts is increasing in a high public estimation, as $\frac{\partial \hat{q}_1}{\partial \delta_2} \geq 0$ and $\frac{\partial \hat{q}_2}{\partial \delta_2} \geq 0$.

■ See Appendix.

For an given idiosyncratic precision, and through the parameter d , an increase of public precision enables δ_2 to be high. If $\tau_{\hat{\theta}} > \tau_{\Delta\theta_i}$, then the relative precision of public signal δ_2 tends to be $\frac{1}{d}$. The relative precision of public signal is high enough to make an operator put less weight on its idiosyncratic estimation in the signal $\hat{\theta}_i$. While accessing to a precise public estimation about the quality of water infrastructure, the regulator assigns a high expected volume of distributed water in order to give incentives to an operator to accept the contract.

An operator's strategy presented by $k_2 = \frac{\alpha}{\lambda} \delta$ depends positively and proportionally on the total precision of signals. At this Separating Bayesian Equilibrium, the operator puts more weight on its signal $\hat{\theta}_i$ when the relative precision of public signal δ_2 increases. Indeed, when $\tau_{\hat{\theta}} > \tau_{\Delta\theta_i}$, the correlation coefficient across private signals is $\rho_{\theta\theta} \in]0, \frac{1}{2} + \frac{1}{2} \tau_{\Delta\theta_i} (\mathbb{E}[h_\theta])^2 [$. It may send little information between operators and the regulator. Since the average information acquisition is under the Separating Bayesian Equilibrium, an operator is likely to increase its precision of idiosyncratic estimation.

When other operators rely on precise public signal, an operator finds it is favorable to rely more on its own private signal about the quality. It's actions are *strategic substitutes*, and the strategy $k_2 = \frac{\alpha}{\lambda} \delta \equiv \frac{\alpha}{\lambda} (\delta_1 + \delta_2)$ depends also positively on the relative precision of private signal δ_1 . Under the competition motive, an operator faces a trade-off between δ_1 and δ_2 .¹³ It can obtain the information rent $|1 + \frac{2a - \lambda}{a} \mu_\theta|$ by deviating from this Separating Bayesian Equilibrium. This information rent depends directly on the average estimation μ_θ . Moreover, the competition motive is strengthened by the correlation coefficient

¹³As seen in Definition 1, the relative precision of private estimation decrease in the precision of public signal $\tau_{\hat{\theta}}$.

of private precision, and it generates both strategic and informational distortions on the fundamental and coordination motives.¹⁴

It is worth remarking that there is some substitutability between the relative precision of public signal and the relative precision of private signal, as $\frac{\partial^2 \tilde{q}_1}{\partial \delta \partial \delta_1} \leq 0$ and $\frac{\partial^2 \tilde{q}_2}{\partial \delta \partial \delta_1} \leq 0$. Even though the relative precision of public signal is high, an operator relies more on its idiosyncratic estimation about the quality. This is the competition motive that dominates the coordination motive. Hence, the expected volume chosen by an operator increases in a high relative precision of public signal. Nevertheless, an increase in the relative precision of private signal restricts this augmentation. Indeed, the more precise is the idiosyncratic estimation, the more information about the quality is sent by $\rho_{\theta\theta}$ to the regulator. The latter finally reduces the level of expected volume authorized to an operator through the contract.

Corollary 3. When $\tau_{\Delta\theta_i} \geq \tau_{\tilde{\theta}}$, there is an informational distortion linked to the misleading estimation.

It is measured by the information rent $|\frac{\lambda}{a}\mathbb{E}[h_\theta]|$ depending on the sign of $\mathbb{E}[h_\theta]$. When $\tau_{\tilde{\theta}} > \tau_{\Delta\theta_i}$, an information rent measured by $|1 + \frac{2a-\lambda}{a}\mu_\theta|$ is drawn from the strategic substitutability.

There are two opposite effects when the regulator raises the public policy variables λ . An information rent $|\frac{\lambda}{a}\mathbb{E}[h_\theta]|$ is given up to an operator who does not acquire information when the misleading estimation is $\mathbb{E}[h_\theta] < 0$. Meanwhile, an operator gets a less rent $|1 + \frac{2a-\lambda}{a}\mu_\theta|$, when it moves away from the precise public estimation by acquiring additional information.

When the average estimation is $\mu_\theta \in]-1, 0[$, there is an overestimation the bad quality, so that $\mathbb{E}[h_\theta] < 0$. We find that an increase in λ generates $|1 + \frac{2a-\lambda}{a}\mu_\theta| < |\frac{\lambda}{a}\mathbb{E}[h_\theta]|$. The reduced level of information distortion due to an operator's strategic behaviors is lower than the increased level of information rent given up to an operator because of the misleading estimation. When the average estimation is $\mu_\theta \in]0, (a-1)[$, there is an underestimate the good quality giving by $\mathbb{E}[h_\theta] < 0$. An augmentation of λ yields $|1 + \frac{2a-\lambda}{a}\mu_\theta| > |\frac{\lambda}{a}\mathbb{E}[h_\theta]|$. Making an operator coordinate with the public signal, the regulator prefers to reduce strategic distortion. Therefore, we find that $\tilde{q}_1 > \tilde{q}_2$. The expected volume assigned to the contracts by the regulator is lower than that allocated in the regulation policy, as $q_2^* > q_1^* > \tilde{q}_1 > \tilde{q}_2$.

On the contrary, when the misleading estimation is $\mathbb{E}[h_\theta] > 0$, the regulator tends to lower λ . An operator gets a more information rent from its strategic behavior than that from the misleading estimation. When the average estimation is $\mu_\theta \in]-1, 0[$, $\mathbb{E}[h_\theta] > 0$ signifies an underestimation of bad quality. When the public estimation is $\mu_\theta \in]0, (a-1)[$, $\mathbb{E}[h_\theta] > 0$ presents an overestimation of good quality. In both of cases, an decrease in λ yields $|1 + \frac{2a-\lambda}{a}\mu_\theta| > |\frac{\lambda}{a}\mathbb{E}[h_\theta]|$. Since the regulator cares for the coordination of an operator's private signal with the public signal, it prefers that an operator type $(\mathbb{E}[\tilde{\theta}_i|\hat{\theta}_i])$ accepts the contract. Hence, $\tilde{q}_2 > \tilde{q}_1$, and $q_1^* > q_2^* > \tilde{q}_2 > \tilde{q}_1$.

¹⁴Cornand and Ferreira (2017) find the same result in their price/quantity games.

4.4 The Second-Best Water Prices

The expected water prices is fixed in the contracts during the negotiation stage. According to an operator's choice, we obtain the expected volume which depends not only on the precision of signals, but also on the strategic decision of acquiring information. We now analyze how the precision of signals affects the prices.

We recall that according to the precision of public and private signals, there are two Bayesian Nash equilibria of the expected volume satisfying the Expected Individual Rationality Constraint. As the prices is fixed by the regulator with respect to the revised public estimation on the basis of the signal $\hat{\theta}_i$, it is worthy noting that the prices is not affected by the additional information in revised private estimation. Indeed, the regulator can revise its public estimation all along with the delegation process, and then the improvement of precision of public estimation reduces informational distortion resulting from an operator's competition motive, which accounts for acquiring information. This issue is explained and tested by Cornand and Heinemann (2014, 2015) in their empirical papers analyzing "the k-levels of reasoning". Therefore, the price is fixed to be one, and it just satisfies Expected Individual Rationality Constraint at these two Bayesian Nash equilibria.

4.4.1 The expected water prices

The prices can be computed with respect to the expected volume of distributed water \tilde{q}_1 in (4.34) and \tilde{q}_2 in (4.35). Thus, we have

$$\tilde{P}_1 = \frac{a(1 + \mathbb{E}[\tilde{\theta}_i|\hat{\theta}_i]) + \lambda\mathbb{E}[h_\theta]}{(1 + \mathbb{E}[\tilde{\theta}_i|\hat{\theta}_i] + \mathbb{E}[\Delta\theta_i|\hat{\theta}_i])}, \quad (4.41)$$

$$\tilde{P}_2 = \frac{a(1 + \mathbb{E}[\tilde{\theta}_i|\hat{\theta}_i]) + a\mathbb{E}[h_\theta]}{(1 + \mathbb{E}[\tilde{\theta}_i|\hat{\theta}_i] + \mathbb{E}[\Delta\theta_i|\hat{\theta}_i] + 2\mathbb{E}[h_\theta])}, \quad (4.42)$$

where $\mathbb{E}[h_\theta] = [\mu_\theta - g(h_\theta^*)(\mu_\theta - h_\theta)(1 + \mu_\theta)]$. As assuming that $\mathbb{E}[h_\theta] < 0$, we find that $\tilde{P}_2 > \tilde{P}_1$. We analyze the effects of revised public and idiosyncratic signals on the prices.

For a given relative precise private estimation δ_1 , if $\tau_{\tilde{\theta}} > \tau_{\Delta\theta_i}$, then the relative precise public signal δ_2 increases. The prices thus decrease with δ_2 . We obtain a relationship between the average information acquisition and the precision of signals:

$$g(h_\theta^*) \leq \frac{1}{(\mu_\theta - h_\theta)(1 + \mu_\theta)} \left((1 + \frac{2a - \lambda}{a}\mu_\theta) + \frac{\lambda}{a} [K_2] \right). \quad (4.43)$$

The condition (4.43) shows that the average information acquisition is always under the Separating Bayesian Equilibrium $K_2 = (1 - k_2)\mu_\theta + k_2\hat{\theta}_i$, at which an operator's actions are *strategic substitutes*, as $k_2 = \frac{a}{\lambda}\delta$. The weight assigned to an operator's signal $\hat{\theta}_i$ is raising with the relative total precision of signals $\delta \equiv \delta_1 + \delta_2$. Moreover, under the competition motive, the correlation coefficient $\rho_{\theta\theta}$ sends less information among all parties. When other operators rely more on the improved public signal, an

operator has more incentives to rely more on its private signal. Hence, the operator tends to acquire additional information in order to improve its private precision. However, through the parameter d in the signal $\hat{\theta}_i$,¹⁵ we find that $\tau_{\hat{\theta}} > \frac{1}{d^2}\tau_{\Delta\theta_i}$. A little improved private precision can contribute to an increase of δ_2 .

The condition (4.43) is the same as (4.40). An operator can get the informational rent $|1 + \frac{2a-\lambda}{a}\mu_\theta|$ due to its strategic behavior. Indeed, its idiosyncratic precision increases not only its relative precision of private signal, but also the relative precision of public signal. The improvement of precision in public signal makes the coordination motive dominate the competition motive. Therefore, the prices decrease with an improved precise public signal, while the expected volume of distributed water increases with it.

By contrast, for a given relative precise public signal δ_2 , if $\tau_{\Delta\theta_i} > \tau_{\hat{\theta}}$, then the relative precise private signal δ_1 increases. The prices are thus increasing in δ_1 . We get the relationship between the information acquisition and the precision of signals:

$$\frac{1}{(\mu_\theta - h_\theta)(1 + \mu_\theta)} \left[\left(1 - \frac{a}{2a-\lambda}\delta_2\right)\mu_\theta + \left(\frac{a}{2a-\lambda}\delta_2\right)\hat{\theta}_i \right] \geq g(h_\theta^*) \geq \frac{1}{(\mu_\theta - h_\theta)(1 + \mu_\theta)} [K_1]. \quad (4.44)$$

The condition (4.44) shows that the average information acquisition is always over the Separating Bayesian Equilibrium $K_1 = (1 - k_1)\mu_\theta + k_1\hat{\theta}_i$, at which an operator's actions are *strategic complements*, as $k_1 = -\frac{a}{\lambda}\delta_2$. When $\tau_{\Delta\theta_i} > \tau_{\hat{\theta}}$, the weight assigned to an operator's signal $\hat{\theta}_i$ increases. Indeed, an increase in the precision of private signal lowers the relative precision of public estimation δ_2 . An operator finds optimal to put more weight on its signal $\hat{\theta}_i$ than the average estimation. In other words, when other operators rely more on their private signal, an operator is also induced to rely more on its own private signal.

Since $\rho_{\theta\theta} \in [\frac{1}{2} + \frac{1}{2}\tau_{\Delta\theta_i}(\mathbb{E}[h_\theta])^2, 1]$, the correlation coefficient across operators' private signals is high enough to convey additional information to an operator, who doesn't acquire information. Liking to know what others know, this operator tends to learn from this additional information. This makes the average information acquisition be above the Separating Bayesian Equilibrium. However, the regulator can improve its public estimation by observing $\rho_{\theta\theta}$. The average information acquisition is thus limited by an increase in the relative precision of public signal.¹⁶ The condition (4.44) shows that a minimum average information acquisition leads the prices to increase in the precise idiosyncratic signal. It is

$$g(h_\theta^*) = \frac{1}{(\mu_\theta - h_\theta)(1 + \mu_\theta)} [K_1]. \quad (4.45)$$

Meanwhile, it is the minimum average information acquisition in condition (4.38), at which, the expected volume of distributed water decreases with the relative precision of private signal. We then investigate the volatility of information acquisition with respect to the precision of signals and the parameter d .

¹⁵As $\delta_2 \equiv \frac{d(1-\rho_{\theta\theta})}{\rho_{\theta\theta}+d^2(1-\rho_{\theta\theta})}$, $\lim_{\rho_{\theta\theta} \rightarrow 0} \delta_2 = \frac{1}{d}$.

¹⁶In the linear conditional expectation $\left[\left(1 - \frac{a}{2a-\lambda}\delta_2\right)\mu_\theta + \left(\frac{a}{2a-\lambda}\delta_2\right)\hat{\theta}_i \right]$, the more precise is δ_2 , the more weight put on the signal $\hat{\theta}_i$.

4.4.2 The volatility of information acquisition

Let's denote $Var[g(h_{\hat{\theta}}^*)] \equiv \frac{1}{(\mu_{\theta}-h_{\theta})^2(1+\mu_{\theta})^2} Var([K_1])$, we get:

$$Var[g(h_{\hat{\theta}}^*)] \equiv \frac{a^2 d^2 \tau_{\hat{\theta}}}{\lambda^2 (\mu_{\theta} - h_{\theta})^2 (1 + \mu_{\theta})^2 [\tau_{\Delta\theta_i} (\tau_{\Delta\theta_i} + d^2 \tau_{\hat{\theta}})]}. \quad (4.46)$$

First, $\frac{\partial Var[g(h_{\hat{\theta}}^*)]}{\partial d} = \frac{2a^2}{\lambda^2 (\mu_{\theta} - h_{\theta})^2 (1 + \mu_{\theta})^2 \tau_{\Delta\theta_i}} \delta_2 \delta_1 > 0$. The more weight put on the idiosyncratic estimation in the signal $\hat{\theta}_i$, the more is the volatility of information acquisition. When $\tau_{\hat{\theta}} > \tau_{\Delta\theta_i}$, the relative precision of private and public signals is decreasing in $d \in [0, 1]$. As the correlation coefficient $\rho_{\theta\theta} \in]0, \frac{1}{2} + \frac{1}{2} \tau_{\Delta\theta_i} (\mathbb{E}[h_{\theta}])^2]$, there is less information sent by $\rho_{\theta\theta}$ to all parties. If an operator puts a high weight on its signal $\hat{\theta}_i$ as the same as other operators, then this operator tends to acquire additional information in order to increase the private precision. Hence, the complementarity between δ_2 and δ_1 generates the volatility of information acquisition.

Then, $\frac{\partial Var[g(h_{\hat{\theta}}^*)]}{\partial \tau_{\Delta\theta_i}} = -\frac{a^2 d^2}{\lambda^2 (\mu_{\theta} - h_{\theta})^2 (1 + \mu_{\theta})^2 \tau_{\Delta\theta_i}^2} \delta_2 [\frac{2}{d} \delta_1 + \delta_2] < 0$, where $d \in [0, 1]$. The volatility of information acquisition is decreasing in the precision of idiosyncratic precision. The economic intuition behind it is that an increase in the idiosyncratic precision can raise the relative precision of private signal. When $\tau_{\Delta\theta_i} > \tau_{\hat{\theta}}$, a high level of the correlation coefficient across operators' private signals plays a role of public information, and, hence, the parameter d biases the observations from the private signal towards the public signal.¹⁷ Therefore, the volatility of information acquisition is limited by an increase in the relative precision of public signal.

Third, $\frac{\partial Var[g(h_{\hat{\theta}}^*)]}{\partial \tau_{\hat{\theta}}} = \frac{a^2 d^2}{\lambda^2 (\mu_{\theta} - h_{\theta})^2 (1 + \mu_{\theta})^2 \tau_{\Delta\theta_i}^2} \delta_1^2 > 0$, where $d \in [0, 1]$. For a given private precision, the volatility of information acquisition is increasing in the public precision. Since an increase in the precision of public signal lowers the relative precision of private signal, as $\frac{\partial \delta_1}{\partial \tau_{\hat{\theta}}} < 0$, an operator is likely to acquire additional information in order to raise its private precision. If all operators do the same thing, then there is a volatility of information acquisition. In addition, we recall that an operator can draw information rent either from the misleading estimation or from its strategic behavior of information learning.¹⁸ In this case, even though $\tau_{\hat{\theta}} > \tau_{\Delta\theta_i}$, an operator may find favorable to rely more on the private signal than the precise public signal. Therefore, there is an increasing volatility of information acquisition, but it is limited by a high precision of idiosyncratic estimation.

5 Screening Policy and the Optimal Menu of Contracts

As an owner of water distribution networks, the regulator must be concern about the water leaks in the network of mains. Up to present, our analyses show that with the information structure $(\tau_{\hat{\theta}}, \tau_{\Delta\theta_i})$, contracts offered by the regulator prevent operators conspiring to misapply their estimation about the

¹⁷If $\frac{\tau_{\Delta\theta_i}}{\tau_{\hat{\theta}}} > d$, then $\frac{\partial \delta_2}{\partial d} > 0$.

¹⁸We consider that the ex post participation rent resulted from informational distortion due to misleading estimation, and the information rent is linked to informational distortion arisen from information learning. Ollier and Thomas (2013) argue an optimal trade-off between the ex post participation rent and the information rent.

quality of water infrastructure. We focus on two situations of the precision of signals: $\tau_{\tilde{\theta}} > \tau_{\Delta\theta_i}$ and $\tau_{\Delta\theta_i} > \tau_{\tilde{\theta}}$ to compare the expected volume of distributed water authorized by the regulator on the basis of revised estimation. Evidence that the regulator extracts more information rent by leaving as less as possible water leakages to an operator, whatever is the type of contracts chosen by the operator. In this section, we formulate these comparisons with respect to the precision of signals, and we summarize the main features of the optimal menu of contracts.

5.1 The Choice of an Operator type $\left(\mathbb{E}[\tilde{\theta}_i|\hat{\theta}_i]\right)$

We analyze whether or not consumers benefit from the volume and price of water negotiated by an operator type $\left(\mathbb{E}[\tilde{\theta}_i|\hat{\theta}_i]\right)$. When this operator chooses \tilde{q}_2 formulated in equation (4.35), then the expected volume benefited by consumers is less than the expected volume \tilde{q}_2^* . The distortion of the volume is linked to information acquisition.

Table 6 shows that \tilde{q}_2 is above or under q_2^* depends on an operator's misleading estimation $\mathbb{E}[h_\theta]$ about the quality of water infrastructures. As the regulator may learn information either from the signal $\hat{\theta}_i$ or from the stage of negotiation, it improves its public estimation all along with the delegation process. An increase in the precision of public signal allows the regulator to reduce informational distortion results from operators' limited levels of reasoning (See Cornand and Heinemann, 2014, 2015; Cornand and Ferreira, 2017).

5.1.1 Precise public signal and imprecise private signal

At $\tau_{\tilde{\theta}} > \tau_{\Delta\theta_i}$, when $0 < \mathbb{E}[h_\theta] < [(a-1)(1+\mu_\theta) + (a-2)\Delta\theta_i]$ and $-1 < \mu_\theta < (a-1)$, we find that,

$$\mathbb{E}[\tilde{q}_2^*] > \mathbb{E}[\tilde{q}_2] > \mathbb{E}[q_2^*]. \quad (5.1)$$

If $\tau_{\tilde{\theta}} \rightarrow +\infty$, then the ex post biased estimation $\frac{1}{a}[\hat{\theta}_i - \mu_\theta]$ depends only on $\Delta\theta_i$. In the contract selection, the volume \tilde{q}_2 increases with $\Delta\theta_i$, while in the regulation, the volume q_2^* decreases with $\Delta\theta_i$. In addition, since an operator overestimates the good quality or underestimates the bad quality, the information distortion linked to $\Delta\theta_i$ is considered the expected level of water leakage in the networks of water mains.

By giving incentives to an operator type $\left(\mathbb{E}[\tilde{\theta}_i|\hat{\theta}_i]\right)$ to accept the contract, the regulator authorizes the expected volume of water distribution \tilde{q}_2^* . Whatever is the operator's private estimation, \tilde{q}_2^* allows it to just cover its operational cost. Moreover, \tilde{q}_2^* is higher than \tilde{q}_2 . The gap between the $\mathbb{E}[\tilde{q}_2^*]$ and $\mathbb{E}[\tilde{q}_2]$ is the expected level of water leakages, which is linked to the misleading estimation about the quality of water infrastructures. Even though $\tau_{\tilde{\theta}} > \tau_{\Delta\theta_i}$, the operator assesses the quality at $\mathbb{E}[h_\theta] > 0$. Thus, the

expected level of water leakage is computed as:

$$\begin{aligned}\mathbb{E}[q^{loss}] &= \mathbb{E}[\tilde{q}_2^*] - \mathbb{E}[\tilde{q}_2] \\ &= \frac{(a-1)(1+\mu_\theta) - \mathbb{E}[h_\theta]}{b(1+\mu_\theta)(1+\mu_\theta + \mathbb{E}[h_\theta])}.\end{aligned}\tag{5.2}$$

If the quality of water infrastructures is overestimated to be good, then the expected water leakages decreases. Indeed, the expected volume of distributed water \tilde{q}_2 enjoyed by consumers is increasing in $\mathbb{E}[h_\theta] > 0$. When an operator type $(\mathbb{E}[\tilde{\theta}_i|\hat{\theta}_i])$ is incited to choose \tilde{q}_2^* , it will be obliged to improve the quality of water infrastructure because it overestimates the good quality of water services. As long as the quality of water services is maintained to be good, consumers benefit from less water leaks in the network of water mains. Although the operator benefits from some ex post participation rent measured as the water leaks linked to its misleading estimation, this rent is reduced with the improvement of service quality.

5.1.2 Precise private signal and imprecise public signal

At $\tau_{\Delta\theta_i} > \tau_{\hat{\theta}}$, when $0 < \mathbb{E}[h_\theta] < \sqrt{a(1+\hat{\theta}_i)} - (1+\hat{\theta}_i)$ and $-1 < \mu_\theta < (a-1)$, we find also that,

$$\mathbb{E}[\tilde{q}_2^*] > \mathbb{E}[q_2^*] > \mathbb{E}[\tilde{q}_2].\tag{5.3}$$

It is worth noting that $\mathbb{E}[\tilde{q}_2^*]$ tends to be the social desirable volume of distributed water when the public and private estimation are not biased. Though the regulator's public signal is imprecise, as $\tau_{\hat{\theta}} < \tau_{\Delta\theta_i}$, the regulator can learn about the state of the quality from a high level of correlation coefficient across operators' private signals when the idiosyncratic signal is precise. This is information learning from the correlation coefficient, which largely analyzed in Vives (1988, 2008, 2011, 2014, 2017) and in the literature of k-levels of reasoning (See Cornand and Heinemann, 2015, 2014). In addition, the regulator tends to use contracts to restrict informational distortion due to operators' misleading estimation about the quality. Information rent requested from an operator is large enough to lead the expected volume in a contract to converge towards the social desirable level. This informational distortion is assumed as the ex post participation rent extracted from the operator, who is obliged to improve the quality of water services as long as it accepts the contract.

When an operator overestimates the good quality or underestimates the bad quality, the regulator offers a contract with \tilde{q}_2^* to it. Thus, the regulator leaves more water leakage than if the operator had revealed truthfully its revised private estimation, as $\mathbb{E}[\tilde{q}_2^*] > \mathbb{E}[q_2^*]$. The operator obtains some ex post participation rent generated by its misleading estimation. Moreover, we remark that both q_2^* and \tilde{q}_2 decrease with the signal $\hat{\theta}_i$. The more precise is idiosyncratic signal, the more information sent by the signal $\hat{\theta}_i$. Hence, the regulator can reduce the water leakage tolerated in the networks of water mains. However, there is always a distortion depending on $\mathbb{E}[h_\theta]$, so that $\mathbb{E}[q^{loss}] = \frac{(a-1)(1+\mu_\theta) - \mathbb{E}[h_\theta]}{b(1+\mu_\theta)(1+\mu_\theta + \mathbb{E}[h_\theta])}$. This level of water leakage is decreasing in $\mathbb{E}[h_\theta]$. Consumers benefit from the fact that an operator must

improve the quality when it underestimates the bad quality or overestimates the good quality.

5.1.3 Screening policy of an operator type $\left(\mathbb{E}[\tilde{\theta}_i|\hat{\theta}_i]\right)$

Both at $\tau_{\tilde{\theta}} > \tau_{\Delta\theta_i}$ and $\tau_{\tilde{\theta}} < \tau_{\Delta\theta_i}$, when $\mathbb{E}[h_\theta] < -(1 + \mu_\theta)$ and $-1 < \mu_\theta < (a - 1)$, we observe that,

$$\mathbb{E}[q_2^*] > \mathbb{E}[\tilde{q}_2^*] > \mathbb{E}[\tilde{q}_2]. \quad (5.4)$$

the regulator applies the screening policy if and only if an operator type $\left(\mathbb{E}[\tilde{\theta}_i|\hat{\theta}_i]\right)$ overestimates the bad quality or underestimates the good quality, as $\mathbb{E}[h_\theta] < -(1 + \mu_\theta)$. If an operator chooses the contract with the volume \tilde{q}_2^* , then the expected volume enjoyed by consumers is less than it had been in the networks. There is a large amount of water leaks in the networks of water mains.

Whatever is the precision of public estimation, the regulator learns about the quality of water infrastructure from operators. At $\tau_{\tilde{\theta}} > \tau_{\Delta\theta_i}$, the relative precision of public estimation depends inversely on d in the signal $\hat{\theta}_i$. The more weight put on idiosyncratic signal, the less precise is the public signal. The regulator may have misguided learning about the quality. On the other side, at $\tau_{\tilde{\theta}} < \tau_{\Delta\theta_i}$, the correlation coefficient across operators' estimation $\rho_{\theta\theta}$ is high, as $\rho_{\theta\theta} \in]\frac{1}{2} + \frac{1}{2}\tau_{\Delta\theta_i}(\mathbb{E}(h_\theta)^2), 1]$. It sends operators' misleading estimation to the regulator. Therefore, the regulator prefers that an operator, who doesn't acquire information, wins the contract. Some information rent is left to this operator if it coordinates its private estimation towards the average estimation. This information rent is linked to information learning and drawn from an operator who acquires additional information.

Under the conditions $-\frac{a-(1+\mu_\theta)}{\lambda} < \mathbb{E}[h_\theta] < -\frac{(a-1)(1+2\mu_\theta)}{\lambda}$ and $-1 < \mu_\theta < 0$, we obtain

$$\begin{aligned} & -\omega\lambda\mathbb{E}[h_\theta]\mathbb{E}[\tilde{q}_1] \geq \\ & (1 - \omega) \{SC(\mathbb{E}[\tilde{q}_2^*]) + \lambda\tilde{\pi}_2(\mathbb{E}[\tilde{q}_2^*])\} \\ & -\omega \{[SC(\mathbb{E}[q_1^*]) - SC(\mathbb{E}[\tilde{q}_1])] + \lambda[\pi_1(\mathbb{E}[q_1^*]) - \tilde{\pi}_1(\mathbb{E}[\tilde{q}_1])]\}. \end{aligned} \quad (5.5)$$

For the probability $0 \leq \omega \leq 1$, the left-hand side of (5.5) represents the expected cost of misleading estimation, which is provoked by giving up information rent to an operator, who does not acquire information. Meanwhile, the right-hand side of (5.5) represents the expected benefit of an operator, who acquires information. It is drawn from transacting with an operator, who does not acquire information, at the second-best level of volume. A screening policy for an operator type $\left(\mathbb{E}[\tilde{\theta}_i|\hat{\theta}_i]\right)$ takes place when its expected benefit is lower than its expected cost. In particular, the regulator extracts information rent by proposing a contract with the volume \tilde{q}_1 to an operator, who does not acquire information. If the regulator decides to authorize some volume of water leaks to this operator by applying $\mathbb{E}[\tilde{q}_1] = \mathbb{E}[q_1^*]$, then (5.5) becomes,

$$-\omega\lambda\mathbb{E}[h_\theta]\mathbb{E}[\tilde{q}_1] \geq (1 - \omega) (SC(\mathbb{E}[\tilde{q}_2^*]) + \lambda\tilde{\pi}_2(\mathbb{E}[\tilde{q}_2^*])). \quad (5.6)$$

By choosing \tilde{q}_2^* , the expected cost of an operator type $\left(\mathbb{E}[\tilde{\theta}_i|\hat{\theta}_i]\right)$ caused by giving up information rent to an operator, who does not acquire information, is more than the expected social benefit generated by the operator type $\left(\mathbb{E}[\tilde{\theta}_i|\hat{\theta}_i]\right)$. For the parameters $\omega\lambda$ that is large enough, screening occurs for an operator type $\left(\mathbb{E}[\tilde{\theta}_i|\hat{\theta}_i]\right)$ if and only if there is an overestimation of bad quality of water infrastructure.

5.2 The Choice of an Operator type $\left(\mathbb{E}[\tilde{\theta}_i|\hat{\theta}_i]\right)$

We analyze consumers' advantages benefited from the choice of an operator type $\left(\mathbb{E}[\tilde{\theta}_i|\hat{\theta}_i]\right)$, when it does not acquire any information. Nevertheless, it may be misguided by the information sent by other operators and choose the expected volume of water distribution \tilde{q}_1 computed in Equation (4.34). According to different precision of estimation, we compare \tilde{q}_1 with \tilde{q}_2 and q_1^* in Table 7. Even though an operator does not acquire any information, it incorrectly assesses the service quality due to the misleading information sent by the other operators through $\rho_{\theta\theta}$.

5.2.1 Precise public signal and imprecise private signal

When $\tau_{\tilde{\theta}} > \tau_{\Delta\theta_i}$, even without additional information, an operator is influenced by the misleading estimation and overestimates the bad quality (or underestimates the good quality), as $\mathbb{E}[h_\theta] < 0$. It chooses a contract with the expected volume \tilde{q}_1 . The regulator may extract some level of information rent from it, because the expected volume $\mathbb{E}[\tilde{q}_1]$ is less than if it had reported honestly its revised private estimation without learning information, as $\mathbb{E}[q_1^*]$.

