Université Paris-Dauphine
École Doctorale d'Économie des Organisations : Concurrence, Innovation, Finance

Stratégies d'Engagement et Pouvoir de Marché : une Application au Marché du Gaz Naturel

Thèse

Pour l'obtention du grade de Docteur de l'Université de Paris-Dauphine

Discipline : Sciences Économiques

Présentée et soutenue publiquement par

Mme Laure Durand-Viel

Directeur de recherche : Monsieur le Professeur Bertrand Villeneuve

Jury :

M. Claude Crampes (rapporteur)	Professeur à l'École d'Économie de Toulouse
Mme Anna Creti (rapporteur)	Professeur à l'Université Paris-Ouest Nanterre
M. Guido Friebel	Professeur à l'Université Goethe de Francfort
Mme Corinne Chaton	Docteur en économie, chercheur à EDF-Recherche et Développement
M. Bertrand Villeneuve	Professeur à l'Université Paris-Dauphine

Université Paris-Dauphine
École Doctorale d'Économie des Organisations : Concurrence, Innovation, Finance

Stratégies d'Engagement et Pouvoir de Marché : une Application au Marché du Gaz Naturel

Thèse

Pour l'obtention du grade de Docteur de l'Université Paris-Dauphine

Discipline : Sciences Économiques

Présentée et soutenue publiquement par

Mme Laure Durand-Viel

Directeur de recherche : Monsieur le Professeur Bertrand Villeneuve

Jury :

M. Claude Crampes (rapporteur)	Professeur à l'École d'Économie de Toulouse
Mme Anna Creti (rapporteur)	Professeur à l'Université Paris-Ouest Nanterre
M. Guido Friebel	Professeur à l'Université Goethe de Francfort
Mme Corinne Chaton	Docteur en économie, chercheur à EDF-Recherche et Développement
M. Bertrand Villeneuve	Professeur à l'Université Paris-Dauphine

À mes parents

À mon mari

Remerciements

Je tiens en premier lieu à remercier Bertrand Villeneuve, qui a dirigé cette thèse, pour son encadrement et ses conseils durant mes recherches. Sa grande disponibilité et son soutien permanent ont joué un rôle décisif dans la progression de mes travaux. Par ses conseils fondés sur son expérience approfondie dans le domaine de l'économie industrielle mais aussi sur son ouverture à de nombreux autres domaines et sa capacité à trouver des ponts entre des disciplines souvent trop cloisonnées, il a rendu ces années de recherche extrêmement enrichissantes.

Je remercie également les rapporteurs de cette thèse Claude Crampes et Anna Creti pour leurs commentaires et l'intérêt qu'ils ont porté à mon travail. Merci aussi à Guido Friebel qui a accepté de faire partie de ce jury de soutenance.

Mes remerciements les plus sincères à Corinne Chaton, qui a suivi l'avancée de mes travaux depuis mon mémoire de master jusqu'à ce jour. Sa connaissance solide de l'économie et du secteur énergétique ont été la source de contributions précieuses à mes travaux. C'est grâce à sa patience et à son soutien sans faille, sans oublier son indéfectible optimisme, que j'ai pu faire face même aux moments difficiles dans les meilleures conditions.

Les travaux présentés dans cette thèse, financés par une bourse du Centre de Recherche en Economie et Statistiques (CREST), ont été réalisés dans le cadre du Laboratoire d'Economie Industrielle du CREST. Je remercie Philippe Choné, grâce à qui j'ai pu rejoindre ce laboratoire, et Philippe Février, qui l'a dirigé pendant les années qui ont suivi. Les séminaires internes ont été l'occasion de présenter les premières versions de mes travaux, qui ont ainsi pu bénéficier des conseils toujours pertinents des membres du laboratoire. Je remercie ainsi tout particulièrement Thibaud Vergé et Laurent Linnemer pour des discussions passionnées et passionnantes sur des choix de modélisation, et les autres membres, Marie-Laure Allain, Saïd Souam, Nathalie Sonnac, pour leur écoute et leurs remarques.