It is noteworthy that, under the conditions $-\frac{a-(1+\mu_\theta)}{\lambda} < \mathbb{E}[h_\theta] < -\frac{(a-1)(1+2\mu_\theta)}{\lambda}$ and $-1 < \mu_\theta < 0$, we observe

$$\mathbb{E}[q_2^*] > \mathbb{E}[q_1^*] > \mathbb{E}[\tilde{q}_1] > \mathbb{E}[\tilde{q}_2^*] > \mathbb{E}[\tilde{q}_2]. \quad (5.7)$$

Though the regulator extracts information rent either from an operator type $\left(\mathbb{E}[\tilde{\theta}_i|\hat{\theta}_i]\right)$ or from an operator type $\left(\mathbb{E}[\tilde{\theta}_i|\hat{\theta}_i]\right)$, some level information rent is always given up to an operator type $\left(\mathbb{E}[\tilde{\theta}_i|\hat{\theta}_i]\right)$. This rent is requested from the operator type $\left(\mathbb{E}[\tilde{\theta}_i|\hat{\theta}_i]\right)$, who acquires information. The precise public signal can allow the regulator to restrict the misleading estimation about the quality of water services. This informational distortion is caused by the fact that the coordination motive dominates the competition motive (See Cornand and Ferreira, 2017), and it is considered the ex post participation rent that incited an operator type $\left(\mathbb{E}[\tilde{\theta}_i|\hat{\theta}_i]\right)$ to accept the contract. Indeed, the regulator authorizes a high expected volume to an operator type $\left(\mathbb{E}[\tilde{\theta}_i|\hat{\theta}_i]\right)$ when the operator does not acquire information and coordinates its private estimation towards the precise public signal.

5.2.2 Precise private signal and imprecise public signal

When $\tau_{\Delta\theta_i} > \tau_{\tilde{\theta}}$, the correlation coefficient $\rho_{\theta\theta}$ conveys more information to an operator type $\left(\mathbb{E}[\tilde{\theta}_i|\hat{\theta}_i]\right)$. The operator may be influenced by the misleading estimation about the quality sent by other operators.

There is two effects on the public signal. Under the competition motive, a high correlation coefficient across operators' private signals due to the precise idiosyncratic estimation renders the relative precision of private signal be equal to one: $\lim_{\rho_{\theta\theta} \rightarrow 1} \delta_1 = 1$. Hence, a high relative precise of private signal increases the precision of total signals. Under the coordination motive, this high correlation coefficient plays a role of public information and sends the signal about the quality to all parties. Even though the public signal is imprecise, the regulator can learn about the quality from this correlation coefficient. An operator, who does not acquire information, may coordinate its revised private estimation with the average estimation.

Being influenced by the misleading estimation, as $-\frac{a-(1+\mu_\theta)}{\lambda} < \mathbb{E}[h_\theta] < -\frac{(a-1)(1+2\mu_\theta)}{\lambda}$ and $-1 < \mu_\theta < 0$, the regulator does not give any information rent to an operator type $(\mathbb{E}[\tilde{\theta}_i|\hat{\theta}_i])$. However, it always gives up some level of information rent to an operator type $(\mathbb{E}[\tilde{\theta}_i|\hat{\theta}_i])$, if this operator chooses a contract with the expected volume \tilde{q}_1 . We find that $\mathbb{E}[\tilde{q}_2] < \mathbb{E}[\tilde{q}_1]$. In addition, by comparing to the situation that an operator type $(\mathbb{E}[\tilde{\theta}_i|\hat{\theta}_i])$ truthfully reports its revised private estimation, the regulator restricts the expected volume of water leakages by offering \tilde{q}_1 in the contract, as $\mathbb{E}[\tilde{q}_1] < \mathbb{E}[q_1^*]$. Thus, the restricted volume of water leakages to an operator type $(\mathbb{E}[\tilde{\theta}_i|\hat{\theta}_i])$ can be written as

$$\begin{aligned} \mathbb{E}[q^{loss}] &= \mathbb{E}[q_1^*] - \mathbb{E}[\tilde{q}_1] \\ &= \frac{[a - (1 + \mu_\theta)](1 + \mu_\theta) + \lambda \mathbb{E}[h_\theta]}{b(1 + \mu_\theta)^2}. \end{aligned} \quad (5.8)$$

where $-\frac{a-(1+\mu_\theta)}{\lambda} < \mathbb{E}[h_\theta] < -\frac{(a-1)(1+2\mu_\theta)}{\lambda}$ and $-1 < \mu_\theta < 0$.

This restricted volume of water leakages depends on both the average estimation μ_θ and the misleading estimation $\mathbb{E}[h_\theta]$. As long as the service quality is estimated better, either the average estimation becomes high or the misleading estimation is reduced, the regulator authorizes the water leaks as the less as possible in the networks of water mains.

If an operator type $(\mathbb{E}[\tilde{\theta}_i|\hat{\theta}_i])$ chooses the contract with the expected volume \tilde{q}_1 , then it improves the quality of water infrastructure in order to reduce the water leaks. Consumers benefit from this reduced water leaks. Moreover, the regulator can increase the public-policy variable λ so that an operator type $(\mathbb{E}[\tilde{\theta}_i|\hat{\theta}_i])$ is incited to accept the unique non-null contract. An operator type $(\mathbb{E}[\tilde{\theta}_i|\hat{\theta}_i])$ benefits more from the expected volume than an operator type $(\mathbb{E}[\tilde{\theta}_i|\hat{\theta}_i])$. However, a high public-policy variable limits both the information rent obtained by the operator type $(\mathbb{E}[\tilde{\theta}_i|\hat{\theta}_i])$ and the misleading estimation about the quality of water infrastructures. As a result, an operator type $(\mathbb{E}[\tilde{\theta}_i|\hat{\theta}_i])$ must improve the quality of water infrastructure and reduce the water leaks.

For an overestimation of the bad quality or an underestimation of the good quality $\mathbb{E}[h_\theta] < 0$, the main features of a menu of contracts can be presented in the following proposition:

Proposition 8. At $\tau_{\bar{\theta}} \geq \tau_{\Delta\theta_i}$, there is an overestimation of bad quality or an underestimation of good quality, as $-\frac{a-(1+\mu_\theta)}{\lambda} < \mathbb{E}[h_\theta] < -\frac{(a-1)(1+2\mu_\theta)}{\lambda}$ and $-1 < \mu_\theta < 0$, a menu of contracts entails:

- the regulator extracts always information rent either from an operator type $(\mathbb{E}[\tilde{\theta}_i|\hat{\theta}_i])$ or from an operator type $(\mathbb{E}[\tilde{\theta}_i|\hat{\theta}_i])$;

- A *screening policy* for an operator type $\left(\mathbb{E}[\tilde{\theta}_i|\hat{\theta}_i]\right)$, who acquires information about the quality of water infrastructure;
- An operator type $\left(\mathbb{E}[\tilde{\theta}_i|\hat{\theta}_i]\right)$, who does not acquires any information, but is influenced by the misleading estimation sent by other operators, chooses a unique non-null contract with the volume \tilde{q}_1 .
- Some level of information rent is given up to an operator type $\left(\mathbb{E}[\tilde{\theta}_i|\hat{\theta}_i]\right)$ by a unique non-null contract, in which $\mathbb{E}[\tilde{q}_1] > \mathbb{E}[\tilde{q}_2]$. This rent is requested from the operator type $\left(\mathbb{E}[\tilde{\theta}_i|\hat{\theta}_i]\right)$.
- Consumers benefit from a reduction of water leaks, if an operator type $\left(\mathbb{E}[\tilde{\theta}_i|\hat{\theta}_i]\right)$ accepts the unique non-null contract. We obtain that $\mathbb{E}[\tilde{q}_1] < \mathbb{E}[q_1^*]$.
- An increase in the public-policy variable λ incites an operator type $\left(\mathbb{E}[\tilde{\theta}_i|\hat{\theta}_i]\right)$ to accept the unique non-null contract with the volume \tilde{q}_1 , and allows the regulator to limit the ex post participation rent due to the misleading estimation $\mathbb{E}[h_\theta]$. The operator must improve the quality of water infrastructures.

5.2.3 Screening policy of an operator type $\left(\mathbb{E}[\tilde{\theta}_i|\hat{\theta}_i]\right)$

An operator type $\left(\mathbb{E}[\tilde{\theta}_i|\hat{\theta}_i]\right)$ is guided by the misleading estimation to underestimate the bad quality or overestimate the good quality, as $\mathbb{E}[h_\theta] > 0$. There is a screening policy for it. For $\tau_{\tilde{\theta}} \geq \tau_{\Delta\theta_i}$ this type operator is misguided to choose the volume \tilde{q}_1 that is not social desirable. While choosing the contract, the operator is failing to provide adequate services because of ignorance or insufficient incentive. There is a heavy water leaks that is not favorable to consumers. Therefore, the screening policy is a way allowing to limit informational distortion arisen from the misleading estimation in the delegation process.

Proposition 9. At $\tau_{\tilde{\theta}} \geq \tau_{\Delta\theta_i}$, and $0 < \mu_\theta < (a - 1)$, when the misleading estimation is $\mathbb{E}[h_\theta] > 0$, a menu of contracts entails:

- A *screening policy* for an operator type $\left(\mathbb{E}[\tilde{\theta}_i|\hat{\theta}_i]\right)$, who does not acquires any information, but is influenced by the misleading estimation.
- An operator type $\left(\mathbb{E}[\tilde{\theta}_i|\hat{\theta}_i]\right)$ chooses a unique non-null contract with the volume \tilde{q}_2^* . It profits from the maximum expected volume of distributed water.
- There is a distortion of water distribution for consumers, as $\mathbb{E}[\tilde{q}_2^*] > \mathbb{E}[\tilde{q}_2]$. The expected volume of water leakages depends both on the average estimation and misleading estimation, as $\mathbb{E}[q^{loss}] = \frac{(a-1)(1+\mu_\theta)-\mathbb{E}[h_\theta]}{b(1+\mu_\theta)(1+\mu_\theta+\mathbb{E}[h_\theta])}$.
- The expected volume of water leakage is decreasing in $\mathbb{E}[h_\theta] > 0$: an operator type $\left(\mathbb{E}[\tilde{\theta}_i|\hat{\theta}_i]\right)$ must improve the quality of water infrastructures.

Under the conditions $0 < \mathbb{E}[h_\theta] < [a - (1 + \mu_\theta)]$ and $0 < \mu_\theta < (a - 1)$, we observe that, when $\tau_{\tilde{\theta}} > \tau_{\Delta\theta_i}$,

$$\mathbb{E}[\tilde{q}_2^*] > \mathbb{E}[q_1^*] > \mathbb{E}[\tilde{q}_2] > \mathbb{E}[q_2^*] > \mathbb{E}[\tilde{q}_1]. \quad (5.9)$$

But, $\mathbb{E}[\tilde{q}_1] < 0$. The screening of an operator $\left(\mathbb{E}[\tilde{\theta}_i|\hat{\theta}_i]\right)$ occurs as long as it chooses \tilde{q}_1 . Hence,

$$\begin{aligned} & -\omega\lambda\mathbb{E}[h_\theta]\mathbb{E}[\tilde{q}_1] \geq \\ & \omega \{SC(\mathbb{E}[\tilde{q}_1]) + \lambda\tilde{\pi}_1(\mathbb{E}[\tilde{q}_1])\} \\ & +(1-\omega) \{[SC(\mathbb{E}[\tilde{q}_2^*]) - SC(\mathbb{E}[q_2^*])] + \lambda[\tilde{\pi}_2(\mathbb{E}[\tilde{q}_2^*]) - \pi_2(\mathbb{E}[q_2^*])]\}. \end{aligned} \quad (5.10)$$

The left-hand side of (5.10) represents the expected cost of an operator type $\left(\mathbb{E}[\tilde{\theta}_i|\hat{\theta}_i]\right)$, when it is influenced by the misleading estimation and chooses \tilde{q}_1 . The right-hand side of (5.10) instead represents the expected benefit from the transacting with an operator type $\left(\mathbb{E}[\tilde{\theta}_i|\hat{\theta}_i]\right)$ at the second-best volume of distributed water. When $\tau_{\tilde{\theta}} > \tau_{\Delta\theta_i}$, screening of an operator type $\left(\mathbb{E}[\tilde{\theta}_i|\hat{\theta}_i]\right)$ happens if and only if its expected benefit is lower than the expected cost. Laffont and Martimort (2002) advance the screening policy for the inefficient agent in the two-type model. The benefit of such a policy is that no rent is given up to the efficient type. The authors also stresses that there is no distortion away from the first-best for the efficient agent's output. Nevertheless, our model shows that even if the precision of public estimation is high, when an operator type $\left(\mathbb{E}[\tilde{\theta}_i|\hat{\theta}_i]\right)$ chooses \tilde{q}_2^* , there is always some tolerated water leaks in the networks of water mains. Thus, when the regulator imposes $\mathbb{E}[\tilde{q}_2^*] = \mathbb{E}[q_2^*]$ in order to limiter water leaks, then (5.10) becomes

$$-\omega\lambda\mathbb{E}[h_\theta]\mathbb{E}[\tilde{q}_1] \geq \omega (SC(\mathbb{E}[\tilde{q}_1]) + \lambda\tilde{\pi}_1(\mathbb{E}[\tilde{q}_1])). \quad (5.11)$$

For a positive value of $\omega\lambda$, the expected cost of the misleading estimation for an operator type $\left(\mathbb{E}[\tilde{\theta}_i|\hat{\theta}_i]\right)$ is larger than the expected utility of the regulator by offering the contract with \tilde{q}_1 to the operator. Thereby, a screening policy for an operator type $\left(\mathbb{E}[\tilde{\theta}_i|\hat{\theta}_i]\right)$ will take place.

In addition, the regulator authorizes some level of water leakage to an operator type $\left(\mathbb{E}[\tilde{\theta}_i|\hat{\theta}_i]\right)$ in order to give incentives to it to accept the unique non-null contract, in which $\mathbb{E}[\tilde{q}_2^*] > \mathbb{E}[\tilde{q}_2] > \mathbb{E}[q_2^*]$. The expected volume of water leakage linking to this contract is the same as equation (5.2). It is decreasing in misleading estimation $\mathbb{E}[h_\theta] > 0$ in the sens that the operator type $\left(\mathbb{E}[\tilde{\theta}_i|\hat{\theta}_i]\right)$ must improve the quality of water mains.

By contrast, when $\tau_{\tilde{\theta}} < \tau_{\Delta\theta_i}$, under the conditions $0 < \mathbb{E}[h_\theta] < [a - (1 + \mu_\theta)]$ and $0 < \mu_\theta < (a - 1)$, we observe that,

$$\mathbb{E}[\tilde{q}_2^*] > \mathbb{E}[q_1^*] > \mathbb{E}[q_2^*] > \mathbb{E}[\tilde{q}_2] > \mathbb{E}[\tilde{q}_1]. \quad (5.12)$$

At $\tau_{\tilde{\theta}} < \tau_{\Delta\theta_i}$, an operator accesses to the precise idiosyncratic estimation. Though the regulator's public signal is imprecise, a high correlation coefficient across private signals $\rho_{\theta\theta}$ sends the information about the state of quality to the regulator. As $\rho_{\theta\theta} \in [\frac{1}{2} + \frac{1}{2}\tau_{\Delta\theta_i}(\mathbb{E}[h_\theta])^2, 1]$, the regulator may learn about the quality from an operator type $\left(\mathbb{E}[\tilde{\theta}_i|\hat{\theta}_i]\right)$. It is possible that the regulator is misguided by the information sent by the operator type $\left(\mathbb{E}[\tilde{\theta}_i|\hat{\theta}_i]\right)$ and proposes an inefficient contract to this operator.

Through $\rho_{\theta\theta}$, an operator type $(\mathbb{E}[\tilde{\theta}_i|\hat{\theta}_i])$ may have misguided learning about the quality of water infrastructure. If this type operator accepts the contract with the volume \tilde{q}_1 , then this volume generates social losses due to the misleading estimation. the regulator restricts thus water leaks by offering the contract with \tilde{q}_2^* to an operator type $(\mathbb{E}[\tilde{\theta}_i|\hat{\theta}_i])$. Hence, a screening policy to an operator type $(\mathbb{E}[\tilde{\theta}_i|\hat{\theta}_i])$ occurs, when:

$$\begin{aligned} & -\omega\lambda\mathbb{E}[h_\theta]\mathbb{E}[\tilde{q}_1] \geq \\ & \omega \{SC(\mathbb{E}[\tilde{q}_1]) + \lambda\tilde{\pi}_1(\mathbb{E}[\tilde{q}_1])\} \\ & +(1-\omega) \{[SC(\mathbb{E}[\tilde{q}_2^*]) - SC(\mathbb{E}[q_2^*])] + \lambda[\tilde{\pi}_2(\mathbb{E}[\tilde{q}_2^*]) - \pi_2(\mathbb{E}[q_2^*])]\}. \end{aligned} \quad (5.13)$$

If the water leaks is restricted as high as possible that the regulator imposes $\mathbb{E}[\tilde{q}_2^*] = \mathbb{E}[q_2^*]$ to an operator type $(\mathbb{E}[\tilde{\theta}_i|\hat{\theta}_i])$, then (5.13) becomes,

$$-\omega\lambda\mathbb{E}[h_\theta]\mathbb{E}[\tilde{q}_1] \geq \omega(SC(\mathbb{E}[\tilde{q}_1]) + \lambda\tilde{\pi}_1(\mathbb{E}[\tilde{q}_1])). \quad (5.14)$$

Condition (5.14) is the same as (5.11) for a screening policy of an operator type $(\mathbb{E}[\tilde{\theta}_i|\hat{\theta}_i])$. For a positive value of $\omega\lambda$, social losses are resulted from $\mathbb{E}[h_\theta]$. By offering a contract with \tilde{q}_1 , the expected utility of the regulator drawn from the operator type $(\mathbb{E}[\tilde{\theta}_i|\hat{\theta}_i])$ is lower than the expected cost of the misleading estimation. Therefore, a screening policy is optimal for an operator type $(\mathbb{E}[\tilde{\theta}_i|\hat{\theta}_i])$.

By inciting an operator type $(\mathbb{E}[\tilde{\theta}_i|\hat{\theta}_i])$ to accept a unique non-null contract with the volume \tilde{q}_2^* , the regulator gives up some information rent to this type operator. The rent is measured by the expected volume of water leakage tolerated in the networks of water mains, as $\mathbb{E}[q^{loss}] = \frac{(a-1)(1+\mu_\theta) - \mathbb{E}[h_\theta]}{b(1+\mu_\theta)(1+\mu_\theta + \mathbb{E}[h_\theta])}$. It depends on the average estimation μ_θ and the misleading estimation $\mathbb{E}[h_\theta] > 0$, and it decreases with $\mathbb{E}[h_\theta]$. Therefore, the operator type $(\mathbb{E}[\tilde{\theta}_i|\hat{\theta}_i])$ must improve the quality of water infrastructures.

5.3 Transfers

The transfer is negatively depending on an operator's realized profit in managing the networks of water mains. It is extracted from an operator $i = \{\mathbb{E}[\tilde{\theta}_i|\hat{\theta}_i], \mathbb{E}[\tilde{\theta}_i|\hat{\theta}_i]\}$ according to the choice of the contract. With respect to the precision of public and private signals, the regulator proposes different contracts.

Proposition 10. At $\tau_{\tilde{\theta}} > \tau_{\Delta\theta_i}$, an operator type $(\mathbb{E}[\tilde{\theta}_i|\hat{\theta}_i])$ chooses the contract $\{\tilde{q}_2^* = \frac{(a-1)}{b(1+\mu_\theta)}, \tilde{P}_2^* = 1\}$.

Whereas, at $\tau_{\Delta\theta_i} > \tau_{\tilde{\theta}}$, an operator type $(\mathbb{E}[\tilde{\theta}_i|\hat{\theta}_i])$ chooses the contract $\{\tilde{q}_2^* = \frac{(a-1)}{b(1+\tilde{\theta}_i)}, \tilde{P}_2^* = 1\}$. The regulator does not extract any transfer from the operator.

If the quality of water infrastructure is publicly estimated to be good, as $0 < \mu_\theta < (a-1)$, then there is not any expected transfer extracted from an operator, who acquires information and has the misleading estimation about the quality $\mathbb{E}[h_\theta] > 0$, as $\mathbb{E}[\tilde{T}_2^*] = \mathbb{E}[-t\tilde{\pi}_2(\mathbb{E}[\tilde{\theta}_i|\hat{\theta}_i])] = 0$. Whatever is the precision of signals, the contracts just allow that the expected revenue of operating water distribution covers

the expected operational costs. The social welfare is consumers' surplus: when $\tau_{\tilde{\theta}} > \tau_{\Delta\theta_i}$, $\mathbb{E}[\tilde{W}_2^*] = \mathbb{E}[\tilde{S}C_2^*] = \frac{(a-1)^2}{2b(1+\mu_\theta)}$. Meanwhile, when $\tau_{\Delta\theta_i} > \tau_{\tilde{\theta}}$, $\mathbb{E}[\tilde{W}_2^*] = \mathbb{E}[\tilde{S}C_2^*] = \frac{(a-1)^2}{2b(1+\hat{\theta}_i)}$.

Moreover, the regulator may have false beliefs about how much of water leaks in the networks of water mains can be left to the operator with the contracts. Though the operator benefits from a high-level of distributed water, by accepting the fixed price, it undertakes all operational costs in managing the water services. Therefore, it is favorable for the regulator to allocate the contracts to an operator type $(\mathbb{E}[\tilde{\theta}_i|\hat{\theta}_i])$. The precision of public and private signals mitigate the effects of misleading estimation on the contracts, under which the operator must improve the quality of water infrastructure.

By contrast, the regulator does extract some level transfer from an operator type $(\mathbb{E}[\tilde{\theta}_i|\hat{\theta}_i])$, when the latter is influenced by the misleading estimation about the service quality from other operators. If this type operator has the misguided learning about the quality, as $-\frac{(a-1)(1+\mu_\theta)}{\lambda} < \mathbb{E}[h_\theta] < -\frac{(a-1)(1+2\mu_\theta)}{\lambda}$, and $-1 < \mu_\theta < 0$, then it chooses the contract $\{\tilde{q}_1, \tilde{P}_1\}$. Hence, the expected transfer extracted from an operator type $(\mathbb{E}[\tilde{\theta}_i|\hat{\theta}_i])$ is given by:

$$\begin{aligned}\tilde{q}_1 &= -t\tilde{\pi}_1 \\ &= -t \left[(\tilde{P}_1 - 1) (1 + \mathbb{E}[\tilde{\theta}_i|\hat{\theta}_i])\tilde{q}_1 \right] \\ &= -t \left(\frac{\left[(a-1) \left(1 + \mathbb{E}[\tilde{\theta}_i|\hat{\theta}_i] \right) - \mathbb{E}[\Delta\theta_i|\hat{\theta}_i] + \lambda\mathbb{E}[h_\theta] \right] (1 + \mathbb{E}[\tilde{\theta}_i|\hat{\theta}_i]) \left[a\mathbb{E}[\Delta\theta_i|\hat{\theta}_i] - \lambda\mathbb{E}[h_\theta] \right]}{b \left[1 + \mathbb{E}[\tilde{\theta}_i|\hat{\theta}_i] \right] \left(1 + \mathbb{E}[\tilde{\theta}_i|\hat{\theta}_i] + \mathbb{E}[\Delta\theta_i|\hat{\theta}_i] \right)^2} \right). \quad (5.15)\end{aligned}$$

The decision-making of the regulator about the transfer tends to be misguided by its false beliefs about the quality, even if there is different level of precision of public and private signals.

Proposition 11. At $\tau_{\tilde{\theta}} > \tau_{\Delta\theta_i}$, the expected transfer depends on the average estimation, the misleading estimation and the ex post biased estimation, so that

$$\begin{aligned}\tilde{T}_1^{(\tau_{\tilde{\theta}} > \tau_{\Delta\theta_i})} &= -t \left(\frac{\left[(a-1) \left(1 + \mu_\theta + \frac{1}{d}(\hat{\theta}_i - \mu_\theta) \right) - \frac{1}{d}(\hat{\theta}_i - \mu_\theta) + \lambda\mathbb{E}[h_\theta] \right]}{b \left[1 + \mu_\theta \right] \left[1 + \mu_\theta + \frac{2}{d}(\hat{\theta}_i - \mu_\theta) \right]^2} \right) \\ &\quad \times \left(\left[1 + \mu_\theta + \frac{1}{d}(\hat{\theta}_i - \mu_\theta) \right] \left[\frac{a}{d}(\hat{\theta}_i - \mu_\theta) - \lambda\mathbb{E}[h_\theta] \right] \right). \quad (5.16)\end{aligned}$$

The effects of changing $\mathbb{E}[h_\theta]$, μ_θ , $\frac{1}{d}[\hat{\theta}_i - \mu_\theta]$ on the expected transfer are:

$$\frac{\partial \tilde{T}_1^{(\tau_{\tilde{\theta}} > \tau_{\Delta\theta_i})}}{\partial \mathbb{E}[h_\theta]} < 0, \quad \frac{\partial \tilde{T}_1^{(\tau_{\tilde{\theta}} > \tau_{\Delta\theta_i})}}{\partial \mu_\theta} < 0, \quad \text{and} \quad \frac{\partial \tilde{T}_1^{(\tau_{\tilde{\theta}} > \tau_{\Delta\theta_i})}}{\partial \frac{1}{d}[\hat{\theta}_i - \mu_\theta]} > 0. \quad (5.17)$$

■ See Appendix.

The misleading estimation raises the ex post biased estimation, and it makes the regulator give up a large part of revenue to the operator. But, an accurate precision of public signal enforces the regulator's beliefs about the state of water infrastructure. Therefore, the better is average estimation about the

quality, the more transfer is extracted from the operator. The following corollary states the public-policy choices λ which allows the regulator to get the transfer from the operator.

Corollary 4. For $-1 < \mu_\theta < 0$, and the misleading estimation $-\frac{(a-1)(1+\mu_\theta)}{\lambda} < \mathbb{E}[h_\theta] < -(1+\mu_\theta)$, at $\tau_{\hat{\theta}} > \tau_{\Delta\theta_i}$, when the choke price is $a > (1+2\lambda) + \frac{2(\hat{\theta}_i - \mu_\theta)}{(1+\mu_\theta)}$, there exists a threshold value of the public-policy choices $\lambda_{\tau_{\hat{\theta}} > \tau_{\Delta\theta_i}}^{transfer}$ that guarantees a minimum expected transfer (in absolute value) extracted from the operator:

$$\lambda_{\tau_{\hat{\theta}} > \tau_{\Delta\theta_i}}^{transfer} = \frac{\frac{2}{d}(\hat{\theta}_i - \mu_\theta) - (a-1)(1+\mu_\theta)}{2\mathbb{E}[h_\theta]}, \quad (5.18)$$

$$\tilde{T}_1^{(\tau_{\hat{\theta}} > \tau_{\Delta\theta_i})} = \left| \frac{t(a-1)^2 \left[1 + \mu_\theta + \frac{1}{d}(\hat{\theta}_i - \mu_\theta) \right]}{b(1+\mu_\theta)} \right|. \quad (5.19)$$

■ See Appendix.

The decision-making of public-policy is affected by the misleading estimation and a fortiori by the ex post biased estimation. The regulator may have false beliefs about the quality of water infrastructure and tolerate a high-level of water leaks in the volume of distributed water defined in a contract. As long as the contract is accepted by an operator type $\left(\mathbb{E}[\tilde{\theta}_i | \hat{\theta}_i] \right)$, the regulator gets a part of revenue through the transfer. An increase in the precision of public signal allows the regulator to raise the public-policy choices λ through a high marginal transfer t . The higher is the ex post biased estimation, the more transfer is extracted from the operator. The public precision mitigates the effects of misleading estimation on the design of contracts.

Increasing $\tau_{\hat{\theta}}$ makes an operator place less weight on the idiosyncratic estimation, which increases the overall relative informativeness of the signal $\hat{\theta}_i$, as $\delta = \frac{1}{d}$. Thus, the weighted degree of biased estimation is lowered on the reason that an operator coordinates its estimation towards the public estimation. the regulator can reduce information distortion $\left| 1 + \frac{2a-\lambda}{a}\mu_\theta \right|$ linked to the operator's strategic behavior by decreasing t , which results in a high $(1-t)$. Therefore, when an operator coordinates its private estimation towards the precise public estimation, the regulator extracts less transfer from it. The operator can have incentives to improve the quality of water infrastructures. By combining “sticks and carrots” effects, the precision of public signal makes the contract $\left\{ \tilde{q}_1, \tilde{T}_1 \right\}$ positively influence the improvement of water services.

However, an increase in the precision of private signal $\tau_{\Delta\theta_i}$ lacks incentives of improving the quality. It hinders the regulator to extract more transfer from a cost-efficient operator through the contract.

Proposition 12. At $\tau_{\Delta\theta_i} > \tau_{\hat{\theta}}$, the expected transfer depends on the signal $\hat{\theta}_i$, the misleading estimation:

$$\tilde{T}_1^{(\tau_{\Delta\theta_i} > \tau_{\hat{\theta}})} = -t \left(\frac{\left[(a-1)(1+\hat{\theta}_i) + \lambda\mathbb{E}[h_\theta] \right] (-\lambda\mathbb{E}[h_\theta])}{b(1+\hat{\theta}_i)^2} \right). \quad (5.20)$$

For a given choke price $a > 1 + \frac{2\lambda}{(1+\hat{\theta}_i)}$, the effects of changing $\mathbb{E}[h_\theta]$, $(1+\hat{\theta}_i)$ on the expected transfer

are:

$$\frac{\partial \tilde{T}_1^{(\tau_{\Delta\theta_i} > \tau_{\hat{\theta}})}}{\partial \mathbb{E}[h_\theta]} < 0, \quad \frac{\partial \tilde{T}_1^{(\tau_{\Delta\theta_i} > \tau_{\hat{\theta}})}}{\partial (1 + \hat{\theta}_i)} < 0, \quad \text{if } -\frac{(a-1)(1 + \hat{\theta}_i)}{\lambda} < \mathbb{E}[h_\theta] < -\frac{(a-1)(1 + \hat{\theta}_i)}{2\lambda}, \quad (5.21)$$

$$\frac{\partial \tilde{T}_1^{(\tau_{\Delta\theta_i} > \tau_{\hat{\theta}})}}{\partial \mathbb{E}[h_\theta]} > 0, \quad \frac{\partial \tilde{T}_1^{(\tau_{\Delta\theta_i} > \tau_{\hat{\theta}})}}{\partial (1 + \hat{\theta}_i)} > 0, \quad \text{if } -\frac{(a-1)(1 + \hat{\theta}_i)}{2\lambda} < \mathbb{E}[h_\theta] < -(1 + \mu_\theta). \quad (5.22)$$

■ See Appendix.

We recall that, the correlation coefficient across operators' signals $\rho_{\theta\theta}$ plays a role of public information, as $\rho_{\theta\theta} \in [\frac{1}{2} + \frac{1}{2}\tau_{\Delta\theta_i}(\mathbb{E}[h_\theta])^2, 1]$. It sends the misleading estimation of other operators to the regulator and an operator type $(\mathbb{E}[\tilde{\theta}_i|\hat{\theta}_i])$. When the regulator has misguided learning about the quality of water infrastructure, it not only tolerates a high-level of water leaks in the networks of water mains, but also extracts more revenue from the operator type $(\mathbb{E}[\tilde{\theta}_i|\hat{\theta}_i])$ influenced by its misguided learning about the quality. The condition (5.21) shows that when the misleading estimation is worse than the average estimation, the regulator shares more revenue with an operator. Thus, the regulator undertakes mostly costs of improving the quality.

Nevertheless, the more precise is the idiosyncratic signal, the more accurate information about the quality is conveyed by $\rho_{\theta\theta}$. Thus, the ex post signal $\hat{\theta}_i$ sends less misleading estimation. The condition (5.22) indicates that if the misleading estimation is reduced, then an operator benefits less water leaks in the networks of water mains. The regulator shares less revenue with an operator in order to give the operator incentives to improve the quality of water infrastructure. In addition, the public-policy choices λ can be used to internalize the effect of misleading estimation on the contract.

Corollary 5. At $\tau_{\Delta\theta_i} > \tau_{\hat{\theta}}$, when the choke price is $a > (1 + 2\lambda) + \frac{2(\hat{\theta}_i - \mu_\theta)}{(1 + \mu_\theta)}$, then for the misleading estimation $-\frac{(a-1)(1 + \mu_\theta)}{\lambda} < \mathbb{E}[h_\theta] < -\frac{(a-1)(1 + 2\mu_\theta)}{\lambda}$, there exists a threshold value of the public-policy choices $\lambda_{\tau_{\Delta\theta_i} > \tau_{\hat{\theta}}}^{transfer}$ that guarantees a maximum expected transfer (in absolute value) extracted from the operator:

$$\lambda_{\tau_{\Delta\theta_i} > \tau_{\hat{\theta}}}^{transfer} = \frac{-(a-1)(1 + \hat{\theta}_i)}{2\mathbb{E}[h_\theta]}, \quad (5.23)$$

$$\tilde{T}_1^{(\tau_{\Delta\theta_i} > \tau_{\hat{\theta}})} = \left| \frac{t(a-1)^2}{4b} \right|. \quad (5.24)$$

■ See Appendix.

The public-policy choices λ becomes high as soon as the overall informativeness of signal $\hat{\theta}_i$ increases with reduced misleading estimation. But it is more important than it had been at $\tau_{\hat{\theta}} > \tau_{\Delta\theta_i}$, as $(\lambda_{\tau_{\Delta\theta_i} > \tau_{\hat{\theta}}}^{transfer}) > (\lambda_{\tau_{\hat{\theta}} > \tau_{\Delta\theta_i}}^{transfer})$. Indeed, the regulator is more likely to be affected by the ex post biased estimation when the private signal is precise. When operators' idiosyncratic signal is precise, the correlation coefficient across operators' signals makes the regulator greatly use its public-policy choices to limit the misleading estimation. We find that the minimum expected transfer (in absolute value) drawn from an operator is smaller than that when the private signal is imprecise, as $|\tilde{T}_1^{(\tau_{\Delta\theta_i} > \tau_{\hat{\theta}})}| < |\tilde{T}_1^{(\tau_{\hat{\theta}} > \tau_{\Delta\theta_i})}|$. An important information rent $|\frac{\lambda}{a}\mathbb{E}[h_\theta]|$ is given up to an operator, who accepts the contracts.

When sharing less revenue with an operator, the regulator undertakes few costs of improving water services. Hence, the water price can be kept at a low-level. It is favorable for a cost-efficient operator to win the contract. If the quality of water infrastructures is better in reality than it had been estimated, then a cost-efficient operator can support the costs of managing water services, and have incentives to maintain the quality. Otherwise, an inefficient operator has not any incentives to improve the quality. Therefore, increasing $\tau_{\Delta\theta_i}$ makes the regulator choose a cost-efficient operator through the contract $\{\tilde{q}_1, \tilde{T}_1\}$.

By comparing incentives of different contracts illustrated in Table 8, a contract allocated to an operator, who acquires information and has the misleading estimation $\mathbb{E}[h_\theta] > 0$, is the most incentives. The operator undertakes all costs of improving the quality, and the social welfare is the consumers' surplus. The contract offered to an operator, who has precise private signal and is influenced by the misleading estimation $\mathbb{E}[h_\theta] < -(1 + \mu_\theta)$, is the less incentives. But an increase in the public signal can internalize the effects of misleading estimation, and permit the regulator to chooses a cost-efficient operator.

6 Concluding Remarks

We analyze the precision of information disclosure in the delegation of drinking water networks. The regulator and potential operators are uncertain about the quality of water infrastructure at the time of delegation. Information about the quality can be disclosed by two channels: public channel and private channel.

Public channel means that the regulator publishes its estimation about the quality on the basis of collected data. All potential operators have access to this public information. They signal their private estimation conditional on both public and idiosyncratic information to the regulator in the delegation process. Based on announced private signals, the regulator and the operators revise their estimation in order to negotiate the contractual form that delegated management of drinking water networks may take. On this view, private channel means that an operator can decide to learn from other operators' signals in accordance with its strategy. Therefore, there is an interaction between the precision of public signal and the precision of private signal. This interaction can be associated with three motives: the fundamental motive, the coordination motive and the competition motive.

We find that different contracts derive from a trade-off between information learning and coordinating towards the average estimation. First, according to the precision of signals, we find two Nash equilibria, in which an operator, who revise its private estimation by acquiring information, can undertake different expected volume of distributed water. Then, by analyzing the strategies in information learning, we observe two Bayesian Separating Equilibria. An operator, who is influenced by the other operators' information, tends to deviate from an equilibrium in order to capture as much as possible information rent. This information rent is drawn from the conflicts between the coordination motive (strategic complementarity) and the competition motive (strategic substitutability).

If the precision of public signal is low, then the coordination motive dominates the competition motive. This strategic distortion is limited by a high correlation coefficient across operators' signals. On the contrary, if the precision of public signal is high, then the competition motive dominates the coordination motive. The strategic distortion linked to the competition motive is reduced by an increase in the precision of public and private signals. Local authorities can also adjust the public-policy choices to restrict the misleading estimation and limit the information rent left to the operator.

Both public and private precision reduce the possibility of controlling over information between local authorities and operators with conflicting interests. Another source of strategic uncertainty is the private information about operators' efforts, encompassing the efforts in information acquisition and processing, and the efforts in improving the quality of water services. It is not difficult to see that the concept of information disclosure readily extends to this analysis. Recent studies show that in delegated decision making, when the principal keeps the decision-making authority, the optimal effort is at its highest when agents has not precise private information (See Omiya et al., 2017).

Finally, we like to mention two issues, which we believe deserve further research. The first issue is to apply a potential empirical investigation about transparency in allocation system in public water services. As Taylor and Kelsey (2016) point out that in public services, transparency is promoted on the grounds that public services organizations are misallocating resources, sometimes corruptly, and are failing to provide adequate services either through ignorance or insufficient incentive. The investigation will consider the quality of water services as an indicator of population-level transparency, which examines both input information transparency and the outcome transparency. Input information transparency measures the accuracy of allocation systems by improving the quality and completeness of information available to regulators (the municipalities) making decisions. Outcome transparency measures the degree to which the results of delegation processes are observable. This is seen in agency efforts to measure and publish information about its performance in increasing the quality of water services or reducing their costs. Population-level transparency allows us to understand the bias and skew in the errors of allocation systems, seen as the volatility of water prices and water leakages after delegating the public water services. The extent of second issue concerns about an empirical analysis of the relationship between information manipulation and corruption in public services. And Iossa and Martimort (2016) seems to be a good starting point in theory.

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7 Appendix

7.1 Proofs

Proof of Table 1. We first consider that h_θ is a continue variable over the interval $[\theta^l, \theta^h] \subset]-1, +\infty[$, where we find mean $\mathbb{E}[\theta] = \mu_\theta$, and $\mu_\theta \in [\theta^l, \theta^h]$. The density of distribution $g(h_\theta)$ is continue over interval $] -1, \mu_\theta]$, and $g(h_\theta) > 0$. Hence, we have $\mathbb{E}[\theta] = \int_{-1}^{\mu_\theta} u g(u) du$. If $\{u | \forall h_\theta \in [\theta^l, \theta^h], h_\theta \leq u \leq \mu_\theta\}$, then we have $\int_{h_\theta}^{\mu_\theta} g(u) du > 0$. By contrast, if $\{u | \forall h_\theta \in [\theta^l, \theta^h], \mu_\theta \leq u \leq h_\theta\}$, then we obtain $-\int_{h_\theta}^{\mu_\theta} g(u) du > 0$. We now write the cumulative distribution as $G(u) = \int_{h_\theta}^{\mu_\theta} g(u) du$. When $\{u | \forall h_\theta \in [\theta^l, \theta^h], h_\theta \leq u \leq \mu_\theta\}$, $G(u) = \int_{h_\theta}^{\mu_\theta} g(u) du$. Meanwhile, when $\{u | \forall h_\theta \in [\theta^l, \theta^h], \mu_\theta \leq u \leq h_\theta\}$, $G(u) = -\int_{h_\theta}^{\mu_\theta} g(u) du$.

Moreover, by *Mean Value Theorem*, when $\{u | \forall h_\theta \in [\theta^l, \theta^h], h_\theta \leq u \leq \mu_\theta\}$, if $g(\cdot)$ est continue over $[h_\theta, \mu_\theta]$, then there is $h_\theta^* \in [h_\theta, \mu_\theta]$ such that $\int_{h_\theta}^{\mu_\theta} g(u) du = g(h_\theta^*)(\mu_\theta - h_\theta)$, $h_\theta^* \in [h_\theta, \mu_\theta]$. When $\{u | \forall h_\theta \in [\theta^l, \theta^h], \mu_\theta \leq u \leq h_\theta\}$, if $g(\cdot)$ est continue over $[\mu_\theta, h_\theta]$, then there is $h_\theta^* \in [\mu_\theta, h_\theta]$ such that $\int_{h_\theta}^{\mu_\theta} g(u) du = -g(h_\theta^*)(h_\theta - \mu_\theta)$, $h_\theta^* \in [\mu_\theta, h_\theta]$.

In addition, $G(\mu_\theta) = P\{u \leq \mu_\theta\} = 1$, and $G(-1) = P\{u \leq -1\} = 0$. By using the partial integration, we compute $\mathbb{E}[h_\theta] = \int_{-1}^{\mu_\theta} ug(u)du$,

$$\mathbb{E}[h_\theta] = \int_{-1}^{\mu_\theta} udG(u) = [uG(u)]_{-1}^{\mu_\theta} - \int_{-1}^{\mu_\theta} G(u)du, \quad (7.1)$$

hence, we obtain,

- when $\{u | \forall h_\theta \in [\theta^l, \theta^h], -1 < \theta^l \leq h_\theta \leq u \leq \mu_\theta, \text{ or } h_\theta \leq u \leq \mu_\theta < \theta^h\}$,

$$\begin{aligned} \mathbb{E}[h_\theta] &= [uG(u)]_{-1}^{\mu_\theta} - \int_{-1}^{\mu_\theta} \left[\int_{h_\theta}^{\mu_\theta} g(u)du \right] du \\ \mathbb{E}[h_\theta] &= \mu_\theta - g(h_\theta^*)(\mu_\theta - h_\theta)[u]_{-1}^{\mu_\theta} \\ \mathbb{E}[h_\theta] &= \mu_\theta - g(h_\theta^*)(\mu_\theta - h_\theta)(1 + \mu_\theta) < 0, \square \end{aligned} \quad (7.2)$$

- when $\{u | \forall h_\theta \in [\theta^l, \theta^h], -1 < \theta^l \leq \mu_\theta \leq u < h_\theta, \text{ or } 0 < \mu_\theta < h_\theta \leq \theta^h\}$,

$$\begin{aligned} \mathbb{E}[h_\theta] &= [uG(u)]_{-1}^{\mu_\theta} - \int_{-1}^{\mu_\theta} \left[\int_{\mu_\theta}^{h_\theta} g(u)du \right] du \\ \mathbb{E}[h_\theta] &= \mu_\theta + g(h_\theta^*)(h_\theta - \mu_\theta)[u]_{-1}^{\mu_\theta} \\ \mathbb{E}[h_\theta] &= \mu_\theta + g(h_\theta^*)(h_\theta - \mu_\theta)(1 + \mu_\theta) > 0. \square \end{aligned} \quad (7.3)$$

- when $h_\theta \equiv \mu_\theta$, we have $\mathbb{E}[h_\theta] \equiv \mu_\theta. \square$

Proof of Proposition 1. We consider that both public and private information are precise, as $\tau_{\hat{\theta}} \rightarrow +\infty$ and $\tau_{\Delta\theta_i} \rightarrow +\infty$. For information structure $d \in [0, 1]$, the relative precision of total estimation $\delta = \frac{d\tau_{\hat{\theta}} + \tau_{\Delta\theta_i}}{d^2\tau_{\hat{\theta}} + \tau_{\Delta\theta_i}} > 1$, and the relative precision of private estimation $\delta_1 = \frac{\tau_{\Delta\theta_i}}{d^2\tau_{\hat{\theta}} + \tau_{\Delta\theta_i}} \equiv 0$. The equation (4.11) can be rewritten as:

$$q_1^*(\delta) = \frac{a - (1 + \mu_\theta + \delta [\hat{\theta}_i - \mathbb{E}[\hat{\theta}_i]])}{b(1 + \mu_\theta)}. \quad (7.4)$$

Note that by definition, $var(\hat{\theta}_i) = \mathbb{E} \left\{ \left[\hat{\theta}_i - \mathbb{E}[\hat{\theta}_i] \right]^2 \right\}$, and $var(\hat{\theta}_i) = \sigma_{\hat{\theta}_i}^2 = \sigma_{\hat{\theta}}^2 + d^2\sigma_{\Delta\theta_i}^2$. If both $\tau_{\hat{\theta}} \rightarrow +\infty$ and $\tau_{\Delta\theta_i} \rightarrow +\infty$, then $\sigma_{\hat{\theta}}^2 \rightarrow 0$ and $\sigma_{\Delta\theta_i}^2 \rightarrow 0$. Therefore, $\sigma_{\hat{\theta}_i}^2 \equiv 0$, and $\mathbb{E} \left\{ \left[\hat{\theta}_i - \mathbb{E}[\hat{\theta}_i] \right]^2 \right\} \equiv 0$. We thus obtain the result of proposition 2. \square

Proof of Proposition 2 and Proposition 3. We firstly show that if $\tau_{\Delta\theta_i} \rightarrow +\infty$ and $\tau_{\Delta\theta_i} > \tau_{\hat{\theta}}$, then $\lim_{\tau_{\Delta\theta_i} \rightarrow +\infty} \delta_1 = \lim_{\tau_{\Delta\theta_i} \rightarrow +\infty} \frac{\tau_{\Delta\theta_i}}{d^2\tau_{\hat{\theta}} + \tau_{\Delta\theta_i}} \equiv 1$, and $\lim_{\tau_{\Delta\theta_i} \rightarrow +\infty} \delta = \lim_{\tau_{\Delta\theta_i} \rightarrow +\infty} \frac{d\tau_{\hat{\theta}} + \tau_{\Delta\theta_i}}{d^2\tau_{\hat{\theta}} + \tau_{\Delta\theta_i}} \equiv 1$. The equation (4.11) can be given by:

$$q_1^*(\hat{\theta}_i) = \frac{a - (1 + \hat{\theta}_i)}{b(1 + \hat{\theta}_i)}. \quad (7.5)$$

We now consider the volatility of volume linked to the imprecise public information. By using Taylor Expansions for the Moments of Functions of Random Variables, we obtain:

$$\begin{aligned} \text{var} \left(q_1^*(\hat{\theta}_i) \right) &= \left(\frac{a}{b} \right)^2 \text{var} \left(\frac{1}{(1 + \hat{\theta}_i)} \right) \\ &= \left(\frac{a}{b} \right)^2 \frac{1}{(1 + \mu_\theta)^4} \left(\frac{\tau_{\Delta\theta_i} + d^2 \tau_{\tilde{\theta}}}{\tau_{\Delta\theta_i} \tau_{\tilde{\theta}}} \right). \end{aligned} \quad (7.6)$$

Recall that we have $\frac{\tau_{\tilde{\theta}}}{\tau_{\Delta\theta_i}} = \frac{(1-\rho_{\theta\theta})}{\rho_{\theta\theta}}$. Hence, we obtain the result of equation (4.16) in Proposition 2. In the same way, we can get the result of equation (4.17). \square

Secondly, if $\tau_{\tilde{\theta}} \rightarrow +\infty$ and $\tau_{\tilde{\theta}} > \tau_{\Delta\theta_i}$, then $\lim_{\tau_{\tilde{\theta}} \rightarrow +\infty} \delta_1 = \lim_{\tau_{\tilde{\theta}} \rightarrow +\infty} \frac{\tau_{\Delta\theta_i}}{d^2 \tau_{\tilde{\theta}} + \tau_{\Delta\theta_i}} \equiv 0$, and $\lim_{\tau_{\tilde{\theta}} \rightarrow +\infty} \delta = \lim_{\tau_{\tilde{\theta}} \rightarrow +\infty} \frac{d\tau_{\tilde{\theta}} + \tau_{\Delta\theta_i}}{d^2 \tau_{\tilde{\theta}} + \tau_{\Delta\theta_i}} \equiv \frac{1}{d}$. The equation (3.1) is rewritten as:

$$\begin{aligned} q_1^*(\tilde{\theta}; \Delta\theta_i) &= \frac{a - \left(1 + \mu_\theta + \frac{1}{d}(\tilde{\theta} - \mu_\theta) \right)}{b(1 + \mu_\theta)} \\ &= \frac{a - \left(1 + \mu_\theta + \frac{1}{d} [\tilde{\theta} - \mathbb{E}[\tilde{\theta}]] + \Delta\theta_i \right)}{b(1 + \mu_\theta)}. \end{aligned} \quad (7.7)$$

As $\tau_{\tilde{\theta}} \rightarrow +\infty$, $\text{var}(\tilde{\theta}) = \mathbb{E} \left\{ [\tilde{\theta} - \mathbb{E}[\tilde{\theta}]]^2 \right\} \equiv 0$, the weighted degree of ex post biased public estimation $\frac{1}{d} [\tilde{\theta} - \mathbb{E}[\tilde{\theta}]] \equiv 0$. In addition, $\Delta\theta_i = \tilde{\theta}_i - \tilde{\theta}$, from (7.4), we get:

$$\begin{aligned} q_1^*(\tilde{\theta}_i) &= \frac{a - 1 + [\tilde{\theta} - \mu_\theta] - \tilde{\theta}_i}{b(1 + \mu_\theta)} \\ &= \frac{a - 1 - \tilde{\theta}_i}{b(1 + \mu_\theta)}. \end{aligned} \quad (7.8)$$

We now show the volatility of volume linked to the imprecise private information. By using Taylor Expansions for the Moments of Functions of Random Variables, we obtain:

$$\begin{aligned} \text{var} \left(q_1^*(\tilde{\theta}_i) \right) &= \left(\frac{1}{b} \right)^2 \text{var} \left(\frac{\tilde{\theta}_i}{(1 + \mu_\theta)} \right) \\ &= \left(\frac{1}{b} \right)^2 \frac{1}{(1 + \mu_\theta)^2} \left(\frac{\tau_{\Delta\theta_i} + \tau_{\tilde{\theta}}}{\tau_{\Delta\theta_i} \tau_{\tilde{\theta}}} \right). \end{aligned} \quad (7.9)$$

As $\frac{\tau_{\tilde{\theta}}}{\tau_{\Delta\theta_i}} = \frac{(1-\rho_{\theta\theta})}{\rho_{\theta\theta}}$, we obtain the result of equation (4.18) in Proposition 3. Correspondingly, we have the result of equation (4.19). \square

Proof of Proposition 4. We first compare the volume of water distribution when the private estimation is precise ($\delta_1 = 1$, and $\delta = 1$) with that when the public estimation is precise ($\delta_1 = 0$, and

$\delta = \frac{1}{d}$):

$$\begin{aligned} & \frac{a - (1 + \hat{\theta}_i) - \mathbb{E}[h_\theta]}{b(1 + \hat{\theta}_i)} - \frac{a - (1 + \tilde{\theta}_i) - \mathbb{E}[h_\theta]}{b(1 + \mu_\theta)} \\ &= - \frac{(a - \mathbb{E}[h_\theta]) \left[\hat{\theta}_i - \mathbb{E}[\hat{\theta}_i] \right] - (1 + \hat{\theta}_i) \left[\tilde{\theta}_i - \mathbb{E}[\tilde{\theta}_i] \right]}{b(1 + \hat{\theta}_i)(1 + \mu_\theta)}, \end{aligned} \quad (7.10)$$

for $a > 1 + \hat{\theta}_i + \mathbb{E}[h_\theta]$ and $\mathbb{E}[h_\theta] \leq 0$, we have $\frac{a - (1 + \hat{\theta}_i) - \mathbb{E}[h_\theta]}{b(1 + \hat{\theta}_i)} < \frac{a - (1 + \tilde{\theta}_i) - \mathbb{E}[h_\theta]}{b(1 + \mu_\theta)}$ when the weighted degree of biased estimation is large. Then, we compare the volume of water distribution when the public estimation is precise ($\delta_1 = 0$, and $\delta = \frac{1}{d}$) with that when both public and private estimation are precise ($\delta_1 = 0$, and $\delta = 0$):

$$\begin{aligned} & \frac{a - (1 + \tilde{\theta}_i) - \mathbb{E}[h_\theta]}{b(1 + \mu_\theta)} - \frac{a - (1 + \mu_\theta) - \mathbb{E}[h_\theta]}{b(1 + \mu_\theta)} \\ &= - \frac{\left[\tilde{\theta}_i - \mathbb{E}[\tilde{\theta}_i] \right]}{b(1 + \mu_\theta)}, \end{aligned} \quad (7.11)$$

for $\mu_\theta > -1$ and $\mathbb{E}[h_\theta] \leq 0$, we have $\frac{a - (1 + \tilde{\theta}_i) - \mathbb{E}[h_\theta]}{b(1 + \mu_\theta)} < \frac{a - (1 + \mu_\theta) - \mathbb{E}[h_\theta]}{b(1 + \mu_\theta)}$ when the weighted degree of biased estimation is large. In other words, operators continue to put more weight on the idiosyncratic estimation $\Delta\theta_i$. Finally, we compare the volume if both public and private estimation are imprecise ($\delta_1 = \frac{1}{1+d^2}$, and $\delta = \frac{1+d}{1+d^2}$) with that if there is only the imprecise public estimation ($\delta_1 = 1$, and $\delta = 1$)

$$\begin{aligned} & \frac{(1 + d^2) [a - (1 + \mu_\theta)] - (1 + d) \left[\hat{\theta}_i - \mu_\theta \right] - \mathbb{E}[h_\theta]}{b \left[(1 + d^2)(1 + \mu_\theta) + \left[\hat{\theta}_i - \mu_\theta \right] \right]} - \frac{a - (1 + \hat{\theta}_i) - \mathbb{E}[h_\theta]}{b(1 + \hat{\theta}_i)} \\ &= \frac{\left[ad^2 - (1 + \hat{\theta}_i) \right] + \mathbb{E}[h_\theta](1 + \mu_\theta)(1 + 2d^2)}{b(1 + \hat{\theta}_i) \left[(1 + d^2)(1 + \mu_\theta) + \left[\hat{\theta}_i - \mu_\theta \right] \right]} \end{aligned}$$

for $d \in [0, 1]$. The more weight put on the precise private information, the weaker is the weighted degree of biased estimation. But the imprecise public information strengthens misleading estimation about the quality of water infrastructures. As a result, the regulator may be misguided to set the volume of water distribution when both public and private estimation are imprecise, as $\frac{a - (1 + \mu_\theta) + \frac{1}{d}(\mu_\theta - \hat{\theta}_i) - \mathbb{E}[h_\theta]}{b(1 + \mu_\theta)} > \frac{a - (1 + \hat{\theta}_i) - \mathbb{E}[h_\theta]}{b(1 + \hat{\theta}_i)}$ depending on $\mathbb{E}[h_\theta] \geq 0$. We find the relationship between each volume of water distribution illustrated by (4.20), and correspondingly, the relationship between each water price illustrated by (4.21) in Proposition 4. \square

Proof of Proposition 5. As $\tilde{q}_2^* = \frac{(a-1)}{b(1+d\delta_2\mu_\theta+\delta_1\hat{\theta}_i)}$, and from the definition 1, we have:

$$\lim_{\tau_{\Delta\theta_i} \rightarrow +\infty} \tilde{q}_2^* = \lim_{\tau_{\Delta\theta_i} \rightarrow +\infty} \frac{(a-1)}{b(1+d\delta_2\mu_\theta+\delta_1\hat{\theta}_i)},$$

and $\lim_{\tau_{\Delta\theta_i} \rightarrow +\infty} \delta_1 = 1$, $\lim_{\tau_{\Delta\theta_i} \rightarrow +\infty} \delta_2 = 0$. Hence,

$$\lim_{\tau_{\Delta\theta_i} \rightarrow +\infty} \tilde{q}_2^* = \frac{(a-1)}{b(1+\hat{\theta}_i)}. \quad (7.12)$$

Moreover, if $\lim_{\tau_{\hat{\theta}} \rightarrow +\infty} \delta_1 = 0$ and $\lim_{\tau_{\hat{\theta}} \rightarrow +\infty} \delta_2 = \frac{1}{d}$, $d \in]0, 1[$, then,

$$\lim_{\tau_{\hat{\theta}} \rightarrow +\infty} \tilde{q}_2^* = \frac{(a-1)}{b(1+\mu_\theta)}. \quad (7.13)$$

Whichever is the matter the precision of public estimation, (7.13) forms one Bayes Nash equilibrium if the expected volume of water leakage is less tolerated by the regulator. Otherwise, (7.14) forms another Bayes Nash equilibrium, in which whatever is the precision of private estimation, the expected volume of water leakage is more tolerated by the regulator. Therefore, the expected volume of water leakage is the difference between (7.13) and (7.14). \square

Proof of Corollary 1. From (7.13) and (7.14), we first obtain the expected volume of water leakage tolerated by the regulator:

$$q^{loss} = \frac{(a-1) [\hat{\theta}_i - \mathbb{E}[\hat{\theta}_i]]}{b(1+\mu_\theta)(1+\hat{\theta}_i)}. \quad (7.14)$$

We now use Taylor Expansions for the Moments of Functions of Random Variables to analyze the volatility of water leakage:

$$\begin{aligned} var(q^{loss}) &= \frac{(a-1)^2}{b^2} \frac{1}{(1+\mu_\theta)^4} var(\hat{\theta}_i) \\ &= \frac{(a-1)^2}{b^2} \frac{1}{(1+\mu_\theta)^4} \left[\frac{1}{\tau_{\hat{\theta}}} + d^2 \frac{1}{\tau_{\Delta\theta_i}} \right]. \square \end{aligned} \quad (7.15)$$

Proof of Proposition 6. Since $a > 1$, and $\delta = \delta_1 + \delta_2$, from equations of the expected volume (4.36) and (4.37), we analyze:

$$\frac{\partial \tilde{q}_1}{\partial \delta_1} = \frac{-a \left(\delta_2 [\hat{\theta}_i - \mu_\theta] - \frac{\lambda}{a} \mathbb{E}[h_\theta] \right) [\hat{\theta}_i - \mu_\theta] \left(1 + (1-\delta)\mu_\theta + \delta\hat{\theta}_i \right) \left(1 + 2\delta_2 [\hat{\theta}_i - \mu_\theta] \right)}{b \left[1 + (1-\delta_1)\mu_\theta + \delta_1\hat{\theta}_i \right]^2 \left[1 + (1-\delta)\mu_\theta + \delta\hat{\theta}_i + \delta_2(\hat{\theta}_i - \mu_\theta) \right]^2} \leq 0, \quad (7.16)$$

hence, we have:

$$\begin{aligned} \left(\delta_2 [\hat{\theta}_i - \mu_\theta] - \frac{\lambda}{a} \mathbb{E}[h_\theta] \right) &\geq 0, \\ \delta_2 [\hat{\theta}_i - \mu_\theta] &\geq \frac{\lambda}{a} \mathbb{E}[h_\theta]. \end{aligned} \quad (7.17)$$

And

$$\frac{\partial \tilde{q}_2}{\partial \delta_2} = \frac{-a \left(\delta_2 [\hat{\theta}_i - \mu_\theta] + \mathbb{E}[h_\theta] \right) \left[\hat{\theta}_i - \mu_\theta \right] \left(1 + (1 - \delta) \mu_\theta + \delta \hat{\theta}_i \right) \left(1 + 2\delta_2 [\hat{\theta}_i - \mu_\theta] + \mathbb{E}[h_\theta] \right)}{b \left[1 + (1 - \delta_1) \mu_\theta + \delta_1 \hat{\theta}_i \right]^2 \left[1 + (1 - \delta) \mu_\theta + \delta \hat{\theta}_i + \delta_2 (\hat{\theta}_i - \mu_\theta) \right]^2} \leq 0, \quad (7.18)$$

we have thus:

$$\begin{aligned} \left(\delta_2 [\hat{\theta}_i - \mu_\theta] + \mathbb{E}[h_\theta] \right) &\geq 0, \\ \delta_2 [\hat{\theta}_i - \mu_\theta] &\geq -\mathbb{E}[h_\theta]. \end{aligned} \quad (7.19)$$

By combining (7.17) with (7.19), we can get:

$$\frac{1}{(\mu_\theta - h_\theta)(1 + \mu_\theta)} \left(\mu_\theta + \mathbb{E}[\Delta\theta_i | \hat{\theta}_i] \right) \geq g(h_\theta^*) \geq \frac{1}{(\mu_\theta - h_\theta)(1 + \mu_\theta)} [K_1]. \quad (7.20)$$

where $K_1 = (1 - k_1)\mu_\theta + k_1\hat{\theta}_i$ and $k_1 = -\frac{\alpha}{\lambda}\delta_2$. If we rewrite this separating Bayesian Equilibrium, then we can obtain the ex post biased estimation due to information acquisition: $[K_1] = \left[\mu_\theta - \frac{\alpha}{\lambda} \mathbb{E}[\Delta\theta_i | \hat{\theta}_i] \right]$. \square

Proof of Corollary 2. Since $\delta = \frac{d\tau_{\hat{\theta}} + \tau_{\Delta\theta_i}}{d^2\tau_{\hat{\theta}} + \tau_{\Delta\theta_i}}$, we analyze:

$$\frac{\partial \delta}{\partial d} = \frac{-d^2\tau_{\hat{\theta}} + (1 - 2d)\tau_{\hat{\theta}}\tau_{\Delta\theta_i}}{(d^2\tau_{\hat{\theta}} + \tau_{\Delta\theta_i})^2}. \quad (7.21)$$

- If $-d^2\tau_{\hat{\theta}} + (1 - 2d)\tau_{\hat{\theta}}\tau_{\Delta\theta_i} \geq 0$, then $0 < d \leq \sqrt{2} - 1 < \frac{1}{2}$. Hence, for $\frac{\tau_{\Delta\theta_i}}{\tau_{\hat{\theta}}} \geq 1$ and $\rho_{\theta\theta} \in]\frac{1}{2} + \frac{1}{2}\tau_{\Delta\theta_i}(\mathbb{E}[h_\theta])^2, 1]$, we have $\frac{\partial \delta}{\partial d} \geq 0$.
- If $-d^2\tau_{\hat{\theta}} + (1 - 2d)\tau_{\hat{\theta}}\tau_{\Delta\theta_i} \leq 0$, then $\sqrt{2} - 1 \leq d < \frac{1}{2}$. Hence, for $\frac{\tau_{\Delta\theta_i}}{\tau_{\hat{\theta}}} \leq 1$ and $\rho_{\theta\theta} \in]0, \frac{1}{2} + \frac{1}{2}\tau_{\Delta\theta_i}(\mathbb{E}[h_\theta])^2]$, we have $\frac{\partial \delta}{\partial d} \leq 0$.