Ces années passées au LEI ont aussi permis des échanges enrichissants avec des doctorants sur nos centres d'intérêts communs, la politique de concurrence avec Arnold Vialfont et Romain de Nijs, l'énergie et l'environnement avec Céline Letrémy et Amélie Mauroux, sans oublier tous les bons moments passés avec les "nouveaux" de Malakoff (Lionel Wilner, Raphaël Lévy, Isis Durrmeyer) ou les "anciens" des Saints-Pères (Laurent Lamy, Thomas Tregouët, et Radoslava Nikolova qui a partagé mon bureau, mes moments d'enthousiasme et mes phases de découragement).

Je remercie le groupe EDF pour son soutien financier qui m'a permis de réaliser mes recherches dans les meilleures conditions. Au centre de recherche et développement d'EDF à Clamart, j'ai pu confronter mes recherches théoriques à la vision de praticiens spécialistes de l'électricité et du gaz naturel. Je remercie Hélène Imberty et Michèle Dhaussy qui m'y ont accueillie. J'ai une pensée particulière pour Frederik Boujot dont la culture encyclopédique m'a impressionnée, pour Virginie Pignon, Marie-Anne Plagnet, Isabelle Bigard, Vincent Briat, Laurent Gilotte et tous les autres qui m'ont souvent donné des informations précieuses, et avec qui j'ai partagé journées de travail et séminaires à Clamart ou conférences à l'étranger.

J'ai eu la chance de rejoindre dès sa création le Laboratoire de Finance des Marchés de l'Energie (FIME), projet de recherche commun entre l'Université Paris Dauphine, le CREST et EDF-Recherche et Développement. Si les séminaires du FIME m'ont permis de découvrir une approche des marchés de l'énergie souvent différente de la mienne, ce qui a suscité des questionnements à l'origine d'une partie des travaux de cette thèse, les groupes de travail ont été l'occasion de présenter et de voir présenter des travaux en cours dans une atmosphère conviviale et constructive. Je remercie tout particulièrement René Aïd, ainsi que Gilles Chemla, pour nos discussions fructueuses.

Je remercie mes collègues actuels à l'Autorité de la concurrence, Gautier Duflos, Etienne Pfister, Valérie Meunier et Mariya Litinskaya, qui m'ont soutenue pendant ces derniers mois où, grâce à leur patience et leurs encouragements, il m'a été plus facile de combiner ma fin de thèse et mon premier emploi.

Enfin, je tiens à remercier mes parents, ma soeur Claire et mon frère Guillaume, qui m'ont entourée de leur affection tout au long de ces années de thèse, en m'encourageant aux moments de doute, et en m'écoutant avec patience raconter mes recherches sans toujours pouvoir me suivre. Mes derniers remerciements vont à mon mari, Nikolaï, qui par sa présence et son amour m'a apporté le plus précieux des soutiens.

Table des matières

Table des figures

Liste des tableaux

Introduction générale

Cette thèse est consacrée à l'étude de différentes stratégies dynamiques d'exercice du pouvoir de marché, avec une application au secteur du gaz naturel. L'analyse s'appuie sur la modélisation de ce marché dans ses différentes dimensions : horizontale, avec l'importance du pouvoir de marché des firmes en situation d'oligopole, verticale, avec la prise en compte des interactions entre les différents niveaux de la chaîne de valeur (producteurs, fournisseurs, consommateurs), et temporelle, puisque les stratégies des acteurs se déploient dans la durée. Le choix des thèmes traités s'explique par le désir de confronter certaines approches traditionnelles, qui s'appuient sur des hypothèses simplificatrices concernant la structure du marché, avec les éclairages que peut apporter la prise en compte des jeux d'acteurs et des spécificités de l'industrie du gaz naturel.