Therefore, $d^{SB} \equiv \underset{d}{\operatorname{argmax}}\{\delta\} = \frac{\sqrt{\rho_{\theta\theta} - \rho_{\theta\theta}}}{1 - \rho_{\theta\theta}} < \frac{1}{2}$. \square

Proof of Proposition 7.

$$\frac{\partial \tilde{q}_1}{\partial \delta_2} = \frac{a(\hat{\theta}_i - \mu_\theta) \left[1 + (1 - \delta)\mu_\theta + \delta \hat{\theta}_i + \frac{\lambda}{a} \mathbb{E}[h_\theta] \right]}{b \left[1 + (1 - \delta_1)\mu_\theta + \delta_1 \hat{\theta}_i \right] \left[1 + (1 - \delta)\mu_\theta + \delta \hat{\theta}_i + \delta_2 (\hat{\theta}_i - \mu_\theta) \right]^2} \geq 0,$$

hence, we have:

$$\begin{aligned} \left[1 + (1 - \delta)\mu_\theta + \delta \hat{\theta}_i + \frac{\lambda}{a} \mathbb{E}[h_\theta] \right] &\geq 0, \\ \left[1 + (1 - \delta)\mu_\theta + \delta \hat{\theta}_i \right] &\geq -\frac{\lambda}{a} \mathbb{E}[h_\theta], \\ g(h_\theta^*) &\leq \frac{1}{(\mu_\theta - h_\theta)(1 + \mu_\theta)} \left[\frac{a}{\lambda} (1 + \mu_\theta) + [K_2] \right], \end{aligned} \quad (7.22)$$

where $K_2 = (1 - k_2)\mu_\theta + k_2\hat{\theta}_i$ and $k_2 = \frac{a}{\lambda}\delta$.

$$\frac{\partial \tilde{q}_2}{\partial \delta_2} = \frac{a(\hat{\theta}_i - \mu_\theta) \left[1 + (1 - \delta)\mu_\theta + \delta\hat{\theta}_i + \mathbb{E}[h_\theta] \right]}{b \left[1 + (1 - \delta_1)\mu_\theta + \delta_1\hat{\theta}_i \right] \left[1 + (1 - \delta)\mu_\theta + \delta\hat{\theta}_i + \delta_2(\hat{\theta}_i - \mu_\theta) + \mathbb{E}[h_\theta] \right]^2} \geq 0,$$

we have thus:

$$\begin{aligned} \left[1 + (1 - \delta)\mu_\theta + \delta\hat{\theta}_i + \mathbb{E}[h_\theta] \right] &\geq 0, \\ \left[1 + (1 - \delta)\mu_\theta + \delta\hat{\theta}_i \right] &\geq -\mathbb{E}[h_\theta], \\ g(h_\theta^*) &\leq \frac{1}{(\mu_\theta - h_\theta)(1 - \mu_\theta)} \left[\left(1 + \frac{2a - \lambda}{a}\mu_\theta \right) + \frac{\lambda}{a} [K_2] \right] \end{aligned} \quad (7.23)$$

Since $\mathbb{E}[h_\theta] < 0$, we obtain $-\mathbb{E}[h_\theta] > -\frac{\lambda}{a}\mathbb{E}[h_\theta]$. By comparing (6.23) and (6.24), we can get:

$$g(h_\theta^*) \leq \frac{1}{(\mu_\theta - h_\theta)(1 + \mu_\theta)} \left[\left(1 + \frac{2a - \lambda}{a}\mu_\theta \right) + \frac{\lambda}{a} [K_2] \right],$$

where $K_2 = (1 - k_2)\mu_\theta + k_2\hat{\theta}_i$ and $k_2 = \frac{a}{\lambda}\delta$. \square

Proof of Screening Policy for an Operator type $\left(\mathbb{E}[\tilde{\theta}_i | \hat{\theta}_i] \right)$. Under the conditions $-\frac{a-(1+\mu_\theta)}{\lambda} < \mathbb{E}[h_\theta] < -\frac{(a-1)(1+2\mu_\theta)}{\lambda}$ and $-1 < \mu_\theta < 0$, we observe that,

$$\mathbb{E}[q_2^*] > \mathbb{E}[q_1^*] > \mathbb{E}[\tilde{q}_1] > \mathbb{E}[\tilde{q}_2^*] > \mathbb{E}[\tilde{q}_2]. \quad (7.24)$$

A screening policy is optimal when:

$$\begin{aligned} \omega \{ SC(\mathbb{E}[q_1^*]) + \lambda\pi_1(\mathbb{E}[q_1^*]) \} &\geq \\ \omega \{ SC(\mathbb{E}[\tilde{q}_1]) + \lambda\tilde{\pi}_1(\mathbb{E}[\tilde{q}_1]) + \lambda\mathbb{E}[h_\theta]\mathbb{E}[\tilde{q}_1] \} & \\ + (1 - \omega) \{ SC(\mathbb{E}[\tilde{q}_2^*]) + \lambda\tilde{\pi}_2(\mathbb{E}[\tilde{q}_2^*]) \} &, \end{aligned} \quad (7.25)$$

or, noting that $\mathbb{E}[q_1^*] > \mathbb{E}[\tilde{q}_1] > \mathbb{E}[\tilde{q}_2^*]$, and thus we get the condition of a screening policy (5.5). \square

Proof of Screening Policy for an Operator type $\left(\mathbb{E}[\tilde{\theta}_i | \hat{\theta}_i] \right)$. If $\tau_{\hat{\theta}} > \tau_{\Delta\theta_i}$, then under the conditions $0 < \mathbb{E}[h_\theta] < [a - (1 + \mu_\theta)]$ and $0 < \mu_\theta < (a - 1)$, a screening policy happens when,

$$\begin{aligned} (1 - \omega) \{ SC(\mathbb{E}[q_2^*]) + \lambda\pi_2(\mathbb{E}[q_2^*]) \} &\geq \\ \omega \{ SC(\mathbb{E}[\tilde{q}_1]) + \lambda\tilde{\pi}_1(\mathbb{E}[\tilde{q}_1]) + \lambda\mathbb{E}[h_\theta]\mathbb{E}[\tilde{q}_1] \} & \\ + (1 - \omega) \{ SC(\mathbb{E}[\tilde{q}_2^*]) + \lambda\tilde{\pi}_2(\mathbb{E}[\tilde{q}_2^*]) \} &. \end{aligned} \quad (7.26)$$

Or, noting that,

$$\mathbb{E}[\tilde{q}_2^*] > \mathbb{E}[q_1^*] > \mathbb{E}[\tilde{q}_2] > \mathbb{E}[q_2^*] > \mathbb{E}[\tilde{q}_1], \quad (7.27)$$

but $\mathbb{E}[\tilde{q}_1] < 0$, and $\tilde{\pi}_2(\mathbb{E}[\tilde{q}_2^*]) = 0$. Hence, we get the condition of a screening policy of an operator type $(\mathbb{E}[\tilde{\theta}_i|\hat{\theta}_i])$ in (5.10). \square

At $\tau_{\Delta\theta_i} > \tau_{\tilde{\theta}}$, then under the conditions $0 < \mathbb{E}[h_\theta] < [a - (1 + \mu_\theta)]$ and $0 < \mu_\theta < (a - 1)$, a screening policy takes place when,

$$\begin{aligned} & (1 - \omega) \{SC(\mathbb{E}[q_2^*]) + \lambda\pi_2(\mathbb{E}[q_2^*])\} \geq \\ & \omega \{SC(\mathbb{E}[\tilde{q}_1]) + \lambda\tilde{\pi}_1(\mathbb{E}[\tilde{q}_1]) + \lambda\mathbb{E}[h_\theta]\mathbb{E}[\tilde{q}_1]\} \\ & + (1 - \omega) \{SC(\mathbb{E}[\tilde{q}_2^*]) + \lambda\tilde{\pi}_2(\mathbb{E}[\tilde{q}_2^*])\}. \end{aligned} \quad (7.28)$$

Since we have,

$$\mathbb{E}[\tilde{q}_2^*] > \mathbb{E}[q_1^*] > \mathbb{E}[q_2^*] > \mathbb{E}[\tilde{q}_2] > \mathbb{E}[\tilde{q}_1]. \quad (7.29)$$

and $\mathbb{E}[\tilde{q}_1] < 0$, and $\tilde{\pi}_2(\mathbb{E}[\tilde{q}_2^*]) = 0$. Therefore, we obtain the condition of a screening policy of an operator type $(\mathbb{E}[\tilde{\theta}_i|\hat{\theta}_i])$ in (5.13). \square

Proof of Proposition 11. We recall that $\tilde{q}_1 = \frac{(a\mathbb{E}[\Delta\theta_i|\hat{\theta}_i] - \lambda\mathbb{E}[h_\theta])}{b[1 + \mathbb{E}[\tilde{\theta}|\hat{\theta}_i]][1 + \mathbb{E}[\tilde{\theta}_i|\hat{\theta}_i] + \mathbb{E}[\Delta\theta_i|\hat{\theta}_i]]}$, correspondingly, $\tilde{P}_1 = \frac{\alpha(1 + \mathbb{E}[\tilde{\theta}_i|\hat{\theta}_i]) + \lambda\mathbb{E}[h_\theta]}{(1 + \mathbb{E}[\tilde{\theta}_i|\hat{\theta}_i] + \mathbb{E}[\Delta\theta_i|\hat{\theta}_i])}$, then the transfer designed in the contract is,

$$\begin{aligned} \tilde{T}_1 &= -t\tilde{\pi}_1 \\ &= -t \left(\frac{\left[(a-1) \left(1 + \mathbb{E}[\tilde{\theta}_i|\hat{\theta}_i] \right) - \mathbb{E}[\Delta\theta_i|\hat{\theta}_i] + \lambda\mathbb{E}[h_\theta] \right] \left(1 + \mathbb{E}[\tilde{\theta}_i|\hat{\theta}_i] \right) \left[a\mathbb{E}[\Delta\theta_i|\hat{\theta}_i] - \lambda\mathbb{E}[h_\theta] \right]}{b \left[1 + \mathbb{E}[\tilde{\theta}|\hat{\theta}_i] \right] \left(1 + \mathbb{E}[\tilde{\theta}_i|\hat{\theta}_i] + \mathbb{E}[\Delta\theta_i|\hat{\theta}_i] \right)^2} \right) \end{aligned} \quad (7.30)$$

If $\tau_{\tilde{\theta}} > \tau_{\Delta\theta_i}$, then $\delta_1 = 0$, $\delta_2 = \frac{1}{d}$ and $\delta = \frac{1}{d}$. The transfer can be rewritten as,

$$\begin{aligned} \tilde{T}_1^{(\tau_{\tilde{\theta}} > \tau_{\Delta\theta_i})} &= -t \left(\frac{\left[(a-1) \left(1 + \mu_\theta + \frac{1}{d}(\hat{\theta}_i - \mu_\theta) \right) - \frac{1}{d}(\hat{\theta}_i - \mu_\theta) + \lambda\mathbb{E}[h_\theta] \right]}{b[1 + \mu_\theta] \left[1 + \mu_\theta + \frac{2}{d}(\hat{\theta}_i - \mu_\theta) \right]^2} \right) \\ &\quad \times \left(\left[1 + \mu_\theta + \frac{1}{d}(\hat{\theta}_i - \mu_\theta) \right] \left[\frac{a}{d}(\hat{\theta}_i - \mu_\theta) - \lambda\mathbb{E}[h_\theta] \right] \right). \end{aligned} \quad (7.31)$$

We analyze the effects of $\mathbb{E}[h_\theta]$, μ_θ and $\frac{1}{d}(\hat{\theta}_i - \mu_\theta)$ on transfer:

$$\begin{aligned} \frac{\partial \tilde{T}_1^{(\tau_{\hat{\theta}} > \tau_{\Delta \theta_i})}}{\partial \mathbb{E}[h_\theta]} &= \left\{ \frac{-t}{b[1 + \mu_\theta] \left[1 + \mu_\theta + \frac{2}{d}(\hat{\theta}_i - \mu_\theta)\right]^2} \right\} \\ &\times \left(\lambda \left[1 + \mu_\theta + \frac{1}{d}(\hat{\theta}_i - \mu_\theta)\right] \right) \\ &\times \left(\left[\frac{a}{d}(\hat{\theta}_i - \mu_\theta) - \lambda \mathbb{E}[h_\theta] \right] - (a-1) \left[1 + \mu_\theta + \frac{1}{d}(\hat{\theta}_i - \mu_\theta)\right] - \frac{1}{d}(\hat{\theta}_i - \mu_\theta) + \lambda \mathbb{E}[h_\theta] \right), \end{aligned} \quad (7.32)$$

since $-\frac{(a-1)(1+\mu_\theta)}{\lambda} < \mathbb{E}[h_\theta] < -\frac{(a-1)(1+2\mu_\theta)}{\lambda}$ and $-1 < \mu_\theta < 0$, we get $\frac{\partial \tilde{T}_1^{(\tau_{\hat{\theta}} > \tau_{\Delta \theta_i})}}{\partial \mathbb{E}[h_\theta]} < 0$. \square

Moreover, since $\tau_{\hat{\theta}} > \tau_{\Delta \theta_i}$, and for $d \in [0, 1]$, $\frac{1}{d}(\hat{\theta}_i - \mu_\theta) > 0$. We assume that $\mathbb{E}[\frac{1}{d}(\hat{\theta}_i - \mu_\theta)] \equiv 0$, then,

$$\frac{\partial \tilde{T}_1^{(\tau_{\hat{\theta}} > \tau_{\Delta \theta_i})}}{\partial \mu_\theta} = -t \left\{ \frac{-(\lambda \mathbb{E}[h_\theta])((a-1)(1+\mu_\theta) + \lambda \mathbb{E}[h_\theta])}{b[1 + \mu_\theta]^2} \right\}, \quad (7.33)$$

since $-\frac{(a-1)(1+\mu_\theta)}{\lambda} < \mathbb{E}[h_\theta] < -\frac{(a-1)(1+2\mu_\theta)}{\lambda}$ and $-1 < \mu_\theta < 0$, we get $\frac{\partial \tilde{T}_1^{(\tau_{\hat{\theta}} > \tau_{\Delta \theta_i})}}{\partial \mu_\theta} < 0$. \square

We now consider that $\frac{1}{d}(\hat{\theta}_i - \mu_\theta) \equiv x > 0$, thus we have,

$$\begin{aligned} \frac{\partial \tilde{T}_1^{(\tau_{\hat{\theta}} > \tau_{\Delta \theta_i})}}{\partial x} &= -t \left\{ \frac{(a-2)(1+\mu_\theta+2x)}{b(1+\mu_\theta)(1+\mu_\theta+2x)^2} \right\} \\ &-t \left\{ \frac{((a-1)(1+\mu_\theta+x) - x - \lambda \mathbb{E}[h_\theta])}{b(1+\mu_\theta)(1+\mu_\theta+2x)^2} \right\} \left[(1+\mu_\theta)^2 + 3\lambda \mathbb{E}[h_\theta](1+\mu_\theta) + 2x\lambda \mathbb{E}[h_\theta] \right], \end{aligned} \quad (7.34)$$

as $-\frac{(a-1)(1+\mu_\theta)}{\lambda} < \mathbb{E}[h_\theta] < -\frac{(a-1)(1+2\mu_\theta)}{\lambda}$ and $-1 < \mu_\theta < 0$, we get $\frac{\partial \tilde{T}_1^{(\tau_{\hat{\theta}} > \tau_{\Delta \theta_i})}}{\partial x} > 0$. \square

Proof of Corollary 4. From proposition 10, we have,

$$\begin{aligned} \frac{\partial \tilde{T}_1^{(\tau_{\hat{\theta}} > \tau_{\Delta \theta_i})}}{\partial \lambda} &= - \frac{t \mathbb{E}[h_\theta] \left[1 + \mu_\theta + \frac{1}{d}(\hat{\theta}_i - \mu_\theta)\right]}{b[1 + \mu_\theta] \left[1 + \mu_\theta + \frac{2}{d}(\hat{\theta}_i - \mu_\theta)\right]^2} \\ &\times \left[\frac{2}{d}(\hat{\theta}_i - \mu_\theta) - 2\lambda \mathbb{E}[h_\theta] - (a-1)(1 + \mu_\theta) \right], \end{aligned} \quad (7.35)$$

as $-\frac{(a-1)(1+\mu_\theta)}{\lambda} < \mathbb{E}[h_\theta] < -(1 + \mu_\theta)$, and $-1 < \mu_\theta < 0$, we analyze,

- $\frac{\partial \tilde{T}_1^{(\tau_{\hat{\theta}} > \tau_{\Delta \theta_i})}}{\partial \lambda} \geq 0$: if $\frac{2}{d}(\hat{\theta}_i - \mu_\theta) - 2\lambda \mathbb{E}[h_\theta] - (a-1)(1 + \mu_\theta) \geq 0$, then $-\frac{(a-1)(1+\mu_\theta)}{\lambda} < \mathbb{E}[h_\theta] \leq -\frac{(a-1)(1+\mu_\theta) - \frac{2}{d}(\hat{\theta}_i - \mu_\theta)}{2\lambda}$, where $a > (1 + 2\lambda) + \frac{\frac{2}{d}(\hat{\theta}_i - \mu_\theta)}{(1+\mu_\theta)}$;
- $\frac{\partial \tilde{T}_1^{(\tau_{\hat{\theta}} > \tau_{\Delta \theta_i})}}{\partial \lambda} \leq 0$: if $\frac{2}{d}(\hat{\theta}_i - \mu_\theta) - 2\lambda \mathbb{E}[h_\theta] - (a-1)(1 + \mu_\theta) \leq 0$, then $-\frac{(a-1)(1+\mu_\theta) - \frac{2}{d}(\hat{\theta}_i - \mu_\theta)}{2\lambda} < \mathbb{E}[h_\theta] < -(1 + \mu_\theta)$, where $a > (1 + 2\lambda) + \frac{\frac{2}{d}(\hat{\theta}_i - \mu_\theta)}{(1+\mu_\theta)}$.

We now consider that for a given choke price $a > (1 + 2\lambda) + \frac{\frac{2}{d}(\hat{\theta}_i - \mu_\theta)}{(1+\mu_\theta)}$, when $-\frac{(a-1)(1+\mu_\theta)}{\lambda} < \mathbb{E}[h_\theta] < -(1 + \mu_\theta)$, and $-1 < \mu_\theta < 0$, the expected transfer tends to be minimum in absolute value at public-policy

variables $\lambda = -\frac{(a-1)(1+\mu_\theta) - \frac{2}{d}(\hat{\theta}_i - \mu_\theta)}{2\mathbb{E}[h_\theta]}$. Thus, we obtain the expected transfer in (5.19). \square

Proof of Proposition 12. From the function of transfer defined in equation (7.31), if $\tau_{\Delta\theta_i} > \tau_{\hat{\theta}}$, then $\delta_1 = 1$, $\delta_2 = 0$ and $\delta = 1$. The transfer can be rewritten as,

$$\tilde{T}_1^{(\tau_{\Delta\theta_i} > \tau_{\hat{\theta}})} = -t \left(\frac{\left(\left[(a-1)(1+\hat{\theta}_i) \right] + \lambda\mathbb{E}[h_\theta] \right) [-\lambda\mathbb{E}[h_\theta]]}{b[1+\hat{\theta}_i]^2} \right), \quad (7.36)$$

here, the transfer depends only on the ex post signal $\hat{\theta}_i$ and the misleading estimation $\mathbb{E}[h_\theta]$. Since $\mathbb{E}[h_\theta] < -(1+\mu_\theta)$, it is favorable for having $\left(\left[(a-1)(1+\hat{\theta}_i) \right] + \lambda\mathbb{E}[h_\theta] \right) > 0$. We have thus $-\frac{(a-1)(1+\hat{\theta}_i)}{\lambda} < \mathbb{E}[h_\theta] < -(1+\mu_\theta)$, and the choke price $a > 1 + \frac{2\lambda}{(1+\hat{\theta}_i)}$. Under this condition, we analyze,

$$\frac{\partial \tilde{T}_1^{(\tau_{\Delta\theta_i} > \tau_{\hat{\theta}})}}{\partial \mathbb{E}[h_\theta]} = \frac{t\lambda}{b[1+\hat{\theta}_i]^2} \left(\left[(a-1)(1+\hat{\theta}_i) \right] + 2\lambda\mathbb{E}[h_\theta] \right), \quad (7.37)$$

- $\frac{\partial \tilde{T}_1^{(\tau_{\Delta\theta_i} > \tau_{\hat{\theta}})}}{\partial \mathbb{E}[h_\theta]} < 0$: if $\left[(a-1)(1+\hat{\theta}_i) \right] + 2\lambda\mathbb{E}[h_\theta] < 0$, then $-\frac{(a-1)(1+\hat{\theta}_i)}{\lambda} < \mathbb{E}[h_\theta] < -\frac{(a-1)(1+\hat{\theta}_i)}{2\lambda}$;
- $\frac{\partial \tilde{T}_1^{(\tau_{\Delta\theta_i} > \tau_{\hat{\theta}})}}{\partial \mathbb{E}[h_\theta]} > 0$: if $\left[(a-1)(1+\hat{\theta}_i) \right] + 2\lambda\mathbb{E}[h_\theta] > 0$, then $-\frac{(a-1)(1+\hat{\theta}_i)}{2\lambda} < \mathbb{E}[h_\theta] < -(1+\mu_\theta)$. \square

And,

$$\begin{aligned} \frac{\partial \tilde{T}_1^{(\tau_{\Delta\theta_i} > \tau_{\hat{\theta}})}}{\partial (1+\hat{\theta}_i)} &= -t [-\lambda\mathbb{E}[h_\theta]] \left(\frac{(a-1)(1+\hat{\theta}_i) - 2 \left(\left[(a-1)(1+\hat{\theta}_i) \right] + \lambda\mathbb{E}[h_\theta] \right)}{b[1+\hat{\theta}_i]^3} \right) \\ &= -t [\lambda\mathbb{E}[h_\theta]] \left(\frac{\left(\left[(a-1)(1+\hat{\theta}_i) \right] - 2\lambda\mathbb{E}[h_\theta] \right)}{b[1+\hat{\theta}_i]^3} \right), \end{aligned} \quad (7.38)$$

- $\frac{\partial \tilde{T}_1^{(\tau_{\Delta\theta_i} > \tau_{\hat{\theta}})}}{\partial (1+\hat{\theta}_i)} < 0$: if $\left(\left[(a-1)(1+\hat{\theta}_i) \right] - 2\lambda\mathbb{E}[h_\theta] \right) < 0$, then $-\frac{(a-1)(1+\hat{\theta}_i)}{\lambda} < \mathbb{E}[h_\theta] < -\frac{(a-1)(1+\hat{\theta}_i)}{2\lambda}$;
- $\frac{\partial \tilde{T}_1^{(\tau_{\Delta\theta_i} > \tau_{\hat{\theta}})}}{\partial (1+\hat{\theta}_i)} > 0$: if $\left(\left[(a-1)(1+\hat{\theta}_i) \right] - 2\lambda\mathbb{E}[h_\theta] \right) > 0$, then $-\frac{(a-1)(1+\hat{\theta}_i)}{2\lambda} < \mathbb{E}[h_\theta] < -(1+\mu_\theta)$. \square

Proof of Corollary 5. From equation (7.37) in the proof of proposition 11, we have,

$$\frac{\partial \tilde{T}_1^{(\tau_{\Delta\theta_i} > \tau_{\hat{\theta}})}}{\partial \lambda} = \frac{t\mathbb{E}[h_\theta]}{b[1+\hat{\theta}_i]^2} \left(\left[(a-1)(1+\hat{\theta}_i) \right] + 2[\lambda\mathbb{E}[h_\theta]] \right), \quad (7.39)$$

- $\frac{\partial \tilde{T}_1^{(\tau_{\Delta\theta_i} > \tau_{\hat{\theta}})}}{\partial \lambda} \geq 0$: if $\left(\left[(a-1)(1+\hat{\theta}_i) \right] + 2[\lambda\mathbb{E}[h_\theta]] \right) \leq 0$, then $-\frac{(a-1)(1+\hat{\theta}_i)}{\lambda} < \mathbb{E}[h_\theta] \leq -\frac{(a-1)(1+\hat{\theta}_i)}{2\lambda}$;
- $\frac{\partial \tilde{T}_1^{(\tau_{\Delta\theta_i} > \tau_{\hat{\theta}})}}{\partial \lambda} \leq 0$: if $\left(\left[(a-1)(1+\hat{\theta}_i) \right] + 2[\lambda\mathbb{E}[h_\theta]] \right) \geq 0$, then $-\frac{(a-1)(1+\hat{\theta}_i)}{2\lambda} \leq \mathbb{E}[h_\theta] < -(1+\mu_\theta)$.

For a given choke price $a > (1+2\lambda) + \frac{2(\hat{\theta}_i - \mu_\theta)}{(1+\mu_\theta)}$, when $-\frac{(a-1)(1+\hat{\theta}_i)}{\lambda} < \mathbb{E}[h_\theta] < -(1+\mu_\theta)$, and $-1 < \mu_\theta < 0$, the expected transfer tends to be minimum in absolute value at $\lambda = -\frac{(a-1)(1+\hat{\theta}_i)}{2\mathbb{E}[h_\theta]}$. \square

7.2 Table 6

Table 6: The schedule of expected volumes for an operator type $\mathbb{E}[\tilde{\theta}_i | \hat{\theta}_i]$

	\tilde{q}_2	\tilde{q}_2^*	q_2^*	$\mathbb{E}[h_\theta] < -(1 + \mu_\theta)$ and when $-1 < \mu_\theta < (a - 1)$	$0 < \mathbb{E}[h_\theta] < [(a - 1)(1 + \mu_\theta) + (a - 2)\Delta\theta_i]$ and when $-1 < \mu_\theta < (a - 1)$
$\tau_{\tilde{\theta}} \rightarrow +\infty; \tau_{\Delta\theta_i} \rightarrow 0$ $\delta_1 = 0; \delta_2 = \frac{1}{a}$	$\frac{a(\frac{1}{a}(\hat{\theta}_i - \mu_\theta) + \mathbb{E}[h_\theta])}{b(1 + \mu_\theta)(1 + \mu_\theta + \frac{1}{a}(\hat{\theta}_i - \mu_\theta) + \mathbb{E}[h_\theta])}$	$\frac{(a-1)}{b(1 + \mu_\theta)}$	$\frac{a - (1 + \mu_\theta) + \frac{1}{a}(\hat{\theta}_i - \mu_\theta) + \mathbb{E}[h_\theta]}{b(1 + \mu_\theta)}$	$\mathbb{E}[q_2^*] > \mathbb{E}[\tilde{q}_2^*] > \mathbb{E}[\tilde{q}_2]$ Screening policy	$\mathbb{E}[\tilde{q}_2^*] > \mathbb{E}[\tilde{q}_2] > \mathbb{E}[q_2^*]$
	\tilde{q}_2	\tilde{q}_2^*	q_2^*	$\mathbb{E}[h_\theta] < -(1 + \mu_\theta)$ and when $-1 < \mu_\theta < (a - 1)$	$0 < \mathbb{E}[h_\theta] < \sqrt{a(1 + \hat{\theta}_i)} - (1 + \hat{\theta}_i)$ and when $-1 < \mu_\theta < (a - 1)$
$\tau_{\tilde{\theta}} \rightarrow 0; \tau_{\Delta\theta_i} \rightarrow +\infty$ $\delta_1 = 1; \delta_2 = 0$	$\frac{a\mathbb{E}[h_\theta]}{b(1 + \hat{\theta}_i)(1 + \hat{\theta}_i + \mathbb{E}[h_\theta])}$	$\frac{(a-1)}{b(1 + \hat{\theta}_i)}$	$\frac{a - (1 + \hat{\theta}_i) - \mathbb{E}[h_\theta]}{b(1 + \hat{\theta}_i)}$	$\mathbb{E}[q_2^*] > \mathbb{E}[\tilde{q}_2^*] > \mathbb{E}[\tilde{q}_2]$ Screening policy	$\mathbb{E}[\tilde{q}_2^*] > \mathbb{E}[q_2^*] > \mathbb{E}[\tilde{q}_2]$

7.3 Table 7

Table 7: The schedule of expected volumes for an operator type $(\mathbb{E}[\tilde{\theta}_i | \hat{\theta}_i])$

	\tilde{q}_1	q_1^*	\tilde{q}_2	$\mathbb{E}[h_\theta] < 0$ and $-1 < \mu_\theta < 0$	$\mathbb{E}[h_\theta] > 0$
$\tau_{\tilde{\theta}} \rightarrow +\infty; \tau_{\Delta\theta_i} \rightarrow 0$ $\delta_1 = 0; \delta_2 = \frac{1}{a}$	$\frac{\frac{a}{2}(\hat{\theta}_i - \mu_\theta) - \lambda\mathbb{E}[h_\theta]}{b(1 + \mu_\theta)(1 + \mu_\theta + \frac{a}{2}(\hat{\theta}_i - \mu_\theta))}$	$\frac{a - (1 + \mu_\theta) + \frac{1}{a}(\mu_\theta - \hat{\theta}_i)}{b(1 + \mu_\theta)}$	$\frac{a(\frac{1}{a}(\hat{\theta}_i - \mu_\theta) + \mathbb{E}[h_\theta])}{b(1 + \mu_\theta)(1 + \mu_\theta + \frac{a}{2}(\hat{\theta}_i - \mu_\theta) + \mathbb{E}[h_\theta])}$	$\mathbb{E}[\tilde{q}_2] < \mathbb{E}[\tilde{q}_1] < \mathbb{E}[q_1^*]$ when $-\frac{a - (1 + \mu_\theta)}{\lambda} < \mathbb{E}[h_\theta] < -\frac{(a - 1)(1 + 2\mu_\theta)}{\lambda}$	$\mathbb{E}[q^{contract1}] < 0$ Screening policy
$\tau_{\tilde{\theta}} \rightarrow 0; \tau_{\Delta\theta_i} \rightarrow +\infty$ $\delta_1 = 1; \delta_2 = 0$	$\frac{-\lambda\mathbb{E}[h_\theta]}{b(1 + \hat{\theta}_i)^2}$	$\frac{a - (1 + \hat{\theta}_i)}{b(1 + \hat{\theta}_i)}$	$\frac{a\mathbb{E}[h_\theta]}{b(1 + \hat{\theta}_i)(1 + \hat{\theta}_i + \mathbb{E}[h_\theta])}$	$\mathbb{E}[\tilde{q}_2] < \mathbb{E}[\tilde{q}_1] < \mathbb{E}[q_1^*]$ when $-\frac{a - (1 + \mu_\theta)}{\lambda} < \mathbb{E}[h_\theta] < -\frac{(a - 1)(1 + 2\mu_\theta)}{\lambda}$	$\mathbb{E}[q^{contract1}] < 0$ Screening policy

7.4 Table 8

Table 8: Informational rents and Ex-post participation rents

Misleading estimation	Contracts	Carrots (Informational rents)	Sticks (Ex-post participation rents)	Distortion
$\mathbb{E}[h_\theta] < 0$	$\{\tilde{q}_1, \tilde{T}_1\}$	$ \frac{\lambda}{a}\mathbb{E}[h_\theta] $	$\mathbb{E}[q^{loss}] = \mathbb{E}[q_1^*] - \mathbb{E}[\tilde{q}_1] = \frac{[a - (1 + \mu_\theta)](1 + \mu_\theta) + \lambda\mathbb{E}[h_\theta]}{b(1 + \mu_\theta)^2}$	$\tilde{q}_1 < q_1^*$
		$(\lambda_{\tau_{\Delta\theta_i} > \tau_{\tilde{\theta}}}^{transfer}) > (\lambda_{\tau_{\tilde{\theta}} > \tau_{\Delta\theta_i}}^{transfer})$	$ \tilde{T}_1^{(\tau_{\Delta\theta_i} > \tau_{\tilde{\theta}})} < \tilde{T}_1^{(\tau_{\tilde{\theta}} > \tau_{\Delta\theta_i})} $	
$\mathbb{E}[h_\theta] > 0$	$\{\tilde{q}_2^*, \tilde{T}_2^*\}$	$ \frac{\lambda}{a}\mathbb{E}[h_\theta] $	$\mathbb{E}[q^{loss}] = \mathbb{E}[\tilde{q}_2^*] - \mathbb{E}[q_2^*] = \frac{(a - 1)(1 + \mu_\theta) - \mathbb{E}[h_\theta]}{b(1 + \mu_\theta)(1 + \mu_\theta + \mathbb{E}[h_\theta])}$	$\tilde{q}_2^* > q_2^*$
			$\tilde{T}_2^* = 0$	

Part III

THE SELECTION STAGE OF THE DELEGATION

Strategic Learning in the Delegation of Water Services

Early and Preliminary Version

Abstract

This paper provides the possibilities of using yardstick competition in the delegation of public water services when there are enough public information. In an environment with symmetric, quadratic costs, and with normally distributed uncertainty about the quality of infrastructure, we associate a correlation coefficient structure, an information structure with yardstick competition. The analysis of Bayes correlated equilibrium shows that a high correlation across private information can lead yardstick competition to be efficient. The analysis of Bayes Nash equilibrium shows that an increase in the precision of public signal generates different levels of information disclosure, which affect the efficiency of yardstick competition. We find that these different levels of information disclosure depend not merely on the strategic interaction, but also on the correlation between actions of operators. With the correlation coefficient structure, the full and partial information disclosure limit operators' collusion behaviors in yardstick competition. The ex-ante competition of delegation process can be improved.

KEYWORDS. Service Quality; Uncertainty; Information Disclosure; Public and Private Signals; Strategic Substitutes; Correlated Equilibrium.

JEL CODES. C72, D82, D83.

1 Introduction

When found that consumers enjoy few advantages in the private provisions of public services, local public authorities are likely to apply ex-post interventions to adapt an initial contract. In the water sector, a local authority frequently reverts back to providing water services itself as long as it is unsatisfied by its private partner. Recent studies show that private operators exhibit high water prices on average,¹ but they rarely improve the quality of the networks of water mains. The poor quality results not only in water leaks, but also water resources wastage linked to inefficient private operator. Either ex post interventions of local authorities, or inefficiencies of private operators derive from the lack of competition when contracts of managing water services are attributed through the delegation process. It is known that the delegation process is composed into two principal stages. The first is the selection stage, where local authorities choose potential private operators. The second is the negotiation stage, where local authorities choose their final partner for the execution of contract. However, their final provider of public services may not be the most efficient of potential private operators.

A private operator generally obtains a temporary monopoly right to manage public water services during contract's lifetime. But the provision of services requires complex mixes of service quality, investments, and ex post adjustments to adapt realized conditions in network industries. These lead to uncertain events arising in the execution of the contract due to which local authorities may unilaterally change the terms of the contract after it is signed. It not only gives incentives to private operators to behave opportunely, but also generates transaction costs for local authorities in renegotiation. Therefore, reducing operators' opportunities and the transaction costs deriving from incomplete contracts, ex-ante competition in the selection stage of the delegation processes under asymmetric information is needed to improve.

In the water sector, there are not only major private operators, but also a number of small operators not affiliated with any of these major operators. However, the competition remains difficult at a local level. First, local conditions have impacts on the way the public water services are managed. In other words, special technical characters are needed to fill with local demands. For example, raw water used in the production of drinking water is generally found in a local area; the exploitation of water services depends on local demographic and geographic conditions; the water supply is influenced by local climate conditions. Few small operators can undertake costly water services, and thus the competition for winning the delegation is only among major operators. Then, even though the costs of managing water services are observed, a local authority lacks knowledge on how efficient an operator may become after winning the delegation contract. When using the two-stage delegation process, the local authority may give up some information rent to the selected private operator. And the magnitude of information rent depends on the competitive pressure during the selection stage. In order to limit information rent given up to the operator; then to promote the competition, it is necessary for the local authority to reduce asymmetric information when choosing potential operators.

¹In France, there are three principal players in the water sector: Veolia, Saur and Suez-Ondeo.

The object of this paper is to provide a possible regulatory approach to reduce asymmetric information and promote ex-ante competition in the delegation processes. It is yardstick competition that can be used in the selection stage. Yardstick competition was first advanced by Shleifer (1985). He argues that average observations on different operators in a particular service or in a local market can be publicly available. Then, such information can be used to deduce the private information of each operator. In his theoretical paper, Shleifer (1985) proposes that in an environment without uncertainty, the reward of an operator in cost-reduction expenditures must be made depending on average performances of other similar operators.² This type of regulation is considered “yardstick competition”. In an environment without uncertainty, by instigating some competition among regulated operators, such mechanism allows the regulator to reduce information rent and provide incentives to operators to achieve the efficient equilibrium outcome.

By contrast, in an environment with uncertainty, such as demand and cost shocks, yardstick competition cannot reach the optimal outcome because the regulator has biased estimates about the characteristics of operators. In addition, if the heterogeneity among operators is not accounted for, then the outcome diverges from the optimum. By this view, Auriol and Laffont (1992) introduce a stochastic structure assumption on the operators’ private information about their costs into yardstick competition. They show that even though there is uncertainty in operators’ cost functions, by the correlation coefficient across operators’ private information, the regulator can detect and punish incompatible reports made by operators. They also show that when using yardstick competition, the regulator can dissuade any untruthful reports through observing the correlation of operators’ private information. Hence, an optimal individual incentive contract can be proposed by the regulator after receiving reports on operators’ common adverse selection parameter measured as the correlation coefficient. In their static model, Auriol and Laffont (1992) find that since the common uncertainty can be filtered out in the first step of choosing potential operators, adverse selection asymmetry is reduced. The regulator gives up less costly informational rent to a selected operator. Therefore, being associated with the correlation coefficient across operators’ private information, yardstick competition can lead to a better solution.

Both Shleifer (1985) and Auriol and Laffont (1992) point out that an important limitation of yardstick competition is the possibility for operators to cooperate or to collude. Reducing informational rent caused by competitive pressure inclines operators towards collusion rather than competing against each other. In this case, yardstick competition is inefficient in providing incentives. Laffont and Martimort (2002) argue that, when using yardstick competition to compel operators to reveal their private information, the regulator gives also incentives to operators to collude. In addition, Laffont and Martimort (2002) show that when the correlation of operators’ private information tends to be perfect, yardstick competition may be completely inefficient. In fact, the higher is the correlation, the more easily to an operator to infer others’ private information from its own information. Hence, operators have interests to coordinate

²Similar operators are firstly considered by Shleifer (1985) that operators have identical cost functions and are comparable among themselves. Then, Shleifer (1985) says that if operators aren’t identical, then the regulator must correctly take into account heterogeneous factors affecting the operators when using yardstick competition.

on a collusive strategy.

In this paper, we try to provide the conditions improving the efficiency of yardstick competition. Thus, a local authority can better choose potential operators in the first-stage of the delegation processes. On the basis of the analysis of correlation coefficient in Auriol and Laffont (1992), we associate an exogenous information structure with yardstick competition. The information structure is a couple of precision of public and private signals. Indeed, there is common uncertainty faced by operators and a local authority, such as the true state of quality of water infrastructure. The information about the state of the infrastructure diffused by the local authority is not perfect. Besides their private information, operators receive noisy public information when making their strategic decisions. Moreover, the local authority needs all available information to reduce asymmetric information in the delegation process. Therefore, the efficiency of yardstick competition is influenced by not only the correlation coefficient across operators' private information, but also the precision of public and private signals.

With these issues in mind, our analysis is carried out with a static model. First, a basic model is the classical "cost-of-service" model in an environment without uncertainty. In this model, we set up an equilibrium at which the volume of water distribution chosen by an operator depends on three parameters: the operator's reaction to the state of the quality of infrastructure; the strategic interaction between the individual volume and the average volume; and the exogenous correlation coefficient across operators' private information about the quality of infrastructure. Then, in an environment with uncertainty, we consider two concepts of equilibrium with information structure that operators may have.

The first concept is the Bayes correlated equilibrium, in which for a fixed information structure, the equilibrium volume of yardstick competition depends on a couple of correlation coefficients. One is the correlation coefficient across operators' individual actions, the other is the correlation coefficient between an operator's individual action and the state of infrastructure quality. Both of them are linked to operators' private information. Pursuing the analysis of Bergemann and Morris (2013), we examine the yardstick competition with normally distributed uncertainty, a continuum of operators who have symmetric quadratic cost and payoff functions. In equilibrium, the expected individual volume is linear with the state of the quality and the average action taken by all other operators. As yardstick competition allows a local authority to exploit the correlation coefficient across operators' private information, we find that a high correlation across individual actions is not desirable to reveal an operator's private information, however, an increasing correlation between an operator's individual action and the state of infrastructure quality can compel the operator to reveal its private information. There are two positive effects on the expected profit in equilibrium: the Auriol-Laffont's yardstick competition effect, which is the better restriction of the dispersion of operators' actions provided by these two correlations; and the Auriol-Laffont's sampling effect, which is the positive impact of the average action on the profit. In consequence, when the demand for water consumption is inelastic at a local level; and when the strategic learning among all parties is weak, using the yardstick competition on the stage of choosing potential operators can be efficient if there are high correlation coefficients. Otherwise, information disclosure

policy is needed to improve the efficiency of yardstick competition.

The second concept is the Bayes Nash equilibrium, in which yardstick competition is associated with an exogenous information structure. A noisy private signal and a noisy public signal of the quality of the infrastructure are introduced into yardstick competition. The social value of information structure is widely analyzed by Morris and Shin (2002), Angeletos and Pavan (2007), Vives (2011, 2017) and Ui (2014). When maintaining symmetric and normality assumptions in the analysis, we used a known result of Bayes Nash equilibrium (see Morris and Shin, 2002; Angeletos and Pavan, 2007), which states that equilibrium expected individual volume is linear with the precision of public and private signals. Nevertheless, we find that in our model, the expected volume depends also on the operator's reaction to the state of infrastructure quality, the interaction between the individual action and the average action, and the exogenous correlation across operators' private information about the quality of the infrastructure. Therefore, in equilibrium, the ratio of weights put on the public and private signals depends proportionally on the ratio of public and private precisions. This proportion is measured by the strategic interaction between the operator's individual action and the average action. In this case, the public and private precisions can be respectively represented by the two correlation coefficients of Bayes correlated equilibrium.

Defining the degree of information disclosure in yardstick competition, we compare Bayes Nash equilibrium with Bayes correlated equilibrium. We find that an increase in the precision of public signal generates a high correlation across operators' actions, whereas an increase in the precision of private signal leads to a high correlation between an operator's individual action and the state of infrastructure quality. The reason is that there is a strategic substitute in learning from the correlation across private information. Indeed, under competitive pressure in yardstick competition, an operator tends to choose an action that is less correlated with the average action, but is greatly correlated with the state of the quality. Thus, an increase in the precision of private signal increases the dispersion across operators' actions. When reducing the negative impact of the dispersion on the expected profit, we find three levels of information disclosure. First, if the demand for water consumption is inelastic and the strategic learning is weak, then the full information disclosure is optimal in yardstick competition. In this case, a local authority can reduce informational rents by exploiting the high correlation across operators' private information. In addition, the full information disclosure leads to a self-selection between operators because of the exogenous correlation across private information about the infrastructure quality, which captures the problem of adverse selection in the symmetric cost function. Then, if the strategic learning is important, presented by a high correlation between individual action and the average action, then the partial public information is favorable for yardstick competition. Hence, yardstick competition can be used in the delegation of public water services in one municipality where the demand for water consumption is a little elastic. Finally, if the demand for water consumption is elastic, then it is better to not have information disclosure when the strategic learning is modest among operators. Otherwise, there is a possible collusive manipulation of operators when yardstick competition is used in the delegation of

public water services.

Section 2 presents the basic model of “cost-of-service”, and the information structure associated with the model. Section 3 examines the equilibrium under the complete information, the Bayes correlated equilibrium and the Bayes Nash equilibrium. Section 4 specializes the disclosed information in yardstick competition by comparing these two types of Bayes equilibrium. Section 5 summarizes our main findings.

2 Setup

2.1 The general model

A continuum of potential risk-neutral operators indexed by $i \in [0, 1]$ participates in the selection stage of delegation. We suppose that the management of public water services is served by one of operators, who may operate in an environment with uncertainty. Each operator chooses a distribution strategy $q_i \in R^+$. The average action of all operators is represented by $Q \in R^+$ and is the integral

$$Q \equiv \int_0^1 q_j dj. \quad (1)$$

In one municipality, the consumers’ gross surplus function is considered $S(Q)$ for $Q > 0$, and $P(Q) = S'(Q)$ is the inverse demand function. We assume that $S(Q)$ is strictly increasing and concave in Q :

$$P(Q) = S'(Q) > 0 \text{ and } P'(Q) = S''(Q) < 0 \text{ for } Q > 0. \quad (2)$$

A local authority sets up water price depending on the average level of volume of water consumed in one municipality. Hence, we write the inverse demand function with uncertainty about the quality of the infrastructure as

$$P(Q, \theta) = s\theta + rQ + \rho_{\theta\theta}, \quad (3)$$

where *the information parameter* s is supposed to be $s \neq 0$. $s > 0$ measures informational sensibility about a higher state of the quality θ , whereas $s < 0$ measures informational sensibility about a lower state of the quality θ . If the regulator doesn’t care about the quality of water networks, as $s = 0$, then it should tolerate a high volume of distributed water in order to keep low-level water prices in one municipality. *The interaction parameter* r is assumed to be $r < 0$. It represents the slope of the aggregated demand of water consumption in one municipality. In addition, we consider that in yardstick competition, the regulator can observe $\rho_{\theta\theta}$, the correlation between private signals across operators about the quality of water services (e.g. the quality of the infrastructure). We refer to it as *the correlated effect* (see Manski, 1993) on water price setting.

Potential operators have cost functions that are chosen strictly convex for positive distribution level, so that $C(q_i) = -\rho_{\theta\theta}q_i + (\frac{1}{2})(q_i)^2$. By the independence and the symmetry of private signals across

operators, $\rho_{\theta\theta}$ is exogenously given. It captures the adverse selection effects in cost functions (see Vives, 2011). When the precision of private signal is low, $\rho_{\theta\theta}$ sends less private information and the adverse selection is worsen. The cost functions become steeper. But when the precision private signal is high, $\rho_{\theta\theta}$ sends more private information. The cost functions are flatter.

All operators have the same utility function. The utility function of an operator is given by:

$$\begin{aligned} U &= \pi_i + T \\ U &= (1-t)[P(Q, \theta)q_i - C(q_i)] \end{aligned} \quad (4)$$

where $T = -t\pi_i$ is a part of payoffs of the operator that is transferred to the regulator. For tractability, we assume that the part of payoffs transferred to the regulator does not affect welfare:

$$\begin{aligned} &S(Q) - P(Q, \theta)q_i + t\pi_i + (1-t)\pi_i \\ &= S(Q) - P(Q, \theta)q_i + \pi_i. \end{aligned} \quad (5)$$

Henceforth, the regulator picks q_i to maximize:

$$S(Q) - C(q_i) \quad (6)$$

subject to the breakeven constraint:

$$U \geq 0 \quad (7)$$

Equation (6) specifies that for a given water price, the regulator cares about the total surplus of one municipality. Constraint equation (7) indicates that the payoffs must at least cover the transfer.

2.2 Information structure

The true state of the quality of the infrastructure $\theta \in \Theta$ is unknown at the time of delegation. But the regulator and potential operators share a common prior: $\theta \sim N(\mu_\theta, \sigma_\theta^2)$. We consider that each operator observes a public signal $\tilde{\theta} = \theta + \eta$, where the common noise is $\eta \sim N(0, \sigma_\eta^2)$. At the same time, each operator forms a private signal $\tilde{\theta}_i = \theta + \varepsilon_i$, where the idiosyncratic noise is $\varepsilon_i \sim N(0, \sigma_{\varepsilon_i}^2)$. All the noise terms are uncorrelated and independent of θ . Moreover, the correlation coefficient between the independence and symmetry of private signals across potential operators in yardstick competition is given as $\rho_{\theta\theta} = \frac{cov(\tilde{\theta}_i, \tilde{\theta}_j)}{\sigma_{\tilde{\theta}_i}^2} = \frac{\sigma_\theta^2}{\sigma_{\tilde{\theta}_i}^2} \equiv \frac{\tau_{\varepsilon_i}}{\tau_\theta + \tau_{\varepsilon_i}}$. It is measured the ratio between the precision of private signal and total precision of signals. So it captures the different qualities of signals about the quality of water networks. Further, we express the variance of the random variables in terms of the precision:

$$\tau_{\tilde{\theta}_i} \equiv \sigma_{\varepsilon_i}^{-2}, \tau_{\tilde{\theta}} \equiv \sigma_\eta^{-2}, \tau_\theta \equiv \sigma_\theta^{-2}, \text{ and } \tau \equiv \tau_\theta + \tau_{\tilde{\theta}} + \tau_{\tilde{\theta}_i}.$$

Associating exogenous information structures with yardstick competition, we are interested in analyzing what is the best response either for potential operators, or for the regulator observing the correlation between operators' signals about the quality of water services.

3 The Equilibrium

We consider a symmetric equilibrium. Before characterizing it in environments with complete and incomplete information, we describe the timing of the selection stage. The regulator proposes a yardstick competition mechanism and announces its pricing rule, in which it describes how it sets water prices on the basis of what it observes. Then, operators make their announcements, in which the regulator observes their cost levels. After equipping this knowledge, the regulator sets production and transfers according to the rule it announced, at the same time each operator assigns its distribution strategy depending on θ . Finally, the regulator chooses at least two competitive operators with whom it will negotiate for the delegation contract. Besides, during the two-stage delegation process the gross consumers' benefit from the project of contract-out management is exogenously fixed at $S(Q)$, which is known by both the regulator and potential operators.

3.1 Complete information

Considering each operator observes the state of the quality θ without noise, it is complete information environment. At any given regulator-set price, an operator has to distribute to meet the demand of water consumption in one municipality. The operator cannot refuse to distribute water if it finds that the price the regulator has set is not sustainable for its costs.

Since the regulator must guarantee that operators are interesting in participating in yardstick competition, it sets $U \geq 0$. The utility function is symmetric and quadratic for all operators:

$$U = (1 - t) \left((s\theta + rQ)q_i + 2\rho_{\theta\theta}q_i - \frac{1}{2}q_i^2 \right), \quad (8)$$

where $r < 0$. It satisfies $U_{qq} < 0$. The interaction between the individual action and the average action is bounded by the own action, such that $-U_{qQ}/U_{qq} < 1$. Hence, an operator chooses its best response to minimize its loss considered $(-t) \left((s\theta + rQ)q_i + 2\rho_{\theta\theta}q_i - \frac{1}{2}q_i^2 \right)$.

Assumption 1. $(1 + 2\lambda)P'(Q)q + \lambda P''(Q)q - (1 + \lambda)C''(q) \leq 0$.

Under assumption 1, if the shadow price of constraint (7) $\lambda \geq 0$ is small enough, then the optimization program of the regulator (see (6) and (7)) is concave and yields two solutions under complete information, for $q = Q$

$$\frac{P(q^*) - C'(q^*)}{P(q^*)} = \frac{\lambda}{1 + \lambda} \frac{1}{\xi(q^*)}, \quad (9)$$

$$q^*(\theta) = \frac{s}{1 - 2r} \theta + \frac{2\rho_{\theta\theta}}{1 - 2r}, \quad (10)$$

where $\xi(q^*)$ is the price elasticity and q^* the regulated full information volume level of water distribution.

Note that Equation (9) is a form of Ramsey pricing. The left side is Lerner index. The right side is elasticity equation that the income effects of pricing is taken into account. So the Lerner index is inversely proportional to the elasticity of demand for water consumption in one municipality. Equation (10) is the breakeven condition. It is an interior equilibrium strategy. As we assume that $s \cdot \theta > 0$ and $r < 0$, $\frac{2\rho_{\theta\theta}}{1-2r}$ is the equilibrium intercept, depending on the exogenous correlation coefficient between private signals about the quality of the infrastructure. $|\frac{s}{1-2r}|$ is the equilibrium slope measuring the response of the equilibrium strategy to the true state of the quality θ .

When q^* is given by Equation (10), a symmetric equilibrium yields costs and water prices satisfying (9). Therefore, under complete information, the unique Nash equilibrium of yardstick competition depending the state θ . It is similar to the “reduced-form regulation” in Shleifer (1985).

3.2 Incomplete information

Even when yardstick competition is used to select potential operators, in the presence of asymmetric information, the regulator lacks knowledge on how efficient an operator possibly and reasonably becomes. Some information rent has to be given up in order to have access to the operator’s private information.

Without the public information, information rent may lead to higher water price paid by consumers whose water services are run through a private operator. Now, if the regulator would like to eliminate the dependence of the water price at an operator’s chosen volume level, then it uses the average volume level to determine the price. All operators are subject to competitive pressures. Each operator is assigned its own “shadow peer”, with the average action Q , and with the quality state θ . Hence, an operator sets the best volume level of water distribution as its expectations over the average action Q , and the state of the quality θ , by conditioning on its own information contained in q_i

$$q_i = s\mathbb{E}[\theta|q_i] + r\mathbb{E}[Q|q_i] + 2\rho_{\theta\theta}, \quad (11)$$

for all i and $q_i \in R^+$. r , s and $\rho_{\theta\theta} \in R$ are the interaction parameters of the best response function and are assumed to be identical across operators in yardstick competition. The interaction parameter $r < 0$ represents the “strategic substitutes”: an operator chooses a high volume if it expects that the average volume is low, whereas it chooses a low volume if there is a high average volume. In particular, the case of $r = 0$ indicates that an operator simply responds the state of the quality θ and it does not care about its interaction with the other operators. The informational parameter $s \neq 0$ measures the responsiveness of an operator to the state of the quality of water networks θ . In addition, the correlation coefficient between the private signals of any two operators $\rho_{\theta\theta}$ represents a measure of the “commonality” of the quality shocks across operators, and implies that operators’ best responses are also affected by common environmental factors.

3.2.1 The expected individual strategic action

We consider a symmetric and normally distribute correlated equilibrium. To characterize it, we assume that a probability distribution ω is the joint distribution of the individual action q_i , the average action Q , and the state of the quality θ . For any such ω , there is then a conditionally independent draw of $q \in R^+$ according to Q . Hence, we use a known definition in Bergemann and Morris (2013) that extends the notion of a correlated equilibrium in Aumann (1987) to an uncertain environment, represented by the state of the world θ :

Definition 1. A probability distribution $\omega \in (R^+ \times R^+ \times \Theta)$ is a symmetric Bayes correlated equilibrium if

$$\mathbb{E}_{\omega(\cdot|q)} [U(q, Q, \theta) | q] \geq \mathbb{E}_{\omega(\cdot|q)} [U(q', Q, \theta) | q], \quad (12)$$

for each $q \in R^+$ and $q' \in R^+$.

Conditioning on the information yielded in q , when an operator chooses q , it should have not any incentives to deviate by choosing any other action q' . In other words, each potential operator conditions only on its action and not on any additional information in yardstick competition.

By definition 1, we assume that $\mu_Q = \mathbb{E}[Q] = \mu_q$, and the individual action q deviates from the average action. Let us denote $q_i - Q$. Thus, the distribution of q_i centers around Q with the dispersion $\sigma_\epsilon^2 = \mathbb{E}\{[q_i - Q]\}^2$. In this case, we can write $q_i = Q + \epsilon$ for $\epsilon \sim N(0, \sigma_\epsilon^2)$. Moreover, ϵ is independent of Q . By the assumption of symmetric equilibrium, we describe the joint distribution of (θ, Q, q_i) as

$$\begin{pmatrix} \theta \\ Q \\ q_i \end{pmatrix} \sim N \left(\begin{pmatrix} \mu_\theta \\ \mu_q \\ \mu_q \end{pmatrix}, \begin{pmatrix} \sigma_\theta^2 & \rho_{q\theta}\sigma_q\sigma_\theta & \rho_{q\theta}\sigma_q\sigma_\theta \\ \rho_{q\theta}\sigma_q\sigma_\theta & \rho_{qq'}\sigma_q^2 & \rho_{qq'}\sigma_q^2 \\ \rho_{q\theta}\sigma_q\sigma_\theta & \rho_{qq'}\sigma_q^2 & \sigma_q^2 \end{pmatrix} \right). \quad (13)$$

Given that an individual strategic action of an operator at equilibrium is based on the information contained in its action, we can characterize the equilibrium conditional expectation of an operator's action q_i . By the joint distribution described in (13) and the law of total expectation, we have

$$\mathbb{E}[q_i] = s\mathbb{E}[\mathbb{E}[\theta|q_i]] + r\mathbb{E}[\mathbb{E}[Q|q_i]] + 2\rho_{\theta\theta}. \quad (14)$$

By symmetry, the expectation of action q_i is equal to the expectation of average action Q , such that $\mathbb{E}[q_i] = \mathbb{E}[Q]$. For any given interaction parameter $r < 0$, the mean of the individual volume is

$$\mathbb{E}[q_i] = \frac{2\rho_{\theta\theta} + s\mathbb{E}[\theta]}{1-r} = \left(\frac{s}{1-r} \right) \mu_\theta + \frac{2\rho_{\theta\theta}}{1-r}. \quad (15)$$

In addition, when exogenous correlation coefficient across operators' private signals $\rho_{\theta\theta} \in [0, 1]$, it is necessary that the mean of the individual action satisfies $s \cdot \mu_\theta \geq 0$. Therefore, the sign of the information parameter s has to equal the sign of average information about the state of the quality μ_θ .

Under incomplete information, the slope of the expected equilibrium individual strategic action defined by (15) is higher than that under full information in (10): for any given interaction parameter $r < 0$, it is straightforward that $|\frac{s}{1-r}| > |\frac{s}{1-2r}|$. The linear coefficients of the equilibrium strategy under incomplete information are more responsive to the true state θ than under complete information. Intuitively this can be explained by the fact that in yardstick competition, an operator is more sensitive to the quality when it is assigned its own “shadow operator” with a similarly defined equilibrium strategy.

According to the conditional expectation of the state of the quality, and of the average action, how does the best volume of water distribution expected by an operator change? As the best response of an operator q_i , see (11), must hold for all $q_i \in R^+$, we observe that the conditional expectation of the state of the quality $\mathbb{E}[\theta|q_i]$ and of the average action $\mathbb{E}[Q|q_i]$ should change with q_i by maintaining the best response property. Hence, by an ordinary differential equation

$$1 = \left(s \frac{d\mathbb{E}[\theta|q_i]}{dq_i} + r \frac{d\mathbb{E}[Q|q_i]}{dq_i} \right), \quad (16)$$

for all $q_i \in R^+$. Using (13) and (15), we obtain

$$1 = s \frac{\rho_{q\theta}\sigma_\theta}{\sigma_q} + r\rho_{qq'}. \quad (17)$$

■ See appendix.

By (17), the expected individual strategic action, at equilibrium, reacts to information revealed by two correlation coefficients: the correlation between an operator’s action and the state of the quality, $\rho_{q\theta}$; the correlation across individual actions of any two operators, $\rho_{qq'}$. At the same time, the higher is $\rho_{q\theta}$, the further deviate the individual action from the average action, however, the higher is $\rho_{qq'}$, the closer is the individual action to the average action. Therefore, the dispersion of the expected individual strategic action $\sigma_q^2 = \mathbb{E}\{[\mathbb{E}[q_i] - \mu_q]\}^2$ can be written by

$$\sigma_q^2 = \left(\frac{s\rho_{q\theta}\sigma_\theta}{1 - r\rho_{qq'}} \right)^2, \quad (18)$$

where σ_q is non-negative. By the assumption of symmetric normal distribution, see (13), the correlation coefficient across the actions of any two operators is $\rho_{qq'} = \frac{\sigma_Q^2}{\sigma_q^2} > 0$.³ The correlation coefficient of an operator’s action with the state of the quality is $\rho_{q\theta} = \rho_{Q\theta} \frac{\sigma_Q}{\sigma_q} = \rho_{Q\theta} \sqrt{\rho_{qq'}}$. It is worth noting that $\rho_{q\theta} \leq \sqrt{\rho_{qq'}}$.

As $\sigma_q \geq 0$, for any $\sigma_\theta > 0$, it is better to have both $1 - r\rho_{qq'} > 0$ and $s \cdot \rho_{q\theta} \geq 0$. Here, note that the sign of information parameter s should equal the sign of the correlation coefficient $\rho_{q\theta}$. For example, as the state of the quality decreases, the average volume of distributed water increases. In this case, $\rho_{q\theta} < 0$. The reaction of an operator to information revealed by $\rho_{q\theta}$ should be $s < 0$ in its expected strategic action. If the state of the quality increases, but the average volume of distributed water also increases, then $\rho_{q\theta} > 0$. Thus, the reaction to information revealed by $\rho_{q\theta}$ should be $s > 0$

³Under the assumption of symmetric normal distribution, we have $\sigma_Q^2 = \rho_{qq'}\sigma_q^2$.

in the operator's expected strategic action. Intuitively both cases mean that the operator at equilibrium estimates the volume of distributed water at least as high as the average level.

Moreover, for $\sigma_\theta^2 > 0$, the symmetric variance-covariance matrix described in (13) has a nonnegative determinant if and only if the correlation coefficient $\rho_{q\theta} \in [-\sqrt{\rho_{qq'}}, +\sqrt{\rho_{qq'}}]$. In particular, if $\rho_{q\theta} = 0$, but $\rho_{qq'} \neq 0$, then the action of each operator does not have any correlation with the state of the quality θ . Thus, the dispersion of the expected individual strategic action σ_q^2 tends to be zero in (18). The average action becomes constant, so that $\mathbb{E}[q_i] \equiv \mathbb{E}[Q] = \mu_q$. Each operator acts as if it were in a complete information, depending on the expected value of the state of the quality $\mathbb{E}[\theta]$ and the exogenous correlation coefficient $\rho_{\theta\theta}$. By our analysis in (3.1), if the operators choose the same action in equilibrium, so that $\rho_{qq'} = 1$, then the interaction parameter $r = -1$. In this case, we have the equilibrium individual strategic action

$$\mathbb{E}[q_i] = \left(\frac{s}{2}\right)\mu_\theta + \rho_{\theta\theta}. \quad (19)$$

Comparing with complete information,⁴ an operator at equilibrium reacts more to information about the quality of the infrastructure because its strategic action can be substituted by others in yardstick competition.