Libéralisation des marchés de l'énergie : les enjeux spécifiques au gaz naturel

Gaz naturel et électricité : nécessité d'une approche contrastée

Si la littérature théorique concernant les marchés de l'électricité est aujourd'hui relativement développée, celle consacrée au gaz naturel en est à ses débuts, du fait de la libéralisation plus tardive de ce marché et des problématiques différentes en Amérique du Nord et en Europe. Les points communs entre gaz naturel et électricité, qui sont à la fois des commodités énergétiques et des industries de réseaux, sont nombreux, et il est tentant de faire des rapprochements peut-être hâtifs. Pourtant, les différences entre ces deux secteurs méritent d'être soulignées.

L'une des différences les plus notables est que l'électricité ne peut pas être stockée à un coût raisonnable, alors que le gaz peut l'être. Cette distinction m'a incitée à m'intéresser aux enjeux liés au stockage de gaz. Le marché du gaz naturel se caractérise par une offre rigide et une demande peu élastique à court terme, présentant des fluctuations saisonnières marquées. Le stockage représente donc un moyen de flexibilité privilégié, auquel il existe cependant des alternatives, notamment le recours à des achats à court terme. Le prix peut alors être élevé en période de forte demande. Le choix des moyens de flexibilité vise à minimiser les coûts d'approvisionnement, mais il a aussi une dimension stratégique : un acheteur qui a recours au stockage modifie sa propre demande future, ce qui peut amener les producteurs à modifier le prix qu'ils pratiqueront aux périodes suivantes. Les modèles proposés dans cette thèse montrent comment les différentes stratégies d'approvisionnement disponibles modifient le comportement des firmes amont et aval (contrats, position sur le marché spot, mode de réservation de capacités) et affectent leur pouvoir de marché.

Une autre distinction entre gaz et électricité est relative à leur mode de production. L'électricité peut être obtenue au moyen de technologies faisant appel à différentes sources d'énergie, tandis que le gaz naturel est une matière première. Il ne peut être produit que dans les pays dotés de réserves, or ces réserves sont inégalement réparties sur la planète. C'est un problème crucial pour l'Europe, région grande consommatrice de gaz, mais dont la production est faible et en déclin, et qui est dépendante de grands producteurs extérieurs. Les importateurs européens de gaz sont eux-mêmes en majorité d'anciens monopoles nationaux encore très puissants sur leurs marchés historiques. Il m'a paru intéressant de proposer, dans les différents chapitres de cette thèse, une alternative aux modèles qui traitent ce marché comme parfaitement concurrentiel, en analysant dans quelle mesure leurs résultats sont robustes à la prise en compte du pouvoir de marché, aussi bien en amont qu'en aval, et en abordant également la question de la dépendance de l'Europe vis-à-vis de producteurs puissants.

Approche des enjeux de la libéralisation du marché du gaz naturel

L'organisation traditionnelle de l'industrie du gaz naturel en Europe, avant la libéralisation du marché, était essentiellement fondée sur des relations bilatérales entre un exportateur monopolistique dans chaque pays producteur, et un acheteur en monopole pour la fourniture aux consommateurs dans chaque pays importateur. Les investissements lourds nécessaires à la construction d'infrastructures de production ou de transport, investissements souvent spécifiques à la relation entre vendeur et acheteur, étaient alors adossés à des contrats d'importation à long terme. Si ces contrats sont généralement considérés comme favorables à l'investissement, la justification théorique est plus complexe qu'il n'y paraît, du fait de l'interaction entre deux engagements à portée stratégique : celui de l'acheteur qui s'engage sur une capacité maximale au moment de l'investissement, et celui du vendeur qui s'engage sur un prix pour toute la durée du contrat. Le lien entre la structure et la durée du contrat, d'une part, et le niveau d'investissement, d'autre part, fait l'objet d'une analyse détaillée dans le premier chapitre.

La libéralisation du marché du gaz naturel dans l'Union Européenne, amorcée dans les années 1990 et approfondie par des directives communautaires successives (en 1998, 2003 et 2009), a conduit à l'apparition de nouveaux entrants sur le marché de la fourniture aux consommateurs finals grâce à la séparation, au sein des anciens monopoles, entre activités commerciales et activités de réseaux et au libre accès des tiers à ces réseaux. Le stockage, s'il n'est pas considéré comme un monopole naturel, ni même comme une infrastructure essentielle (en règle générale), est cependant lui aussi soumis à des règles de non-discrimination en ce qui concerne la réservation des capacités et leur tarification. Les nouveaux entrants se plaignent pourtant régulièrement du manque de transparence sur les capacités disponibles. Les opérateurs historiques qui détiennent le stockage sont notamment soupçonnés d'attribuer les capacités en priorité à leur filiale active dans la fourniture, voire de prétexter un manque de capacités disponibles pour en priver leurs concurrents. Les incitations d'un fournisseur à adopter de telles stratégies sont analysées dans le deuxième chapitre.

Ces deux premiers chapitres s'intéressent particulièrement aux aspects dynamiques de l'analyse du marché, en se concentrant sur les enjeux de long terme dans le premier chapitre, et à l'impact de la saisonnalité, une caractéristique majeure du marché du gaz naturel, dans le second chapitre, tout en simplifiant à l'extrême la modélisation des acteurs. La deuxième partie propose une représentation plus détaillée des différents acteurs, opérateur historique ou nouveaux entrants, purs arbitragistes ou fournisseurs de clients finals. Du fait du poids de l'histoire ou de la régulation, des choix d'investissement passés ou des relations de longue date avec des partenaires commerciaux, tous ne disposent pas des mêmes opportunités. Le troisième et le quatrième chapitre ont ainsi en commun de porter une attention plus particulière aux asymétries, choisies ou subies, dans l'accès aux marchés.

Si les règles imposées au niveau communautaire ou national visent à permettre à tous les opérateurs un accès non-discriminatoire aux infrastructures essentielles, elles ne remédient pas à l'inégalité dans l'accès à la ressource. En effet, les opérateurs historiques conservent un accès privilégié aux contrats d'approvisionnement à long terme auprès des producteurs. La majorité des grands producteurs qui alimentent le marché européen étant situés hors de l'Union Européenne, ils n'entrent pas dans le champ de la régulation. L'enjeu consiste donc à savoir comment, par des mesures qui se limitent à l'aval de la chaîne, il serait possible de stimuler la concurrence entre fournisseurs, notamment en favorisant l'accès des nouveaux entrants à la ressource gazière, sans pour autant affaiblir les fournisseurs européens par rapport aux producteurs extra-communautaires. Cette problématique est abordée dans le troisième chapitre.

Une autre évolution marquante liée à la libéralisation des marchés de l'énergie a été l'apparition de marchés de matières premières qui prennent le relais des relations contractuelles bilatérales de long terme. L'émergence de marchés spot et à terme s'est accompagnée d'une multiplication des produits dérivés financiers. Des techniques de mathématiques financières sophistiquées ont été mises au point pour permettre la valorisation et l'optimisation de la gestion de ces produits. Aujourd'hui, de nombreuses entreprises dont l'activité principale est la fourniture de gaz à des consommateurs finals confient la gestion de leurs actifs réels et le calcul de la valorisation des nouveaux investissements à des divisions spécialisées dans le "trading" sur les marchés de gros, dont les choix reposent sur des logiques d'arbitrage. Pourtant, la libéralisation est loin d'avoir donné naissance, en Europe, à des marchés de l'énergie réellement liquides, et certains acteurs détiennent un pouvoir de marché important aussi bien sur le marché de gros que sur le marché aval. Dans un tel contexte, les techniques de valorisation reposant sur l'hypothèse de marchés liquides et concurrentiels présentent des risques, décrits dans le quatrième chapitre.