The analysis from (14) to (18) highlights that the joint normal distribution $(\theta, Q, q_i,)$ can have a symmetric Bayes correlated equilibrium. It is noteworthy that (15) and (18) are unaffected by the number of operators in yardstick competition. Using the results of (15), (17) and (18), we focus on the ex post profit expected by an operator when it chooses its own action q_i .

3.2.2 Ex post expected profit with Bayes Correlated Equilibrium

The regulator needs to reduce the dispersion of an operator's action in yardstick competition, because the more dispersion is the individual action, the more heterogeneity are exogenous characteristics for the regulator. Shleifer (1985) points out that, if heterogeneity is accounted for correctly and completely, then the equilibrium outcome of yardstick competition can be efficient. We assume that whatever exogenous characteristics are correlated with θ , the individual strategic actions are correlated with each other. Even though operators have not a prior access to a specific information structure, the regulator can use the correlation structure $(\rho_{q\theta}, \rho_{qq'})$ to limit the dispersion of an operator's strategic action at equilibrium in order to reduce the costs of asymmetric information.

At equilibrium, the ex-post profit expected by an operator is given by

$$\mathbb{E}[\pi_i] = \mathbb{E}\left[(s\theta + rQ + \rho_{\theta\theta})q_i + \rho_{\theta\theta}q_i - \frac{1}{2}q_i^2\right], \quad (20)$$

⁴By Equation (10), when $r = -1$, $q_i(\mathbb{E}[\theta]) = \left(\frac{s}{3}\right)\mu_\theta + \frac{2}{3}\rho_{\theta\theta}$.

hence, we find that

$$\begin{aligned}
\mathbb{E}[\pi_i] &= s\mathbb{E}[\theta q_i] + r\mathbb{E}[Qq_i] + 2\rho_{\theta\theta}\mathbb{E}[q_i] - \frac{1}{2}\mathbb{E}[q_i^2] \\
&= \underbrace{\sigma_q^2 \left(s \frac{\rho_{q\theta}\sigma_\theta}{\sigma_q} + r\rho_{qq'} - \frac{1}{2} \right)}_{\text{the yardstick competition effect}} + \underbrace{\mu_q \left[s\mu_\theta + 2\rho_{\theta\theta} + \left(r - \frac{1}{2} \right) \mu_q \right]}_{\text{the sampling effect}}
\end{aligned} \tag{21}$$

■ See appendix.

The first term in Equation (21) is referred to as *the yardstick competition effect* under incomplete information. This effect is positive and can be decomposed in two parts. First, there is a direct effect linked to the correlation coefficients of the equilibrium $(\rho_{qq'}, \rho_{q\theta})$. Conversely, there is an indirect negative effect on the expected profit because of the dispersion of an individual strategic action. In the best response at q_i , see (17), since the sum of $s \frac{\rho_{q\theta}\sigma_\theta}{\sigma_q} + r\rho_{qq'}$ equals one, the expected profit of an operator in yardstick competition is guaranteed by the first effect.

The second term in equation (21) is considered *the sampling effect* under incomplete information. Its first part $\mu_q (s\mu_\theta + 2\rho_{\theta\theta})$ is higher than under the complete information (see Equation (10)) because of the average action of other operators. Then, there is a second term $\mu_q^2 (r - \frac{1}{2})$, which is negative due to the strength of the interaction. Therefore, the sampling effect can be positive. If $|r|$ is small enough, then the sampling effect may be higher under incomplete information than under the complete information.

Moreover, for the given positive sampling effect, the expected profits can be reduced by the variance of individual strategic action, so that $-\frac{1}{2}\sigma_q^2$. Thus, we minimize the variance of individual strategic action $\sigma_q^2 = \left(\frac{s\rho_{q\theta}\sigma_\theta}{1-r\rho_{qq'}} \right)^2$ in order to analyze how the correlations $\rho_{q\theta}$ and $\rho_{qq'}$ affect the expected profit. To this end, we assume that the part of loss in the expected profit is given by

$$Loss_{\mathbb{E}[\pi_i]} = \frac{s^2 \rho_{q\theta}^2 \sigma_\theta^2}{2(1-r\rho_{qq'})^2}, \tag{22}$$

where $\rho_{q\theta}^2 \leq \rho_{qq'}$ and $s \cdot \rho_{q\theta} \geq 0$. If $\rho_{q\theta}^2 = \rho_{qq'}$, then the effect of $\rho_{qq'}$ on the loss in the expected profit can be expressed by

$$\min_{\rho_{qq'}} Loss_{\mathbb{E}[\pi_i]} = \frac{s^2 \rho_{qq'} \sigma_\theta^2}{2(1-r\rho_{qq'})^2}, \tag{23}$$

and

$$\frac{s^2 \sigma_\theta^2 (1+r\rho_{qq'})}{(1-r\rho_{qq'})^3} = 0. \tag{24}$$

We find that, for any given interaction parameter $r < 0$,

$$\left\{ \begin{array}{l} \rho_{qq'} = -\frac{1}{r}, \\ \text{or} \\ \rho_{qq'} \neq -\frac{1}{r}. \end{array} \right. \quad (25)$$

The parameter r presents not only “the interaction” between the individual action and the average action in an operator’s best response, but also the slope of the inverse demand curve. If $-1 \leq r < 0$, then the demand for water is inelastic, or the marginal effect of average action on the individual best response is weak. In this case, $\rho_{qq'} = \rho_{q\theta} = 1$. There is the perfect correlation between the individual actions of any two operators, or between the action of an operator and the state of the quality. The expected profit reaches maximum at $\rho_{qq'} = \rho_{q\theta} = 1$.

However, if $r < -1$, then the correlation coefficient across the actions of operators is strictly less than 1: $\rho_{qq'} = -\frac{1}{r} < 1$. For some $|\rho_{q\theta}| \equiv \sqrt{\rho_{qq'}} < 1$, the expected profit can be maximized at an interior value of $\rho_{qq'}$ because the dispersion of the individual action σ_q^2 is limited by a high interaction parameter: $|r| > 1$. In this case, yardstick competition need to be associated with the information disclosure policy represented by the public and private signals. The above analysis leads us to reach one main result of this paper.

Proposition 1. At a symmetric Bayes correlated equilibrium, the expected profit of an operator increases with the correlation coefficient $\rho_{q\theta}$, but decreases with the correlation between the volume of water distribution chosen by operators $\rho_{qq'}$. In yardstick competition, it is optimal to have the complete information through the perfect correlations $\rho_{qq'} = \rho_{q\theta} = 1$ when the demand is insensitive to price.

The first part of the proposition indicates that the correlation coefficient $\rho_{q\theta}$ can be set as high as possible until $|\rho_{q\theta}| \equiv \sqrt{\rho_{qq'}}$. Hence, in yardstick competition, not only the expected profit of an operator that can increase with $\rho_{q\theta}$, but also the regulator that can benefit from more information disclosed by $\rho_{q\theta}$. Therefore, yardstick competition is efficient when there is a high correlation of the volume of water distribution chosen by an operator with the state of the quality θ . However, a high correlation between the volume chosen by operators $\rho_{qq'}$, makes the expected profit of an operator lower because the operator’s payoff depends on its counterparts’ actions in yardstick competition.

The second part of the proposition indicates that when operators compete to obtain a local monopoly market (e.g., water services) where the demand for water consumption is sufficiently inelastic, as $0 < |r| < 1$, using yardstick competition can be efficient as correlation between the operators’ private information is perfect at $\rho_{qq'} = \rho_{q\theta} = 1$. Otherwise, it is the precision of public and private information that affects the expected best response of an operator, a fortiori, the efficiency of yardstick competition because for a given $|r| > 1$, $\rho_{qq'} = \rho_{q\theta}^2 = -\frac{1}{r} < 1$. Intuitively, this means that, whatever is the signal, public or private, an increase in the precision of the signal may lead to an increase in the correlation of strategic

action across operator as well as in the correlation between individual action and state of the quality.

By Proposition 1, we ask how the information structure encompassing the precision of public and private signals affects the efficiency of yardstick competition: Whether the precision of the signals allows the regulator to explore more information from the correlation structure or leads operators to collude with each other in the selection-stage of delegation process.

3.2.3 Ex post expected profit with Bayes Nash equilibrium

Now we suppose that yardstick competition combined with the information structure is a two-stage game, where each operator receives bivariate noisy signals $(\tilde{\theta}_i, \tilde{\theta})$. In the first stage, each operator chooses the precision of private information. In the second stage, each operator observes public and private signals and chooses an individual action q_i . We analyze how the precision of public and private signals affects the correlation between operators' actions $\rho_{qq'}$, and the correlation of an operator's action with the true state of the quality $\rho_{q\theta}$ in their strategic responses? To this end, we firstly consider a symmetric strategy in incomplete information given by $q: (R^+ \times R^+ \rightarrow R^+)$, then we describe a Bayes Nash equilibrium.

Definition 2 . Conditioning on the public and private signals, a symmetric strategy q is a Bayes Nash equilibrium if

$$\mathbb{E} \left[U \left(q(\tilde{\theta}_i, \tilde{\theta}), Q, \theta \right) | \tilde{\theta}_i, \tilde{\theta} \right] \geq \mathbb{E} \left[U \left(q', Q, \theta \right) | \tilde{\theta}_i, \tilde{\theta} \right]$$

for all $\tilde{\theta}_i, \tilde{\theta} \in R$ and $q' \in R^+$.

An operator i does not directly observe the actions of others, but it can form its conditional expectation about their actions on the basis of the private signal $\tilde{\theta}_i$ and the public signal $\tilde{\theta}$. In doing so, the best response function of an operator i (see Equation (11)) becomes a symmetric strategy conditional on the information structure $(\tilde{\theta}_i, \tilde{\theta})$

$$q_i = s\mathbb{E} \left[\theta | \tilde{\theta}_i, \tilde{\theta} \right] + r\mathbb{E} \left[Q | \tilde{\theta}_i, \tilde{\theta} \right] + 2\rho_{\theta\theta}. \quad (26)$$

It is a linear symmetric equilibrium with normal distribution. To characterize (26) and obtain the equilibrium strategy depending on the signals $\tilde{\theta}_i$ and $\tilde{\theta}$, we utilize a known result that has appeared in Morris and Shin (2002) and Angeletos and Pavan (2007).

Lemma 1. At a Bayes Nash equilibrium of the second-stage game, $\tau_{\tilde{\theta}_i} = \tau_{\tilde{\theta}_j}$ for all operators $i, j \in [0, 1]$.

An operator i 's strategic action depends linearly and proportionally on the private and public signals, so that

$$q_i(\tilde{\theta}_i, \tilde{\theta}) = \delta_0 + \delta_{\tilde{\theta}_i} \tilde{\theta}_i + \delta_{\tilde{\theta}} \tilde{\theta}, \quad (27)$$

where δ_0 , $\delta_{\tilde{\theta}_i}$, and $\delta_{\tilde{\theta}}$ are the coefficients of the equilibrium strategy determined by the interaction parameters $(r, s, 2\rho_{\theta\theta})$ and the information structure $(\tau_{\tilde{\theta}_i}, \tau_{\tilde{\theta}})$.

By Lemma 1, the conditional expectations in the best response of an operator i are rewritten as

$$q_i = s \left(\frac{\tau_{\tilde{\theta}_i} \tilde{\theta}_i + \tau_{\tilde{\theta}} \tilde{\theta} + \tau_{\theta} \mu_{\theta}}{\tau} \right) + r \left\{ \left(\delta_0 + \frac{\delta_{\tilde{\theta}_i} \tau_{\theta} \mu_{\theta}}{\tau} \right) + \left(\frac{\delta_{\tilde{\theta}_i} \tau_{\tilde{\theta}_i}}{\tau} \right) \tilde{\theta}_i + \left(\frac{\delta_{\tilde{\theta}_i} \tau_{\tilde{\theta}}}{\tau} + \delta_{\tilde{\theta}} \right) \tilde{\theta} \right\} + 2\rho_{\theta\theta}, \quad (28)$$

where $s \cdot \mu_{\theta} > 0$, $r < 0$, and $\tau \equiv \tau_{\theta} + \tau_{\tilde{\theta}_i} + \tau_{\tilde{\theta}}$. From (27) and (28), we can obtain a linear equilibrium with the information structure that is similar to the analysis in Bergemann and Morris (2013).

Proposition 2. A linear symmetric equilibrium of yardstick competition is a Bayes Nash equilibrium

$$q_i^{BNE}(\tilde{\theta}_i, \tilde{\theta}) = \delta_0^* + \delta_{\tilde{\theta}_i}^* \tilde{\theta}_i + \delta_{\tilde{\theta}}^* \tilde{\theta}, \text{ with the coefficients}$$

$$\delta_0^* = \frac{2\rho_{\theta\theta}}{1-r} + \left(\frac{s}{1-r} \right) \frac{\tau_{\theta} \mu_{\theta}}{\tau - r\tau_{\tilde{\theta}_i}}, \quad \delta_{\tilde{\theta}_i}^* = \frac{s\tau_{\tilde{\theta}_i}}{\tau - r\tau_{\tilde{\theta}_i}}, \quad \delta_{\tilde{\theta}}^* = \left(\frac{1}{1-r} \right) \frac{s\tau_{\tilde{\theta}}}{\tau - r\tau_{\tilde{\theta}_i}}. \quad (29)$$

■ See appendix.

By Proposition 2, if the interaction parameter $r = 0$, then $q_i^{BNE}(\tilde{\theta}_i, \tilde{\theta}) = 2\rho_{\theta\theta} + s \left[\left(\frac{\tau_{\theta}}{\tau} \right) \mu_{\theta} + \left(\frac{\tau_{\tilde{\theta}_i}}{\tau} \right) \tilde{\theta}_i + \frac{\tau_{\tilde{\theta}}}{\tau} \tilde{\theta} \right]$.

The best response of an operator i at equilibrium depends only on its sensibility to the precision of signals about the quality of water mains. In addition, we recall that $\rho_{\theta\theta} = \frac{\tau_{\varepsilon_i}}{\tau_{\theta} + \tau_{\varepsilon_i}}$. In the absence of strategic interaction, the best volume chosen by an operator i is linked to the relative precision of the public and private signals. In other words, the ability of the signals to predict the true state of the quality θ .

However, if the interaction parameter $r \neq 0$, then we obtain a relationship between the weight put respectively on the public and private signal. It depends proportionally on the ratio of private precision with public precision, so that $\frac{\delta_{\tilde{\theta}_i}^*}{\delta_{\tilde{\theta}}^*} = (1-r) \frac{\tau_{\tilde{\theta}_i}}{\tau_{\tilde{\theta}}}$. For a given precision of public and private signals, when $r < 0$, or for a given r , when $\tau_{\tilde{\theta}_i} > \tau_{\tilde{\theta}}$ due to $\tau_{\varepsilon_i} \rightarrow +\infty$, then an operator i would put more weight on its own private signal than the public signal. In doing so, its individual strategic action moves away from the average action. Thus, we focus on how the correlation coefficients $\rho_{qq'}$ and $\rho_{q\theta}$ vary with the information structure $(\tau_{\tilde{\theta}_i}, \tau_{\tilde{\theta}})$ at the Bayes Nash equilibrium.

We need to define the symmetric variance-covariance matrix of the equilibrium joint distribution over (θ, Q, q_i) in terms of $(\delta_{\tilde{\theta}_i}, \delta_{\tilde{\theta}})$ and $(\sigma_{\theta}^2, \sigma_{\tilde{\theta}_i}^2, \sigma_{\tilde{\theta}}^2)$:

$$\Sigma \begin{pmatrix} \theta \\ Q \\ q_i \end{pmatrix} = \begin{pmatrix} \sigma_{\theta}^2 & \sigma_{\theta}^2(\delta_{\tilde{\theta}_i} + \delta_{\tilde{\theta}}) & \sigma_{\theta}^2(\delta_{\tilde{\theta}_i} + \delta_{\tilde{\theta}}) \\ \sigma_{\theta}^2(\delta_{\tilde{\theta}_i} + \delta_{\tilde{\theta}}) & \delta_{\tilde{\theta}_i}^2 \sigma_{\tilde{\theta}_i}^2 + \sigma_{\tilde{\theta}}^2(\delta_{\tilde{\theta}_i} + \delta_{\tilde{\theta}})^2 & \delta_{\tilde{\theta}}^2 \sigma_{\tilde{\theta}}^2 + \sigma_{\tilde{\theta}}^2(\delta_{\tilde{\theta}_i} + \delta_{\tilde{\theta}})^2 \\ \sigma_{\theta}^2(\delta_{\tilde{\theta}_i} + \delta_{\tilde{\theta}}) & \delta_{\tilde{\theta}_i}^2 \sigma_{\tilde{\theta}_i}^2 + \sigma_{\tilde{\theta}}^2(\delta_{\tilde{\theta}_i} + \delta_{\tilde{\theta}})^2 & \delta_{\tilde{\theta}_i}^2 \sigma_{\tilde{\theta}_i}^2 + \delta_{\tilde{\theta}}^2 \sigma_{\tilde{\theta}}^2 + \sigma_{\tilde{\theta}}^2(\delta_{\tilde{\theta}_i} + \delta_{\tilde{\theta}})^2 \end{pmatrix} \quad (30)$$

■ See appendix.

Since $\rho_{q\theta} \sigma_q \sigma_{\theta} \equiv \sigma_{\theta}^2(\delta_{\tilde{\theta}_i} + \delta_{\tilde{\theta}})$, the weight put on the private signal by an operator i in the equilibrium is given by $\delta_{\tilde{\theta}_i}^* \equiv \rho_{q\theta} \sigma_q \sqrt{\tau_{\theta}} - \delta_{\tilde{\theta}}^*$. And $\rho_{qq'} \sigma_q^2 \equiv \delta_{\tilde{\theta}_i}^2 \sigma_{\tilde{\theta}_i}^2 + \sigma_{\tilde{\theta}}^2(\delta_{\tilde{\theta}_i} + \delta_{\tilde{\theta}})^2$, the weight put on the public signal can be written as $\delta_{\tilde{\theta}}^* \equiv \pm \sigma_q \sqrt{\tau_{\tilde{\theta}}} \sqrt{\rho_{qq'} - \rho_{q\theta}^2}$, where $\rho_{qq'} \geq \rho_{q\theta}^2$. Thus, we attribute the correlation coefficients $\rho_{qq'}$ and $\rho_{q\theta}$ to the public and private signals at the equilibrium.

Corollary 1. An operator's individual strategic action at the Bayes Nash equilibrium depends on both

the information structure $(\tau_{\tilde{\theta}_i}, \tau_{\tilde{\theta}})$ and the correlation coefficient structure $(\rho_{qq'}, \rho_{q\theta})$:

$$q_i^{BNE}(\tilde{\theta}_i, \tilde{\theta}) \equiv \delta_0^* + \sigma_q \left[\left(\rho_{q\theta} \sqrt{\tau_{\tilde{\theta}}} \mp \sqrt{\tau_{\tilde{\theta}}} \sqrt{\rho_{qq'} - \rho_{q\theta}^2} \right) \tilde{\theta}_i \pm \left(\sqrt{\tau_{\tilde{\theta}}} \sqrt{\rho_{qq'} - \rho_{q\theta}^2} \right) \tilde{\theta} \right], \quad (31)$$

with

$$\rho_{q\theta} \equiv \sqrt{\frac{\tau_{\tilde{\theta}_i} \tau_{\tilde{\theta}} (\delta_{\tilde{\theta}_i} + \delta_{\tilde{\theta}})^2}{\left(\delta_{\tilde{\theta}_i}^2 \tau_{\tilde{\theta}} \tau_{\tilde{\theta}} + \delta_{\tilde{\theta}}^2 \tau_{\tilde{\theta}} \tau_{\tilde{\theta}_i} + \tau_{\tilde{\theta}_i} \tau_{\tilde{\theta}} (\delta_{\tilde{\theta}_i} + \delta_{\tilde{\theta}})^2 \right)}}, \quad (32)$$

$$\rho_{qq'} \equiv \frac{\tau_{\tilde{\theta}_i} \left(\delta_{\tilde{\theta}}^2 \tau_{\tilde{\theta}} + \tau_{\tilde{\theta}} (\delta_{\tilde{\theta}_i} + \delta_{\tilde{\theta}})^2 \right)}{\delta_{\tilde{\theta}_i}^2 \tau_{\tilde{\theta}} \tau_{\tilde{\theta}} + \delta_{\tilde{\theta}}^2 \tau_{\tilde{\theta}} \tau_{\tilde{\theta}_i} + \tau_{\tilde{\theta}_i} \tau_{\tilde{\theta}} (\delta_{\tilde{\theta}_i} + \delta_{\tilde{\theta}})^2}. \quad (33)$$

■ See appendix.

From (32) and (33), we note that $|\rho_{qq'} - \rho_{q\theta}^2| = \frac{\delta_{\tilde{\theta}}^2 \tau_{\tilde{\theta}} \tau_{\tilde{\theta}_i}}{\delta_{\tilde{\theta}_i}^2 \tau_{\tilde{\theta}} \tau_{\tilde{\theta}} + \delta_{\tilde{\theta}}^2 \tau_{\tilde{\theta}} \tau_{\tilde{\theta}_i} + \tau_{\tilde{\theta}_i} \tau_{\tilde{\theta}} (\delta_{\tilde{\theta}_i} + \delta_{\tilde{\theta}})^2}$. An increase in the precision of private signal can make $\rho_{q\theta}$ close to $\rho_{qq'}$. Indeed, when the precision of the public signal varies, an operator i faces to a trade-off: whether correlating its individual strategic action more with the average action or with the state of the quality. The public signal correlates operators' actions, whereas the private signal leads each operator to choose its action that is less correlated with the average action. Therefore, the precise private signal makes an operator correlate more its action with the true state of the quality.

Moreover, the volume chosen by an operator, at equilibrium, always increases with the correlation coefficient $\rho_{q\theta}$ if $\rho_{q\theta} \geq \sqrt{\left(\frac{\tau_{\tilde{\theta}}}{\tau_{\tilde{\theta}} + \tau_{\tilde{\theta}_i}} \right) \rho_{qq'}}$. We find that the sum of the weights in (31) is strictly increasing in the precision of either public signal or private signal when there is a more information about θ . Comparing with complete information, the equilibrium volume with information structure becomes more responsive to the true state of the quality. But this reaction is less strong than that of the equilibrium volume with the correlation structure: $|\frac{s}{1-r}| \geq |\frac{s}{1-r}| \left[\frac{(1-r)\tau_{\tilde{\theta}_i} + \tau_{\tilde{\theta}}}{\tau - r\tau_{\tilde{\theta}_i}} \right] > |\frac{s}{1-2r}|$. The reason is that the reaction of each operator to the state of the quality in yardstick competition is weighted by the noisy public and private signals. The precision of public and private signals may attenuate the negative effects of the correlation across operators' actions on the expected profits of an operator i , who reacts more to its own private signal.

Furthermore, when the precision of private signal increases with τ_{ε_i} , an operator i reacts more to its own private information than to the information revealed by $\rho_{qq'}$. If other operators do the same thing, then there is less correlation across the actions. But the correlation coefficient across private signals $\rho_{\theta\theta}$ sends more information about the quality of water mains to all parties of yardstick competition. As a result, an operator i who has an expected low cost of distributing water is winning in yardstick competition.

Note that since the correlation coefficient across the actions has to be non-negative, the condition $\rho_{q\theta} \geq \sqrt{\left(\frac{\tau_{\tilde{\theta}}}{\tau_{\tilde{\theta}} + \tau_{\tilde{\theta}_i}} \right) \rho_{qq'}}$ implies that $(\rho_{qq'}, \rho_{q\theta})$ should satisfy $|\rho_{q\theta}| \leq \sqrt{\rho_{qq'}}$ and $0 \leq \rho_{qq'} \leq 1$. Thus, we find that these conditions are the same as the conditions minimizing the loss in the expected profit of an operator i in Bayes Correlated equilibrium.

Corollary 2. For a given precision of information about θ , at the Bayes Nash equilibrium, the precision of the public and the private signals is the function of the correlation coefficient structure $(\rho_{qq'}, \rho_{q\theta})$:

$$\tau_{\tilde{\theta}_i} \equiv \frac{\tau_{\theta} \rho_{q\theta}^2 (1 - \rho_{qq'})}{\left[(1 - \rho_{qq'}) + (1 - r)(\rho_{qq'} - \rho_{q\theta}^2) \right]^2}, \tau_{\tilde{\theta}} \equiv \frac{(1 - r)^2 \tau_{\theta} \rho_{q\theta}^2 (\rho_{qq'} - \rho_{q\theta}^2)}{\left[(1 - \rho_{qq'}) + (1 - r)(\rho_{qq'} - \rho_{q\theta}^2) \right]^2}, \quad (34)$$

■ See appendix.

From (34), at the Bayes Nash equilibrium, when $\rho_{q\theta}^2 = \rho_{qq'}$, we find that $\rho_{q\theta}^2 = \rho_{qq'} \equiv \frac{\tau_{\tilde{\theta}_i}}{\tau_{\theta}}$, but the precision of the public signal is $\tau_{\tilde{\theta}} \equiv 0$. Intuitively this means that the public signal becomes uninformative about the quality of water mains. As illustrated in Figure 1, there are two opposite reasons. For a given τ_{θ} , an improvement of the precision of the private signal $\tau_{\tilde{\theta}_i}$ makes an increase in $\rho_{q\theta}$ as well as in $\rho_{qq'}$. However, if each operator accesses the precise information about the quality of water mains, then the correlation across individual strategic actions decreases. Even though each operator tends to correlate its strategic action with the state of the quality, the dispersion across operators' actions leads to an imprecise public signal sent to all parties in yardstick competition. Note that, the set of possible Bayes Nash equilibrium with the correlation structure $(\rho_{qq'}, \rho_{q\theta})$ is in the area under the curve of $\tau_{\theta} = 1$. As a result, the equilibrium volume depends on the precision of private signal, the correlation coefficients, so that $q_i^{BNE} \equiv \frac{2\rho_{\theta\theta}}{(1-r)} + \left(\frac{s}{(1-r)} \right) \frac{\tau_{\theta}}{\tau_{\theta} + (1-r)\tau_{\tilde{\theta}_i}} \mu_{\theta} + \frac{s\rho_{qq'}}{(1-\rho_{qq'}r)} \tilde{\theta}_i$.

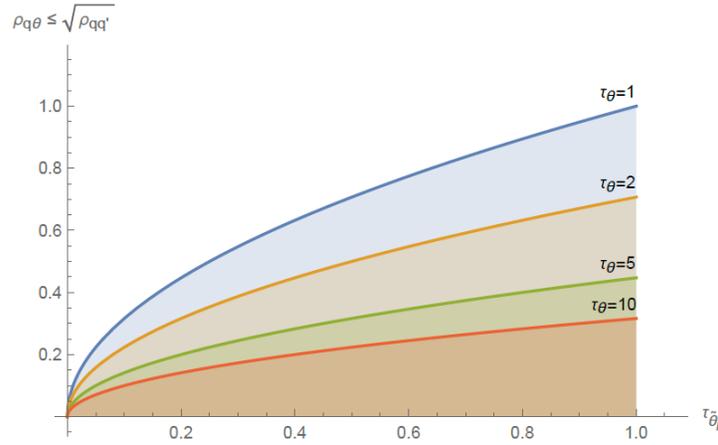


Figure 1: For a given $r = -\frac{1}{2}$, the relationships between the correlation coefficients $(\rho_{qq'}, \rho_{q\theta}^2)$ and the precision of private signal $\tau_{\tilde{\theta}_i}$ at the Bayes Nash equilibrium with varying degrees of precision τ_{θ} of underlying common information.

However, as illustrated in Figure 2, when $\rho_{q\theta}^2 < \rho_{qq'}$ and $\rho_{qq'} \in [0, 1]$, the precision of the public signal leads to both an increase in the correlation across operators' individual strategic actions, and an increase in the correlation of individual action and the state of the quality. There are two paths. In the first path, an increase in the precision of the public signal makes the correlation across operator's actions increase, and hence leads to an increased correlation of individual action with the state of the quality. Intuitively, introducing the precise public signal in yardstick competition allows to raise competition between an

operator and other operators. But an increased competition makes an operator deviate from the average action. The operator relies its actions more on the state θ due to an increase in the precision of its private information. Therefore, being associated with the information structure $(\tau_{\tilde{\theta}_i}, \tau_{\tilde{\theta}})$, yardstick competition allows a self-selection between operators by filtering out the common uncertainty about the state of the quality.

In the second path, an increase in the precision of private signal generates the dispersion across operators' actions. For example, when the precision of private signal rises from the low levels, as in Figure 2, the correlation across individual strategic actions of any two operators $\rho_{qq'}$ decreases. Then, a more public released information about the state θ received by each operator leads to an increase in the correlation of individual action with the state of the quality $\rho_{q\theta}$. Indeed, each operator finds optimal not to coordinate towards the average action in order to minimize the loss in expected profit. Thus, when the regulator releases more information about the state of the quality θ , the competition across operators leads each operator to rely its individual action on the state θ . Even though the common uncertainty is not directly reduced by the correlation across operators' actions, more public release in yardstick competition allows the regulator to reduce informational costs by letting operators self-select.

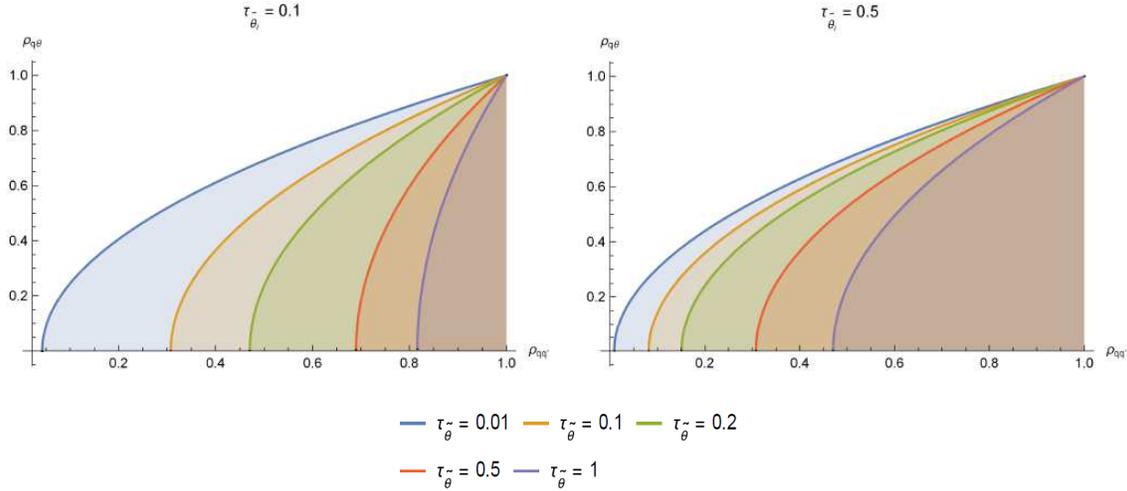


Figure 2: For a given $r = -\frac{1}{2}$, the relationships between the correlation coefficients $(\rho_{qq'}, \rho_{q\theta}^2)$ and different degrees of precision of public signal $\tau_{\tilde{\theta}}$ at the Bayes Nash equilibrium for the precision of private signal $\tau_{\tilde{\theta}_i} = 0.1$ and $\tau_{\tilde{\theta}_i} = 0.5$.