Les stratégies d'engagement et leur mise en œuvre

Si la motivation de ces recherches est l'étude du marché du gaz naturel et des problématiques liées à sa libéralisation, le fil conducteur théorique de la thèse est l'utilisation de stratégies reposant sur un engagement. En s'inspirant de l'approche développée et abondamment illustrée par Schelling (1960), on peut définir un engagement stratégique, de façon très générale, comme une action entreprise dans le but d'influencer le comportement futur d'un autre acteur en modifiant ses anticipations sur la façon dont on va soi-même se comporter. Et c'est en se contraignant soi-même, c'est-à-dire en restreignant ses propres possibilités d'action, qu'on parvient à modifier les anticipations de l'autre, et donc à le contraindre à adopter le comportement souhaité. Il y a donc une dimension fondamentalement paradoxale dans le concept d'engagement : c'est toujours d'abord et avant tout contre soi-même qu'on s'engage. En effet, on s'interdit à l'avance de faire des choix dont, par la suite, on peut regretter de ne plus disposer. Comme on est alors tenté de dévier de la ligne de conduite qu'on avait résolu de tenir, la crédibilité de l'engagement est un problème crucial.

Les stratégies d'engagement dans la littérature économique

La notion de stratégie d'engagement, bien avant d'être reprise par la théorie économique, a été développée dans le monde militaire. Dès 400 avant notre ère, Sun Tzu décrivait, dans "L'art de la guerre", comment le chef des armées, au moment critique, coupe toute possibilité de retrait à ses troupes, comme celui qui, ayant escaladé une hauteur, jette l'échelle derrière lui, ou comme celui qui brûle ses bateaux et casse ses marmites. Selon la légende, le conquistador espagnol Hernan Cortés aurait effectivement brûlé ses bateaux après avoir débarqué au Mexique, afin d'inciter son armée à plus d'ardeur au combat, mais surtout, de signaler aux Aztèques par cet engagement irréversible qu'il ne ferait pas marche arrière, même face à une résistance acharnée. Cette stratégie fut couronnée de succès puisque les Aztèques adoptèrent une réaction passive en laissant envahir Tenochtitlán.

La description la plus classique des bénéfices liés à l'engagement, dans la théorie économique, est celle de Stackelberg (1934). L'expression "leader de Stackelberg" est restée pour désigner, dans le cadre d'une concurrence en quantités, la firme qui "joue en premier" en s'engageant sur un niveau de ventes élevé, sa rivale étant contrainte de s'adapter en vendant un volume plus faible. Il convient de souligner que l'interprétation correcte de ce leadership n'est pas la capacité à être le plus rapide, mais la capacité à s'engager. En effet, à l'équilibre de Stackelberg, le leader ne joue pas sa meilleure réponse à celle du suiveur : il aurait en fait intérêt à réviser à la baisse son niveau de production. Mais c'est précisément parce qu'il ne peut pas le faire, et surtout parce que son concurrent sait qu'il ne le pourra pas, que ce dernier adopte une stratégie moins agressive. Si le deuxième joueur anticipait que le premier ne tiendra pas son engagement, et s'il était lui-même capable de s'engager sur sa propre quantité, il choisirait une quantité plus élevée, et c'est lui qui serait leader de Stackelberg à l'équilibre.

Le lien entre leadership et avantage stratégique n'est cependant pas univoque. Gal-Or (1985) montre ainsi que le premier joueur est avantagé si les actions choisies sont substituts stratégiques (c'est le cas dans la concurrence en quantités), mais que l'avantage va au second joueur lorsqu'elles sont compléments stratégiques. Ainsi, dans la concurrence en prix, le second joueur peut ajuster son prix à un niveau inférieur à celui fixé par le premier joueur, ce qui lui permet de capter toute la demande.