By Figure 2, at a low-level of the precision of the private signal, for example $\tau_{\tilde{\theta}_i} = 0.1$, for a given correlation coefficient of individual strategic actions across operators $\rho_{qq'}$, an increase in the precision of the public signal leads to less possible sets of Bayes Nash equilibrium in the area under the curve $\rho_{q\theta} \leq \sqrt{\rho_{qq'}}$. However, an increase in the precision of the private signal, for example $\tau_{\tilde{\theta}_i} = 0.5$, increases the dispersion across individual strategic actions and a fortiori the heterogeneity across operators in yardstick competition. But an increase in the precision of the public signal makes more possible sets of Bayes Nash equilibrium in the area under the curve $\rho_{q\theta} \leq \sqrt{\rho_{qq'}}$. In this case, the precision of the public

signal can improve the correlation across individual strategic actions, hence, reduce the heterogeneity across operators. But the possibility of collusion may result from the high correlation across individual strategic actions. We ask what is the degree of disclosure that is necessary to allow the regulator to explore more information from the correlation across operators without generating the collusion.

4 Disclosed information in Yardstick competition

An important potential limitation of yardstick competition is the possibility of collusion among operators. Using yardstick competition, the regulator can extract a higher informational rents with the slighter correlation across operators' private information. But operators may find that it is better off from collusion than from competing against each other. Without the information structure as described above $(\tau_{\tilde{\theta}_i}, \tau_{\tilde{\theta}})$, initial yardstick competition makes an operator's payoff depend on other operators' performances. As long as finding their gains resulted from yardstick competition are lower than their costs, operators regulated under the same yardstick scheme tend to have incentives to play cooperative strategies. As a result, collusive behavior of the equilibrium makes the regulation by yardstick competition inefficient. As Laffont and Martimort (2002) show, when using yardstick competition to exploit the correlation across operators' private information, the regulator is creating also incentives for operators to collude. They find that, when the correlation across operators' private information is perfect, yardstick competition will be completely inefficient since operators would like to collude.

In the above analyzed sections, we show that yardstick competition combined with exogenous information structure $(\tau_{\tilde{\theta}_i}, \tau_{\tilde{\theta}})$ can allow the regulator benefit from the reducing informational costs. Indeed, by disclosing some information, the regulator exploits the underlying correlations across operators' private information through $(\rho_{qq'}, \rho_{q\theta})$ so as to let operators self-select. In addition, an increase in the precision of the public signal leads an operator to rely its best response more on the true state of the quality, rather than on others' actions. As a result, the common uncertainty in operators' private information can be "filtered out" through yardstick competition, and hence the regulator could provide better incentives.

We now ask, if the public signal becomes imprecise in yardstick competition, then how the precision of information disclosure affects the efficiency of yardstick competition? Firstly, we need to describe the relationship between the Bayes Nash equilibrium with information structures $(\tau_{\tilde{\theta}_i}, \tau_{\tilde{\theta}})$ and the Bayes correlated equilibrium with the correlation coefficients $(\rho_{qq'}, \rho_{q\theta})$. Then, when introducing the role of the "interaction parameter" ($r < 0$) in the equilibrium strategy, we consider which the degree of information disclosure that is optimal for yardstick competition.

4.1 Bayes Nash equilibrium relative to Bayes Correlated equilibrium

Imposing normality and symmetry assumptions on the analysis of yardstick competition, we show that the Bayes Nash equilibrium can be defined by the precision of the public and private signals. Meanwhile, the Bayes Correlated equilibrium is defined by the correlation coefficient of individual strategic actions

across operators and of individual actions with the state of the quality θ . We find that for a given interaction structure $(s, r, 2\rho_{\theta\theta})$, a unique information structure $(\tau_{\bar{\theta}_i}, \tau_{\bar{\theta}})$ of the Bayes Nash equilibrium can be defined by the correlation coefficient structures $(\rho_{qq'}, \rho_{q\theta})$ of the Bayes Correlated equilibrium. Thus, we referred to the Bayes Nash equilibrium as an interior solution of Bayes Correlated equilibrium. In other words, the joint distribution over actions and the state is Bayes Correlated equilibrium if it forms also a Bayes Nash equilibrium with the information structure.

In addition, recall that the correlation effect on water price setting is measured by the correlation coefficient across operators' private information about the quality of the infrastructure $\rho_{\theta\theta}$. This residual interaction parameter captures the idiosyncratic information in operators' private signals. Each operator can transmit the noisy private information through $\rho_{\theta\theta}$ to the regulator who aggregates the information. Then, the regulator discloses the aggregate information to the operators by setting water price; at the same time the operators take it into account in their cost function of water distribution. Therefore, both of the two equilibria require that for a given state θ , the idiosyncratic information is independent across operators. This disclosure policy in yardstick competition tends to limit the susceptibility of collusive manipulation by the operators. We have the following observation.

Lemma 2. For a given precision structure $(\tau_{\bar{\theta}_i}, \tau_{\bar{\theta}}) \in [0, +\infty[$, the Bayes Nash equilibrium is an interior solution relative to the Bayes Correlated equilibrium.

Proof. One of conditions that the joint normal distribution (θ, Q, q) is the Bayes Correlated equilibrium is $\rho_{qq'} - \rho_{q\theta}^2 \geq 0$. By the assumptions of normality and symmetry, $\rho_{qq'} = \frac{\sigma_Q^2}{\sigma_q^2}$ and $\rho_{qQ} = \frac{\sigma_Q}{\sigma_q}$. Thus, we have $\rho_{qq'} \equiv (\rho_{qQ})^2$, and hence $\rho_{qQ} \geq |\rho_{q\theta}|$. In addition, we recall that for a given interaction parameter $r < -1$, when $\rho_{qq'} \equiv (\rho_{qQ})^2 \equiv \rho_{q\theta}^2 = -\frac{1}{r} < 1$, the Bayes Correlated equilibrium has an interior solution. Thus, the Bayes Nash equilibrium with information structure $(\tau_{\bar{\theta}_i}, \tau_{\bar{\theta}})$ is an interior equilibrium relative to the Bayes Correlated equilibrium if the precision of the public and private signals can reduce the variance of individual and average action.

Moreover, at the Bayes Correlated equilibrium, when for a given $-1 \leq r < 0$, we have $\rho_{qq'} \equiv (\rho_{qQ})^2 \equiv \rho_{q\theta}^2 = 1$. Meanwhile, at the Bayes Nash equilibrium, the necessary condition allowing $\rho_{qq'} \equiv (\rho_{qQ})^2 \equiv \rho_{q\theta}^2 = 1$ is that the precision of the public signal $\tau_{\bar{\theta}}$ becomes uninformative. In this case, the Bayes Nash equilibrium can be an interior equilibrium relative to the Bayes Correlated equilibrium.

Now we need to analyze what is the degree of information disclosure that makes efficient yardstick competition during the selection stage of the delegation process.

4.2 The degree of disclosed information

Suppose that in yardstick competition, each operator receives a private signal with the precision of $\tau_{\bar{\theta}_i}$. If observing the exogenous correlation coefficient of private signals across operators about the quality of the infrastructure $\rho_{\theta\theta}$, the regulator would like to exploit the correlations across operators' individual strategic actions that is the individual supply decisions, then the dispersion of individual strategic actions arises from the interaction measured by the correlation coefficients $(\rho_{qq'}, \rho_{q\theta})$. Hence, the regulator is

better off minimizing the dispersion of individual strategic actions. We return to Equation (21) of the expected individual profit. When the interaction parameter is $r < 0$,

$$\left\{ \begin{array}{l} \min_{\{\rho_{qq'}, \rho_{q\theta}\}} \quad \sigma_q = \frac{s\sigma_\theta \rho_{q\theta}}{1-r\rho_{qq'}} \\ \text{subject to} \\ \rho_{qq'} \geq \rho_{q\theta}^2 \quad , \\ s\rho_{q\theta} \geq 0 \quad . \end{array} \right. \quad (35)$$

The minimum variance of individual actions can be reached at a corner solution as $\rho_{qq'} \equiv \rho_{q\theta}^2 = 1$ when $-1 \leq r < 0$, or at an interior solution as $\rho_{qq'} \equiv \rho_{q\theta}^2 = -\frac{1}{r}$ when $r < -1$. By Corollary 1 and Corollary 2, the precision of the public and private signals affects the formation of the correlation coefficient structure $(\rho_{qq'}, \rho_{q\theta})$.

If the precision of the private signal is $\tau_{\tilde{\theta}_i} \rightarrow +\infty$, then either there is more information about θ that is contained in the private signal, or the idiosyncratic information about the quality is enough precise that $\tau_{\varepsilon_i} \rightarrow +\infty$. The residual interaction $\rho_{\theta\theta}$ is initially high because of the accurate idiosyncratic information. Each operator can transmit disperse but noiseless information to the regulator who aggregates the information. Then, the regulator discloses the aggregated information to the operators. In addition, when the interaction parameter is $-1 \leq r < 0$, from (33), the correlation across operators' individual strategic actions $\rho_{qq'}$ tends to be perfect. Since we know that, at Bayes Correlated equilibrium, minimizing the loss in an operator's expected profit requires also $\rho_{qq'} \equiv \rho_{q\theta}^2 = 1$. Therefore, with a perfect $\rho_{qq'}$ and a high $\rho_{\theta\theta}$, the regulator can completely exploit the private information of each operator; at the same time the operators may have also the complete information about θ .

However, when the interaction parameter $r < -1$, then at Bayes Nash equilibrium, an interior solution of the Bayes Correlated equilibrium, requires that $\rho_{qq'} \in [0, 1]$ and $\rho_{qq'} \equiv (\rho_{qQ})^2 \geq \rho_{q\theta}^2$. From (32) to (34), we know that such correlation structures can be achieved if and only if operators make their individual supply decisions on the basis of the information structure that is $\tau_{\tilde{\theta}_i} > \tau_{\tilde{\theta}}$ and $\tau_{\tilde{\theta}} \rightarrow 0$. In this special environment, we define the degree of information disclosure through the relationship between the strength of interaction parameter r and the relative precision of the private signal.

Proposition 3. If the interaction parameter $-1 \leq r < 0$, then *the full disclosure* in yardstick competition is optimal, so that $\rho_{qq'} \equiv \rho_{q\theta}^2 = 1$. Meanwhile, if $r < -1$, then the degree of information disclosure is obtained by $\rho_{qq'} \equiv \frac{\tau_{\tilde{\theta}_i}}{\tau_\theta + \tau_{\tilde{\theta}_i}}$. Since $\rho_{qq'} \equiv (\rho_{qQ})^2$,

- When $r \in] -1 - \frac{\tau_\theta}{\tau_{\tilde{\theta}_i}}, -1[$, the relative precision of the private signal about the state of the infrastructure θ imposes a low bound on the interaction parameter r . The correlation coefficient across operators' individual strategic actions $\rho_{qQ} \in] \sqrt{\frac{\tau_{\tilde{\theta}_i}}{\tau_\theta + \tau_{\tilde{\theta}_i}}}, 1]$. The *partial public information disclosure* is favorable for yardstick competition.
- When $r \in] -\infty, -1 - \frac{\tau_\theta}{\tau_{\tilde{\theta}_i}}]$, the correlation coefficient across operators' individual strategic

actions ρ_{qQ} is restricted in $\rho_{qQ} \in \left[0, \sqrt{\frac{\tau_{\theta_i}}{\tau_{\theta} + \tau_{\theta_i}}}\right]$. *No public information disclosure* is favorable for operators.

■ See appendix.

Note that, to match the Bayes Correlated equilibrium, it had better allow for a positively correlated individual strategic actions which depends on the relative precision of the private signal. Intuitively, this means that reacting to an increase in the precision of private signal, an operator may adjust strategy to coordinate with the average actions. In particular, if $-1 \leq r < 0$, then the slope of the inverse demand curve is steep; at the same time the operator's individual strategic action becomes insensitive to the average actions of others. The dispersion of individual strategic actions can be reduced by an increase in the relative precision of the private signal that results either from precise information disclosure about the state of the quality θ or from precise idiosyncratic information τ_{ε_i} . Therefore, the expected profit of an operator increases.

Moreover, comparing with complete information, the operator can benefit from a high-level volume of distributed water, as $|\frac{s}{1-r}\mu_{\theta}| > |\frac{s}{1-2r}\mu_{\theta}|$. In addition, the full disclosure allows a self-selection among operators. The operators who have inefficient cost of water distribution can be filtered out. In doing so, the regulator reduces informational costs without detriment to a cost-efficient operator. Let us denote $\Delta(r, s) = |\frac{s}{1-r}\mu_{\theta}| - |\frac{s}{1-2r}\mu_{\theta}|$ as informational rents given up to an operator, we find that for $s \cdot \mu_{\theta} \geq 0$,

$$\frac{\partial \Delta(r, s)}{\partial r} = \begin{cases} > 0, & -1 \leq r < -\frac{\sqrt{2}}{2}, \\ < 0, & -\frac{\sqrt{2}}{2} \leq r < 0. \end{cases} \quad (36)$$

Informational rents firstly increase in r , then decrease in r when the interaction between the individual action and the average action tends to be zero. In other words, the magnitude of informational rents depends on the competitive pressure measured by r in yardstick competition. As we know, if $r = 0$, then it is the situation of complete information in which an operator responds only the state of the quality θ , and the regulator does not leave any informational rent to the operator. As a result, if the interaction parameter $-1 \leq r < 0$, then the full information disclosure is optimal in yardstick competition.

However, if the interaction parameter $r < -1$, then the slope of the inverse demand curve is not steep. The operator's individual strategic action is more sensitive to the average action. More precise information disclosure about the state of the quality ϑ improves the supply decision of an operator who has a low cost of water distribution. But it also increases the correlation across operators' strategic actions. When the correlation tends to be perfect, it is not favorable to operators to compete against each other because their expected profits are low. We have two scenarios.

In the first scenario, the interaction parameter r is restricted by the relative precision of the public and private signals. Though the precision of the public signal $\tau_{\bar{\theta}}$ allows to improve the disclosed private information about θ through an increase of $\rho_{q\theta}$, it increases also the correlation across operator's actions $\rho_{qq'} = (\rho_{qQ})^2$ because the public information correlates operators' actions. Hence, improving the precision of private signals of all operators, the partial public information disclosure is favorable for

yardstick competition if and only if the correlation across operators' strategic actions does not increase to be perfect. In this case, the possibility of collusive behaviors is limited in yardstick competition.

In the second scenario, the correlation across operator's individual strategic actions is limited by the relative precision of the private signal. Nevertheless, the aggregate volatility of actions is increasing in this correlation coefficient: $\sigma_A^2 = \rho_{qq'}\sigma_a^2$ and $\rho_{qq'} = (\rho_{qQ})^2$ for a larger range of strategic interaction parameter r . Even though the competition between operators increases, it is undesirable from point of view of the individual expected profit. As a result, operators prefer no information disclosure.

4.3 Remarks

• **No public information disclosure.** Even though no public information disclosure is favorable to operators, the operators are always affected by the residual correlation coefficient across private information $\rho_{\theta\theta}$, measuring as *a priori common knowledge* between operators and the regulator. If the initial private signals are sufficiently accurate, then $\rho_{\theta\theta}$ becomes exogenously high, even without any public information disclosure. In this case, though the information conveyed by $\rho_{\theta\theta}$ is less than the information revealed by $\rho_{qq'}$, an operator who has an efficient cost of water distribution can benefit from a high $\rho_{\theta\theta}$ because the specification of the cost function is $\frac{\partial C^i}{\partial \rho_{\theta\theta}} < 0$. For example, when $\tau_{\bar{\theta}_i} > \tau_{\bar{\theta}}$ and $\tau_{\bar{\theta}} \rightarrow 0$, the expected volume of the equilibrium chosen by an operator (29) becomes

$$\lim_{\tau_{\bar{\theta}} \rightarrow 0} q_i^{BNE} = \frac{2\rho_{\theta\theta}}{1-r} + \frac{s}{\tau_{\theta} + (1-r)\tau_{\bar{\theta}_i}} \left(\frac{\tau_{\theta}}{(1-r)}\mu_{\theta} + \tau_{\bar{\theta}_i} \right), \quad (37)$$

and hence we have

$$\lim_{\tau_{\bar{\theta}_i} \rightarrow +\infty} \left(P(q_i^{BNE}) - C_q(q_i^{BNE}) \right) = s\theta \text{ with } s \cdot \theta > 0. \quad (38)$$

Recall that the interaction parameter s represents an operator's reaction to the state of the quality of water mains θ . It is also considered the informational externality from which the regulator can benefit through exploiting the correlation across private signals. As a consequence, yardstick competition with the information structure $(\tau_{\bar{\theta}_i}, \tau_{\bar{\theta}})$ favors the cost efficient operator even if there no public information disclosure. In addition, the regulator reduces informational costs without deteriorate the quality of water services.

• **The correlations of the action with the information structure.** If the noisy public and private signals initially contain so little information about the state of the quality θ that the information structure becomes $(\tau_{\bar{\theta}_i} \rightarrow 0, \tau_{\bar{\theta}} \rightarrow 0)$, then by (32) and (33), the correlation coefficients $\rho_{q\theta}$ and $\rho_{qq'}$ tend to be weak. Thus, an individual strategic action does not vary much in the realization of the signals. However, if the private signal contains more information than the public signal, then both $\rho_{q\theta}$ and $\rho_{qq'}$ become high. The action of each operator varies with the realization of the signals. In this case, there exists a large variance of individual action at equilibrium, and hence the expected profits of each operator decreases. Therefore, we ask how the individual strategic action of an operator does vary with the public

and private signals. To this end, we can extend the symmetric variance-covariance matrix of (θ, Q, q) to be that of $(\theta, Q, q, \tilde{\theta}_i, \tilde{\theta})$.

At the Bayes Nash equilibrium, we obtain the correlation between an operator's action and private signal $\rho_{q\tilde{\theta}_i}$, and the correlation between an operator's action and public signal $\rho_{q\tilde{\theta}}$. Thus, when the interaction parameter $r < 0$ and the relationship of correlation coefficients is $\rho_{qq'} \geq \rho_{q\theta}^2$,

$$\rho_{q\tilde{\theta}_i} \equiv \frac{\sqrt{\tau_{\tilde{\theta}_i}}}{\sqrt{\tau_{\tilde{\theta}}}\rho_{q\theta}} [(1 - r\rho_{qq'}) - (1 - r)\rho_{q\theta}^2], \rho_{q\tilde{\theta}} \equiv \frac{\sqrt{\tau_{\tilde{\theta}}}}{(1 - r)\sqrt{\tau_{\tilde{\theta}}}\rho_{q\theta}} [(1 - r\rho_{qq'}) - (1 - r)\rho_{q\theta}^2]. \quad (39)$$

■ See appendix.

We observe that the operator correlates less its action with the relative precision of the public signal than with that of the private signal because of the interaction factor $(1 - r)$. By (39), the extent of the correlation coefficient structures leads us to the following result.

Corollary 3. All other things being equal, the ratio of $\rho_{q\tilde{\theta}_i}$ and $\rho_{q\tilde{\theta}}$ can be given by $\frac{\rho_{q\tilde{\theta}_i}}{\rho_{q\tilde{\theta}}} \equiv (1 - r)\frac{\sqrt{\tau_{\tilde{\theta}_i}}}{\sqrt{\tau_{\tilde{\theta}}}}$.

- When $\sqrt{\tau_{\tilde{\theta}_i}} \geq \sqrt{\tau_{\tilde{\theta}}}$, for some $r \leq 0$, then $\rho_{q\tilde{\theta}_i} \geq \rho_{q\tilde{\theta}}$;
- When $\sqrt{\tau_{\tilde{\theta}_i}} < \sqrt{\tau_{\tilde{\theta}}} \leq 2\sqrt{\tau_{\tilde{\theta}_i}}$, for $-1 \leq r \leq (1 - \frac{\sqrt{\tau_{\tilde{\theta}}}}{\sqrt{\tau_{\tilde{\theta}_i}}})$, then $\rho_{q\tilde{\theta}_i} \geq \rho_{q\tilde{\theta}}$, whereas for $(1 - \frac{\sqrt{\tau_{\tilde{\theta}}}}{\sqrt{\tau_{\tilde{\theta}_i}}}) < r < 0$, then $\rho_{q\tilde{\theta}_i} < \rho_{q\tilde{\theta}}$;
- When $\sqrt{\tau_{\tilde{\theta}}} > 2\sqrt{\tau_{\tilde{\theta}_i}}$, for $r < (1 - \frac{\sqrt{\tau_{\tilde{\theta}}}}{\sqrt{\tau_{\tilde{\theta}_i}}})$, then $\rho_{q\tilde{\theta}_i} \geq \rho_{q\tilde{\theta}}$, whereas for $-1 \leq r < 0$, then $\rho_{q\tilde{\theta}_i} < \rho_{q\tilde{\theta}}$.

Under different level of public information disclosure, there is a discontinuous variation of the correlation coefficients $(\rho_{q\tilde{\theta}_i}, \rho_{q\tilde{\theta}})$ relative to the correlation coefficient structures $(\rho_{qq'}, \rho_{q\theta})$. In fact, the information in the private signal leads each operator to choose an action far away from the average action, but the information in the public signal correlates the operators' actions. If the ratio of the precision of the private and public signals is high, then for a large range of strategic interaction parameter $r \leq 0$, the individual strategic action relies more on the private signal than the public signal. It can be verify indirectly that the correlation coefficient of individual strategic actions across operators $\rho_{qq'}$ is decreasing in an increase of $\rho_{q\tilde{\theta}_i}$, but the correlation coefficient of individual actions with the state of the quality $\rho_{q\theta}$ is increasing in $\rho_{q\tilde{\theta}_i}$.

If the ratio of the precision of the private and public signals is low, then the individual strategic action relies more on the public signal than the private signal. We recall that the interaction parameter r represents the “strategic substitutes” in an operator's action at equilibrium. When the precision of the public signal is higher than that of the private signal, there are two cases: if the strategic substitutes are as weak as $(1 - \frac{\sqrt{\tau_{\tilde{\theta}}}}{\sqrt{\tau_{\tilde{\theta}_i}}}) < r < 0$, then the public signal correlates the individual strategic action across operators; however, if the strategic substitutes tend to be as strong as $r < (1 - \frac{\sqrt{\tau_{\tilde{\theta}}}}{\sqrt{\tau_{\tilde{\theta}_i}}})$, then an increase in the precision of the public signal makes an operator correlate its strategic action with the state θ . In consequence, we have not a monotone equilibrium because of the operators' reaction to the public signal.

Moreover, it is straightforward to verify that for a given correlation with respect to the state of the quality θ , if the relationship between the correlation coefficient of the individual actions across operators

satisfies the conditions that $\rho_{qq'} \leq 1 - \rho_{q\tilde{\theta}_i}^2$ and $\rho_{qq'} \geq \rho_{q\theta}^2 + \rho_{q\tilde{\theta}}^2$, then $\Sigma(\theta, Q, q, \tilde{\theta}_i, \tilde{\theta})'$ is a semidefinite positive variance-covariance matrix. The first condition indicates that if an individual action is already highly correlated with the private signal, then there is less correlation across any two individual actions at equilibrium. The second condition reflects that, an increase in the correlation across individual actions can be generated by $\rho_{q\tilde{\theta}}$ or $\rho_{q\theta}$. In addition, as $\rho_{qq'} > \rho_{\theta\theta}$, the exogenous prior common knowledge about the quality of water mains presented by $\rho_{\theta\theta}$ imposes an upper bound on $\rho_{q\tilde{\theta}_i}$, so that $\rho_{q\tilde{\theta}_i} \leq \sqrt{1 - \rho_{\theta\theta}}$, and imposes a lower bound on $\rho_{q\tilde{\theta}}$, so that $\rho_{q\tilde{\theta}} \geq \sqrt{\rho_{\theta\theta} - \rho_{q\theta}^2}$. The precision of information in the exogenous prior common knowledge makes each operator rely heavily on the public signal, and hence there is an increase in $\rho_{q\tilde{\theta}}$. Then, the correlation across individual strategic action $\rho_{qq'}$ increases because operators rely on the same information. Therefore, an increase in the precision of public signal leads more correlation across actions for a given correlation respect to the state of the quality at equilibrium.

Furthermore, though the informational externality represented by s does not appear in (39), we find that for $s \cdot \rho_{q\theta} > 0$, $s \equiv \frac{\sigma_q \sqrt{\tau_\theta} (1 - \rho_{qq'} r)}{\rho_{q\theta}}$. At the Bayes Nash equilibrium, the information parameter becomes $s \equiv \frac{\sqrt{\delta_{\tilde{\theta}_i}^2 \sigma_{\tilde{\theta}_i}^2 + \delta_\theta^2 \sigma_\theta^2 + \sigma_\theta^2 (\delta_{\tilde{\theta}_i} + \delta_\theta)^2} (1 - \rho_{qq'} r)}{\sigma_\theta \rho_{q\theta}}$. When the precision of the public and private signals increase, operators respond strongly to the precise information. The reaction to the state of the quality is thus attenuated because of the improved equilibrium correlation across the individual strategic actions. As a consequence, the behavior of the equilibrium in yardstick competition can be restricted by the correlation coefficients ($\rho_{qq'}$, $\rho_{q\theta}$) combined with the exogenous information structure. The public information disclosure may make the regulator better exploit the correlation between operators' strategic actions and limit the possibility of operators' collusive behaviors of the equilibrium.

5 Conclusion

We seek whether yardstick competition could be used in the delegation of public water services. The goal of this paper is to draw one possible solution which can limit the collusive behaviors of participating operators in this type of regulation. When there are common underlying uncertainties on operators' private information, the regulator can reduce them by using a yardstick competition. However, an important potential limitation of yardstick competition is that participating operators may have strategic behaviors.

Collusion is one of these strategic behaviors. Such a behavior could undermine the efficiency of yardstick competition. For example, each operator's symmetric cost depends negatively on the correlation coefficient across private information about the quality of water networks. If two cost inefficient operators collude to win from the competition in the stage of selection, then the collusion tends to make the regulator have misguided information about the true state of water mains. The regulator may inefficiently delegate the public water services if these two operators continue to collude in the stage of negotiation.

We show that the public information disclosure can limit operators' collusion in yardstick competition. The regulator exploits not only the correlation between operators' private information, but also

the correlation between each operator's strategic action and the state of the quality. Firstly, we analyze how this correlation coefficient structure can improve yardstick competition. On the basis of a general quadratic payoff environment (see Angeletos and Pavan, 2007), in particular, the linear best response property, we give a full characterization of the correlation coefficient structure in the symmetric equilibrium of yardstick competition. In fact, the correlation of individual strategic actions across operators is always at least equal to the correlation between the individual action and the state of the quality. The analysis shows that the efficient outcome of yardstick competition can be achieved under the perfect correlation coefficient structure at the Bayes Correlated equilibrium.

Then, we consider how this result could vary under a specific information structure. Receiving a noisy public information about the quality of water networks, the linear best response of each operator is affected by the precision of public and private information. Hence, at the Bayes Nash equilibrium, the expected volume of water distribution chosen by an operator depends not only on the correlation coefficient structure, but also the information structure. In addition, according to the ratio of public and private precision, we describe the set of possible equilibrium correlation coefficients which depend on the precision of information disclosure and the strategic interaction parameter r . The analysis shows that whatever the degree of information disclosure is in yardstick competition, the public information can lead to self-selection rather than collusive manipulation by participating operators.

Our analysis should be extended to take into account the convex costs of choosing the precision of private information (see Ui, 2014, for a start).

6 Appendix

Proof of equation (17). As $\mu_q = \mathbb{E}[q_i] = \frac{2\rho_{\theta\theta} + s\mu_\theta}{1-r}$, see (15), the conditional expectations $\mathbb{E}[\theta|q_i]$ and $\mathbb{E}[Q|q_i]$ are given by

$$\begin{aligned}\mathbb{E}[\theta|q_i] &= \mu_\theta + \frac{\rho_{\theta q}\sigma_\theta}{\sigma_q}(q_i - \mu_q) \\ &= \mu_\theta + \frac{\rho_{\theta q}\sigma_\theta}{\sigma_q}\left(q_i - \frac{2\rho_{\theta\theta} + s\mu_\theta}{1-r}\right),\end{aligned}\tag{40}$$

and

$$\begin{aligned}\mathbb{E}[Q|q_i] &= \mu_q + \rho_{qq'}(q_i - \mu_q) \\ &= (1 - \rho_{qq'})\left(\frac{2\rho_{\theta\theta} + s\mu_\theta}{1-r}\right) + \rho_{qq'}q_i.\end{aligned}\tag{41}$$

Thereby, through (40) and (41), the optimality of the best response property at q_i is given by

$$\begin{aligned}1 &= s\frac{d\mathbb{E}[\theta|q_i]}{dq_i} + r\frac{d\mathbb{E}[Q|q_i]}{dq_i} \\ 1 &= s\frac{\rho_{\theta q}\sigma_\theta}{\sigma_q} + r\rho_{qq'},\end{aligned}\tag{42}$$

where $s > 0$ and $r < 0$. ■

Proof of equation (21). Since

$$\mathbb{E}[\pi_i] = s\mathbb{E}[\theta q_i] + r\mathbb{E}[Qq_i] + 2\rho_{\theta\theta}\mathbb{E}[q_i] - \frac{1}{2}\mathbb{E}[q_i^2], \quad (43)$$

and

$$\mathbb{E}[\theta q_i] = \rho_{q\theta}\sigma_q\sigma_\theta + \mu_\theta\mu_q, \quad (44)$$

$$\mathbb{E}[Qq_i] = \rho_{qQ}\sigma_q\sigma_Q + \mathbb{E}[q_i]^2. \quad (45)$$

As $\rho_{qQ}\sigma_q\sigma_Q = \rho_{qq'}\sigma_q^2$, we integrate equations (44) and (45) into the equation (43),

$$\begin{aligned} \mathbb{E}[\pi_i] &= s\rho_{q\theta}\sigma_q\sigma_\theta + r\rho_{qq'}\sigma_q^2 - \frac{1}{2}\mathbb{E}[q_i^2] + \frac{1}{2}\mathbb{E}[q_i]^2 + s\mu_\theta\mu_q + \left(r - \frac{1}{2}\right)\mathbb{E}[q_i]^2 + 2\rho_{\theta\theta}\mathbb{E}[q_i] \\ &= \sigma_q^2 \left(s\frac{\rho_{q\theta}\sigma_\theta}{\sigma_q} + r\rho_{qq'} - \frac{1}{2} \right) + \mu_q \left[s\mu_\theta + \left(r - \frac{1}{2}\right)\mu_q + 2\rho_{\theta\theta} \right]. \end{aligned} \quad (46)$$

■

Proof of Lemma 1. Since $\tau \equiv \tau_\theta + \tau_{\tilde{\theta}} + \tau_{\tilde{\theta}_i}$, by the law of iterated expectation,

$$\mathbb{E}[\theta|\tilde{\theta}_i, \tilde{\theta}] = \frac{\tau_{\tilde{\theta}_i}\tilde{\theta}_i + \tau_{\tilde{\theta}}\tilde{\theta} + \tau_\theta\mu_\theta}{\tau_\theta + \tau_{\tilde{\theta}} + \tau_{\tilde{\theta}_i}} = \frac{\tau_{\tilde{\theta}_i}\tilde{\theta}_i + \tau_{\tilde{\theta}}\tilde{\theta} + \tau_\theta\mu_\theta}{\tau}. \quad (47)$$

As we assume that, in equilibrium, $q_i(\tilde{\theta}_i, \tilde{\theta}) = \delta_0 + \delta_{\tilde{\theta}_i}\tilde{\theta}_i + \delta_{\tilde{\theta}}\tilde{\theta}$, we can write

$$\begin{aligned} \mathbb{E}[Q|\tilde{\theta}_i, \tilde{\theta}] &\equiv \mathbb{E}\left[\int_0^1 q_j dj|\tilde{\theta}_i, \tilde{\theta}\right] \\ &\equiv \delta_0 + \delta_{\tilde{\theta}_i} \left(\frac{\tau_{\tilde{\theta}_i}\tilde{\theta}_i + \tau_{\tilde{\theta}}\tilde{\theta} + \tau_\theta\mu_\theta}{\tau_\theta + \tau_{\tilde{\theta}} + \tau_{\tilde{\theta}_i}} \right) + \delta_{\tilde{\theta}}\tilde{\theta} \\ &\equiv \left(\delta_0 + \frac{\delta_{\tilde{\theta}_i} + \tau_\theta\mu_\theta}{\tau} \right) + \left(\frac{\tau_{\tilde{\theta}_i}\tilde{\theta}_i}{\tau} \right) \delta_{\tilde{\theta}_i} + \left(\frac{\delta_{\tilde{\theta}_i}\tau_{\tilde{\theta}}}{\tau} + \delta_{\tilde{\theta}} \right) \tilde{\theta}. \end{aligned} \quad (48)$$

Thereby, by integrating equations (47) and (48) into $q_i = s\mathbb{E}[\theta|\tilde{\theta}_i, \tilde{\theta}] + r\mathbb{E}[Q|\tilde{\theta}_i, \tilde{\theta}] + 2\rho_{\theta\theta}$, we obtain the equation (28) of Lemma 1. ■

Proof of Proposition 2. Using equations (27) and (28) of Lemma 1, we obtain

$$\begin{cases} r \left(\delta_0 + \frac{\delta_{\tilde{\theta}_i} + \tau_\theta\mu_\theta}{\tau} \right) + s \left(\frac{\tau_\theta\mu_\theta}{\tau} \right) + 2\rho_{\theta\theta} = \delta_0, \\ r \left(\frac{\tau_{\tilde{\theta}_i}\delta_{\tilde{\theta}_i}}{\tau} \right) + s \left(\frac{\tau_{\tilde{\theta}_i}}{\tau} \right) = \delta_{\tilde{\theta}_i}, \\ r \left(\frac{\delta_{\tilde{\theta}_i}\tau_{\tilde{\theta}}}{\tau} + \delta_{\tilde{\theta}} \right) + s \left(\frac{\tau_{\tilde{\theta}}}{\tau} \right) = \delta_{\tilde{\theta}}, \end{cases} \quad (49)$$

by solving this system with three equations, we obtain three coefficients of the equilibrium in Proposition 2. ■

Proof of the symmetric variance-covariance matrix in (30). Since in the equilibrium, $q_i(\tilde{\theta}_i, \tilde{\theta}) = \delta_0 + \delta_{\tilde{\theta}_i} \tilde{\theta}_i + \delta_{\tilde{\theta}} \tilde{\theta}$, we have

$$\Sigma \begin{pmatrix} \theta \\ Q \\ q_i \end{pmatrix} = \begin{pmatrix} \text{var}(\theta) & \text{cov}(\theta, Q) & \text{cov}(\theta, q_i) \\ \text{cov}(\theta, Q) & \text{var}(Q) & \text{cov}(Q, q_i) \\ \text{cov}(\theta, q_i) & \text{cov}(Q, q_i) & \text{var}(q_i) \end{pmatrix}, \quad (50)$$

and for $\tilde{\theta}_i = \theta + \varepsilon_i$, $\tilde{\theta} = \theta + \eta$, using the law of total variance and covariance, we obtain

$$\begin{aligned} \text{var}(q_i) &\equiv \text{var}(\delta_0 + \delta_{\tilde{\theta}_i} \tilde{\theta}_i + \delta_{\tilde{\theta}} \tilde{\theta}) = \text{var}(\delta_0) + \text{var}(\delta_{\tilde{\theta}_i} \tilde{\theta}_i + \delta_{\tilde{\theta}} \tilde{\theta}) + 2\text{cov}(\delta_0, \delta_{\tilde{\theta}_i} \tilde{\theta}_i + \delta_{\tilde{\theta}} \tilde{\theta}) \\ &= \text{var}(\delta_{\tilde{\theta}_i} \tilde{\theta}_i) + \text{var}(\delta_{\tilde{\theta}} \tilde{\theta}) + 2\text{cov}(\delta_{\tilde{\theta}_i} \tilde{\theta}_i, \delta_{\tilde{\theta}} \tilde{\theta}) \\ &= \delta_{\tilde{\theta}_i}^2 \sigma_{\tilde{\theta}_i}^2 + \delta_{\tilde{\theta}}^2 \sigma_{\tilde{\theta}}^2 + \sigma_{\tilde{\theta}}^2 (\delta_{\tilde{\theta}_i} + \delta_{\tilde{\theta}})^2, \end{aligned} \quad (51)$$

$$\begin{aligned} \text{cov}(\theta, Q) &\equiv \text{cov}(\theta, q_i) \equiv \mathbb{E}[\theta q_i] - \mathbb{E}[\theta] \mathbb{E}[q_i] \\ &= \mathbb{E} \left[\theta \left(\delta_0 + \delta_{\tilde{\theta}_i} \tilde{\theta}_i + \delta_{\tilde{\theta}} \tilde{\theta} \right) \right] - \mathbb{E}[\theta] \mathbb{E} \left[\delta_0 + \delta_{\tilde{\theta}_i} \tilde{\theta}_i + \delta_{\tilde{\theta}} \tilde{\theta} \right] \\ &= \sigma_{\tilde{\theta}}^2 (\delta_{\tilde{\theta}_i} + \delta_{\tilde{\theta}}), \end{aligned} \quad (52)$$

$$\begin{aligned} \text{cov}(Q, q_i) &\equiv \text{cov}(q_i, q_j) \equiv \text{var}(Q) \equiv \mathbb{E}[q_i q_j] - \mathbb{E}[q_i] \mathbb{E}[q_j] \\ &= \mathbb{E} \left[\left(\delta_0 + \delta_{\tilde{\theta}_i} \tilde{\theta}_i + \delta_{\tilde{\theta}} \tilde{\theta} \right) \left(\delta_0 + \delta_{\tilde{\theta}_j} \tilde{\theta}_j + \delta_{\tilde{\theta}} \tilde{\theta} \right) \right] \\ &\quad - \mathbb{E} \left[\delta_0 + \delta_{\tilde{\theta}_i} \tilde{\theta}_i + \delta_{\tilde{\theta}} \tilde{\theta} \right] \mathbb{E} \left[\delta_0 + \delta_{\tilde{\theta}_j} \tilde{\theta}_j + \delta_{\tilde{\theta}} \tilde{\theta} \right] \\ &= \delta_{\tilde{\theta}}^2 \sigma_{\tilde{\theta}}^2 + \sigma_{\tilde{\theta}}^2 (\delta_{\tilde{\theta}_i} + \delta_{\tilde{\theta}})^2. \end{aligned} \quad (53)$$

Therefore, integrating equation (51),(52) and (53) in the variance-covariance matrix (50), we obtain

$$\Sigma \begin{pmatrix} \theta \\ Q \\ q_i \end{pmatrix} = \begin{pmatrix} \sigma_{\tilde{\theta}}^2 & \sigma_{\tilde{\theta}}^2 (\delta_{\tilde{\theta}_i} + \delta_{\tilde{\theta}}) & \sigma_{\tilde{\theta}}^2 (\delta_{\tilde{\theta}_i} + \delta_{\tilde{\theta}}) \\ \sigma_{\tilde{\theta}}^2 (\delta_{\tilde{\theta}_i} + \delta_{\tilde{\theta}}) & \delta_{\tilde{\theta}}^2 \sigma_{\tilde{\theta}}^2 + \sigma_{\tilde{\theta}}^2 (\delta_{\tilde{\theta}_i} + \delta_{\tilde{\theta}})^2 & \delta_{\tilde{\theta}}^2 \sigma_{\tilde{\theta}}^2 + \sigma_{\tilde{\theta}}^2 (\delta_{\tilde{\theta}_i} + \delta_{\tilde{\theta}})^2 \\ \sigma_{\tilde{\theta}}^2 (\delta_{\tilde{\theta}_i} + \delta_{\tilde{\theta}}) & \delta_{\tilde{\theta}}^2 \sigma_{\tilde{\theta}}^2 + \sigma_{\tilde{\theta}}^2 (\delta_{\tilde{\theta}_i} + \delta_{\tilde{\theta}})^2 & \delta_{\tilde{\theta}_i}^2 \sigma_{\tilde{\theta}_i}^2 + \delta_{\tilde{\theta}}^2 \sigma_{\tilde{\theta}}^2 + \sigma_{\tilde{\theta}}^2 (\delta_{\tilde{\theta}_i} + \delta_{\tilde{\theta}})^2 \end{pmatrix}. \quad (54)$$

■

Proof of Corollary 1. As we know $\text{cov}(\theta, q_i) \equiv \rho_{q\theta} \sigma_q \sigma_{\theta} = \sigma_{\tilde{\theta}}^2 (\delta_{\tilde{\theta}_i} + \delta_{\tilde{\theta}})$, the correlation coefficient $\rho_{q\theta}$ can be expressed by

$$\rho_{q\theta} = \frac{\sigma_{\tilde{\theta}} (\delta_{\tilde{\theta}_i} + \delta_{\tilde{\theta}})}{\sigma_q}. \quad (55)$$

And from (54), $\sigma_q = \sqrt{\delta_{\tilde{\theta}_i}^2 \sigma_{\tilde{\theta}_i}^2 + \delta_{\tilde{\theta}}^2 \sigma_{\tilde{\theta}}^2 + \sigma_{\tilde{\theta}}^2 (\delta_{\tilde{\theta}_i} + \delta_{\tilde{\theta}})^2}$, thus

$$\rho_{q\theta} = \frac{\sigma_{\theta}(\delta_{\tilde{\theta}_i} + \delta_{\tilde{\theta}})}{\sqrt{\delta_{\tilde{\theta}_i}^2 \sigma_{\tilde{\theta}_i}^2 + \delta_{\tilde{\theta}}^2 \sigma_{\tilde{\theta}}^2 + \sigma_{\tilde{\theta}}^2 (\delta_{\tilde{\theta}_i} + \delta_{\tilde{\theta}})^2}} = \frac{\sqrt{\tau_{\tilde{\theta}_i} \tau_{\tilde{\theta}} (\delta_{\tilde{\theta}_i} + \delta_{\tilde{\theta}})^2}}{\sqrt{(\delta_{\tilde{\theta}_i}^2 \tau_{\theta} \tau_{\tilde{\theta}} + \delta_{\tilde{\theta}}^2 \tau_{\theta} \tau_{\tilde{\theta}_i} + \tau_{\tilde{\theta}_i} \tau_{\tilde{\theta}} (\delta_{\tilde{\theta}_i} + \delta_{\tilde{\theta}})^2)}}. \quad (56)$$

In addition, from (54), we know that $\text{cov}(Q, q_i) \equiv \text{cov}(q_i, q_j) = \rho_{qq'} \sigma_q^2 = \sigma_A^2 \equiv \delta_{\tilde{\theta}}^2 \sigma_{\tilde{\theta}}^2 + \sigma_{\tilde{\theta}}^2 (\delta_{\tilde{\theta}_i} + \delta_{\tilde{\theta}})^2$, thus, the correlation coefficient $\rho_{qq'}$ can be given by

$$\rho_{qq'} = \frac{\sigma_A^2}{\sigma_q^2} = \frac{\delta_{\tilde{\theta}}^2 \sigma_{\tilde{\theta}}^2 + \sigma_{\tilde{\theta}}^2 (\delta_{\tilde{\theta}_i} + \delta_{\tilde{\theta}})^2}{\delta_{\tilde{\theta}_i}^2 \sigma_{\tilde{\theta}_i}^2 + \delta_{\tilde{\theta}}^2 \sigma_{\tilde{\theta}}^2 + \sigma_{\tilde{\theta}}^2 (\delta_{\tilde{\theta}_i} + \delta_{\tilde{\theta}})^2} = \frac{\tau_{\tilde{\theta}_i} (\delta_{\tilde{\theta}}^2 \tau_{\theta} + \tau_{\tilde{\theta}} (\delta_{\tilde{\theta}_i} + \delta_{\tilde{\theta}})^2)}{\delta_{\tilde{\theta}_i}^2 \tau_{\theta} \tau_{\tilde{\theta}} + \delta_{\tilde{\theta}}^2 \tau_{\theta} \tau_{\tilde{\theta}_i} + \tau_{\tilde{\theta}_i} \tau_{\tilde{\theta}} (\delta_{\tilde{\theta}_i} + \delta_{\tilde{\theta}})^2}. \quad (57)$$

■

Proof of Corollary 2. Since $\delta_{\tilde{\theta}_i} = \frac{s\tau_{\tilde{\theta}_i}}{(\tau - \tau_{\tilde{\theta}_i} r)}$, $\delta_{\tilde{\theta}} = \frac{s\tau_{\tilde{\theta}}}{(1-r)(\tau - \tau_{\tilde{\theta}_i} r)}$, and $\delta_{\tilde{\theta}}^2 = \frac{\sigma_q^2}{\sigma_{\tilde{\theta}}^2} (\rho_{qq'} - \rho_{q\theta}^2) = \tau_{\tilde{\theta}} \sigma_q^2 (\rho_{qq'} - \rho_{q\theta}^2)$, we find thus, for a given $\sigma_q = \frac{s\sigma_{\theta} \rho_{q\theta}}{(1 - \rho_{qq'} r)}$

$$\begin{aligned} \tau_{\tilde{\theta}} &\equiv \frac{\tau_{\theta} (\rho_{qq'} - \rho_{q\theta}^2) \rho_{q\theta}^2 (1-r)^2}{\left((1 - \rho_{qq'} r) - \rho_{q\theta}^2 (1-r) \right)^2} \\ &\equiv \frac{\tau_{\theta} (\rho_{qq'} - \rho_{q\theta}^2) \rho_{q\theta}^2 (1-r)^2}{\left((1-r) \rho_{qq'} + (1 - \rho_{qq'}) - \rho_{q\theta}^2 (1-r) \right)^2} \\ &\equiv \frac{\tau_{\theta} (\rho_{qq'} - \rho_{q\theta}^2) \rho_{q\theta}^2 (1-r)^2}{\left((1 - \rho_{qq'}) + (\rho_{qq'} - \rho_{q\theta}^2) (1-r) \right)^2}, \end{aligned} \quad (58)$$

and using (58), from (57), we obtain

$$\begin{aligned} \tau_{\tilde{\theta}_i} &\equiv \frac{\tau_{\theta} (1 - \rho_{qq'}) \rho_{q\theta}^2}{\left((1 - \rho_{qq'} r) - \rho_{q\theta}^2 (1-r) \right)^2} \\ &\equiv \frac{\tau_{\theta} (1 - \rho_{qq'}) \rho_{q\theta}^2}{\left((1 - \rho_{qq'}) + (\rho_{qq'} - \rho_{q\theta}^2) (1-r) \right)^2}. \end{aligned} \quad (59)$$

■

Proof of Proposition 3 (The degree of disclosed information). When the interaction parameter r is $-1 \leq r < 0$, we know that the elasticity of the demand for water is small in one municipality. In this case, an operator's expected profit in yardstick competition can be maximized at $\rho_{qq'} = \rho_{q\theta}^2 = 1$ at equilibrium. Combing with this correlation structure, at the Bayes Nash equilibrium, even though the public information about the quality of water mains is noisy, each operator reduces the loss in its expected profit by coordinating more its individual action either on the average actions, or on the state of the quality. Since $\rho_{qq'} = \frac{\sigma_Q^2}{\sigma_q^2}$ and $\rho_{Qq} \sigma_Q \sigma_q = \sigma_Q^2$, we have also $\rho_{qq'} \equiv (\rho_{Qq})^2 \equiv \rho_{q\theta}^2 = 1$. As a result, operators disclose completely private information if $\tau_{\tilde{\theta}_i} > \tau_{\tilde{\theta}}$ for a given τ_{θ} .

However, when $r < -1$, then the elasticity of the demand for water is sufficiently large if there is more

than one operator in one municipality. On the other hand, the Bayes Nash equilibrium exists provided that $\rho_{qq'} = -\frac{1}{r} < 1$ and $\rho_{qq'} \equiv (\rho_{Qq})^2 \equiv \rho_{q\theta}^2$. Since we know that the Bayes correlated equilibrium exists if $\rho_{qq'} = -\frac{1}{r} < 1$, $\rho_{qq'} \geq \rho_{q\theta}^2$, and hence $\rho_{Qq} > |\rho_{q\theta}|$. Therefore, the Bayes Nash equilibrium may become an interior solution of Bayes correlated equilibrium when operators make decisions on the basis of the precise private signal. In addition, an increase in the precision of the public signal correlates the operator's action, whereas an increase in the precision of the private signal leads each operator correlate its individual strategic action with the state of the quality. Thus, when each operator receives a noisy public information about the state of the quality, the regulator learn more information from ρ_{Qq} because $\rho_{Qq} > |\rho_{q\theta}|$. Since the interaction parameter r has been considered the "strategic substitutes" in the individual action that reacts to the average actions of others, we need to define the interaction parameter r on the basis of the relative precision of private signal. From (29), we find that for $\tau_{\tilde{\theta}} \rightarrow 0$

$$\delta_{\tilde{\theta}} \equiv 0, \quad (60)$$

and, hence, from (30)

$$\sigma_q^2 \equiv \delta_{\tilde{\theta}_i}^2 \sigma_{\tilde{\theta}_i}^2 + \sigma_{\tilde{\theta}}^2 \delta_{\tilde{\theta}_i}^2, \quad (61)$$

in addition,

$$\rho_{qq'} \sigma_q^2 \equiv \sigma_{\tilde{\theta}}^2 \sigma_q^2, \quad (62)$$

therefore, integrating (61) into (62), we obtain

$$\rho_{qq'} \equiv \frac{\sigma_{\tilde{\theta}}^2}{\sigma_{\tilde{\theta}}^2 + \sigma_{\tilde{\theta}_i}^2} \equiv \frac{\tau_{\tilde{\theta}_i}}{\tau_{\tilde{\theta}_i} + \tau_{\tilde{\theta}}}. \quad (63)$$

Using the conditions $\rho_{qq'} = (\rho_{Qq})^2$, $\rho_{qq'} = -\frac{1}{r} < 1$ and the equation (63), we establish the critical value for the degree of disclosed information. ■

Proof of Corollary 3. We extend the variance-covariance matrix $\Sigma(\theta, Q, q_i)$ to $\Sigma(\theta, Q, q_i, \tilde{\theta}_i, \tilde{\theta})'$

$$\Sigma \begin{pmatrix} \theta \\ Q \\ q_i \\ \tilde{\theta}_i \\ \tilde{\theta} \end{pmatrix} \equiv \begin{pmatrix} \sigma_{\tilde{\theta}}^2 & \rho_{q\theta} \sigma_q \sigma_{\tilde{\theta}} & \rho_{q\theta} \sigma_q \sigma_{\tilde{\theta}} & \sigma_{\tilde{\theta}}^2 & \sigma_{\tilde{\theta}}^2 \\ \rho_{q\theta} \sigma_q \sigma_{\tilde{\theta}} & \rho_{qq'} \sigma_q^2 & \rho_{qq'} \sigma_q^2 & \rho_{q\theta} \sigma_q \sigma_{\tilde{\theta}} & \rho_{q\theta} \sigma_q \sigma_{\tilde{\theta}} + \rho_{q\tilde{\theta}} \sigma_q \sigma_{\tilde{\theta}} \\ \rho_{q\theta} \sigma_q \sigma_{\tilde{\theta}} & \rho_{qq'} \sigma_q^2 & \sigma_q^2 & \rho_{q\theta} \sigma_q \sigma_{\tilde{\theta}} + \rho_{q\tilde{\theta}_i} \sigma_q \sigma_{\tilde{\theta}_i} & \rho_{q\theta} \sigma_q \sigma_{\tilde{\theta}} + \rho_{q\tilde{\theta}} \sigma_q \sigma_{\tilde{\theta}} \\ \sigma_{\tilde{\theta}}^2 & \rho_{q\theta} \sigma_q \sigma_{\tilde{\theta}} & \rho_{q\theta} \sigma_q \sigma_{\tilde{\theta}} + \rho_{q\tilde{\theta}_i} \sigma_q \sigma_{\tilde{\theta}_i} & \sigma_{\tilde{\theta}}^2 + \sigma_{\tilde{\theta}_i}^2 & \sigma_{\tilde{\theta}}^2 \\ \sigma_{\tilde{\theta}}^2 & \rho_{q\theta} \sigma_q \sigma_{\tilde{\theta}} + \rho_{q\tilde{\theta}} \sigma_q \sigma_{\tilde{\theta}} & \rho_{q\theta} \sigma_q \sigma_{\tilde{\theta}} + \rho_{q\tilde{\theta}} \sigma_q \sigma_{\tilde{\theta}} & \sigma_{\tilde{\theta}}^2 & \sigma_{\tilde{\theta}}^2 + \sigma_{\tilde{\theta}}^2 \end{pmatrix}. \quad (64)$$

The best response of an operator conditioning on the information structure $(\tilde{\theta}_i, \tilde{\theta})$ can be written by

$$q_i = s\mathbb{E}[\theta|q, \tilde{\theta}_i, \tilde{\theta}] + r\mathbb{E}[Q|q, \tilde{\theta}_i, \tilde{\theta}] + 2\rho_{\theta\theta}. \quad (65)$$

By the law of iterated expectation, for $\forall q, \tilde{\theta}_i, \tilde{\theta}$, we write

$$\mathbb{E}[q_i|q] \equiv s\mathbb{E}[\mathbb{E}[\theta|q, \tilde{\theta}_i, \tilde{\theta}]|q] + r\mathbb{E}[\mathbb{E}[Q|q, \tilde{\theta}_i, \tilde{\theta}]|q] + 2\rho_{\theta\theta}, \quad (66)$$

$$\mathbb{E}[q_i|\tilde{\theta}_i] \equiv s\mathbb{E}[\mathbb{E}[\theta|q, \tilde{\theta}_i, \tilde{\theta}]|\tilde{\theta}_i] + r\mathbb{E}[\mathbb{E}[Q|q, \tilde{\theta}_i, \tilde{\theta}]|\tilde{\theta}_i] + 2\rho_{\theta\theta}, \quad (67)$$

$$\mathbb{E}[q_i|\tilde{\theta}] \equiv s\mathbb{E}[\mathbb{E}[\theta|q, \tilde{\theta}_i, \tilde{\theta}]|\tilde{\theta}] + r\mathbb{E}[\mathbb{E}[Q|q, \tilde{\theta}_i, \tilde{\theta}]|\tilde{\theta}] + 2\rho_{\theta\theta}. \quad (68)$$

From (66), the partial derivative with respect to q is given by

$$\begin{aligned} \sigma_q &\equiv \frac{s\sigma_\theta\rho_{q\theta}}{(1-\rho_{qq'}r)}, \\ s &\equiv \frac{\sigma_q\sqrt{\tau_\theta}(1-\rho_{qq'}r)}{\rho_{q\theta}}. \end{aligned} \quad (69)$$

In yardstick competition, informational externality represented by the interaction parameter $s \geq 0$ depends on the precision of information about the true state of the quality τ_θ , and on the correlation structure $(\rho_{qq'}, \rho_{q\theta})$.

From (64), (67) and (68), the partial derivative with respect to $\tilde{\theta}_i$ and $\tilde{\theta}$ is given by

$$\frac{\rho_{q\theta}\sigma_q\sigma_\theta + \rho_{q\tilde{\theta}_i}\sigma_q\sigma_{\tilde{\theta}_i}}{\sigma_{\tilde{\theta}_i}^2} \equiv \frac{s\sigma_\theta^2}{\sigma_{\tilde{\theta}_i}^2} + r\frac{\rho_{q\theta}\sigma_q\sigma_\theta}{\sigma_{\tilde{\theta}_i}^2}, \quad (70)$$

$$\frac{\rho_{q\theta}\sigma_q\sigma_\theta + \rho_{q\tilde{\theta}}\sigma_q\sigma_{\tilde{\theta}}}{\sigma_{\tilde{\theta}}^2} \equiv \frac{s\sigma_\theta^2}{\sigma_{\tilde{\theta}}^2} + r\frac{\rho_{q\theta}\sigma_q\sigma_\theta + \rho_{q\tilde{\theta}}\sigma_q\sigma_{\tilde{\theta}}}{\sigma_{\tilde{\theta}}^2}, \quad (71)$$

and by integrating (69) respectively in (70) and (71), we have $\rho_{q\tilde{\theta}_i} \equiv \frac{\sqrt{\tau_{\tilde{\theta}_i}}}{\sqrt{\tau_\theta}\rho_{q\theta}} [(1-\rho_{qq'}r) - (1-r)\rho_{q\theta}^2]$, $\rho_{q\tilde{\theta}} \equiv \frac{\sqrt{\tau_{\tilde{\theta}}}}{(1-r)\sqrt{\tau_\theta}\rho_{q\theta}} [(1-\rho_{qq'}r) - (1-r)\rho_{q\theta}^2]$ in (39). ■

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GENERAL CONCLUSION

In this dissertation, we seek a solution allowing local public authorities to benefit from information disclosure when they plan to delegate their services. It is well known that providing public services, i.e., public utilities, heavily involves sunk investment costs and specific technologies, which yields strong local natural monopolies. Hence, the lack of transparency and the inefficient competition *in* the market are two main shortcomings of delegation.

The theoretical and empirical literature covering local utilities regulation focuses on improving the competitive process when it comes to delegate local services to the private sector (through, for instance, enhancing the competition *for* the market). Current economic regulation based on service-related variables (e.g., prices, quantities, costs or service quality), aims to increase the competition between operators in order to enhance efficiency in managing local services. However, the delegation process is shrouded with uncertainties and informational asymmetries, which makes difficult the task of local authorities and undermines their intended goals. In addition, contingencies and asymmetries that emerge during the execution of long-term delegation contract generates huge transaction costs when it ultimately comes to end the contract by either parties. Further, ex-post renegotiation makes crystal clear ex-ante contracting inefficient. Hence, to prevent jeopardizing the regulatory process, local authorities may reveal, through mandated programs or other incentive mechanisms, some privately-held information during the contracting phase.

With this in mind, we explored new paths in monopoly regulation. We stressed that adding the social value of disclosed information to the traditional theoretical frameworks (Baron and Myerson, 1982) may enhance the efficiency of the current regulatory processes. Disclosure is not simply making additional information available to the public in order to comply with the *right-to-know principle*. It is more about the quality of information

that can be controlled by parties with conflicting interests and how it can be used in a beneficial manner. Considering strategic behaviors, the social value of disclosed information has been analyzed to determine the threshold value of disclosure allowing to increase welfare (Grossman and Stiglitz, 1980; Morris and Shin, 2002; Svensson, 2006; Angeletos and Pavan, 2007; Cornand and Heinemann, 2008; Hellwig and Veldkamp, 2009; Colombo et al., 2014; Myatt and Wallace, 2015; Vives, 2017). Then, exogenous and endogenous public information are questioned about the efficiency of disclosure. Indeed, these two types of information influence the revelation process and the use of private information so that generate pecuniary and informational externalities lowering social welfare. When the private information is efficiently used by economic agents, a larger amount of public information does not necessarily improve social welfare. Moreover, when the accuracy of public information is lower than that of private information, social welfare is reduced by more public disclosure. Therefore, the relative precision between public and private information is useful to determine when social welfare can increase with public information for a given accuracy level of private information.

Throughout this dissertation, we highlight that the relative precision between public and private information plays an important role when adding the social value of information in the regulatory process. It allows a local authority to precisely determine the delegation contracts with regards to the quality of disclosed information about the state of the infrastructure. Following Auriol and Laffont (1992), we set up an exogenous information structure in order to measure the relative precision between public and private information. In addition, since a local authority always reveals privately-held information by operators, public information disclosed public information has two effects in delegating contracts. The first effect gives strong incentives to a local authority to reveal private information during the competition between operators for the market. The second effect is to coordinate operators' strategic decisions with that of the local authority, that is to improve the quality of the infrastructure.

An important issue to keep in mind in this dissertation is that operators react strate-

gically to the precision of information disclosure. The efficient outcome of a two-stage delegation game depends therefore on how operators trade-off the precision of public information and the precision of private information. Hence, our results hinge largely and fundamentally on the exogenous nature of publicly disclosed information. Moreover, the pressure of the competition depends on the correlation coefficient of private information between operators. A local authority not only reveals the privately-held information, but also is misguided by additional information conveyed by this correlation coefficient. We find that the accuracy of publicly disclosed information can allow the local authority to reveal private information without costs. In addition, more precise mandated information limits the negative effect of misleading information on the decisions of the local authority.

While our models presented in chapters 2 and 3 deliver interesting results and shed light on various issues concerning the contractual delegation agreements, they can be extended in several ways in order to take extra features of the delegation problems into account. In this conclusion, we present two plausible extensions. Firstly, we have not completely explored the social value of public information in outsourcing local public services. In particular, we realize that our models must be adapted to offer enough insights into how the precision of disclosed information reduces the risk in managing local utilities. This risk is linked to the nature of investment in infrastructure (i.e., large sunk costs). If the transparency in the governance of infrastructure procurement is improved by information disclosure, then efficient investment decisions can be achieved. Such an analysis is complex when we combine information structure with moral hazard in the principal-agent relationship. Secondly, the benevolence of public authorities is adopted throughout this thesis. But, public authorities also favor concentrated and local interests, and care less about the quality of services and the routine maintenance. They react to individual incentives and pursue their own political agenda. In this case, transparency is about the relative degree of control over disclosure concerning what can be used to back the results of their policy. Our models can be adapted to take into account this possibility in a dynamic analysis of competitive solutions in providing local public services.

Finally, Chapter 4 also highlights other possibilities of analyzing information disclosure because we do not consider the correlation between public and private precision. As shown in Bergemann and Morris (2013), the correlation between public and private precision can explain the volatility of information acquisition in a dynamic model with endogenous information disclosure. We leave this issue to future research.

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