Par ailleurs, l'engagement qui caractériste le jeu de Stackelberg est extrême, car la firme s'interdit de réajuster son offre. Un tel engagement peut être difficile à mettre en œuvre de façon crédible. Une solution peut être de contracter avec un tiers, qui sera chargé de faire respecter les engagements souscrits. Les contrats à long terme "take or pay" (chapitre 3), courants dans les relations entre producteurs et importateurs de gaz naturel, impliquent ainsi une forme d'engagement de l'importateur à mettre ces quantités sur le marché, puisqu'il devra de toute façon les payer, qu'il les prenne ou non. Le détenteur d'un tel contrat pourra ainsi mener une concurrence agressive envers des fournisseurs aux approvisionnements plus flexibles.

Des formes d'engagement moins drastiques peuvent néanmoins être efficaces. Plutôt que de s'interdire totalement certaines options, un joueur peut modifier ses incitations futures en rendant certains choix plus ou moins coûteux. Les investissements en capacités sont un moyen efficace d'acquérir un avantage stratégique sur ses rivaux voire de dissuader l'entrée sur un marché (Spence 1979, Fudenberg et Tirole 1983) : si les coûts encourus sont irrécupérables, l'investissement constitue un engagement durable à être capable de produire jusqu'à la capacité maximale, tandis que les rivaux qui n'ont pas investi peuvent être tentés de ne jamais le faire, et se contenter de ventes plus modestes. Pourtant la firme qui a investi reste libre, par ailleurs, d'ajuster son niveau de production : l'engagement porte en fait sur ses coûts. Le stockage (chapitres 2 et 4) est un moyen d'engagement similaire, à ceci près que l'engagement est moins durable (une fois les stocks épuisés, l'effet disparaît) mais plus drastique (le coût de "production" des quantités en stock étant nul, la menace de mettre sur le marché des quantités importantes est encore plus crédible).

Dans tous ces exemples, l'engagement a pour but la préemption, dans le cadre d'une concurrence horizontale : il s'agit de capter la demande future avant ses concurrents. Un autre enjeu concerne la relation verticale entre vendeur et acheteur. L'engagement peut alors consister à modifier sa propre fonction d'offre ou de demande future. Dans le cas d'un bien durable (voir Coase, 1979, et Bulow, 1982), un monopole, à moins de pouvoir s'engager sur ses prix, voit son pouvoir de marché s'éroder, car il a un concurrent — lui-même, aux périodes postérieures : après avoir servi les consommateurs prêts à payer un prix élevé, il sera incité à baisser son prix pour avoir des ventes supplémentaires, mais anticipant ceci, aucun client ne sera prêt à payer un prix élevé. Le stockage correspond à une situation inverse : quand un vendeur commercialise des unités qui vont être stockées par leur acheteur, il fait face, aux périodes suivantes, à la concurrence de ces stocks, ce qui restreint son pouvoir de marché. Autrement dit, en stockant, l'acheteur restreint stratégiquement sa demande future, afin de ne pas être à la merci du prix courant pratiqué par le vendeur (chapitre 2). Une autre forme d'engagement stratégique permettant à un acheteur de limiter le pouvoir de marché du vendeur consiste, lorsqu'un équipement est nécessaire pour consommer le bien proposé par le vendeur, à choisir stratégiquement la capacité de l'équipement (chapitre 1) : l'investisseur garde la possibilité d'ajuster sa consommation à la baisse, mais il ne peut jamais dépasser la capacité maximale.

L'interaction entre les dimensions horizontale et verticale de l'engagement (abordée notamment dans les chapitres 2 et 3) est complexe et peut conduire à des résultats paradoxaux. Dans un modèle devenu célèbre, Allaz et Vila (1993) combinent le motif de préemption et la modification de sa propre fonction d'offre future, en montrant que lorsque des firmes en concurrence en quantités ont la possibilité de s'engager par des contrats forward sur une quantité et un prix de vente pour une période future, l'existence du marché forward réduit leur pouvoir de marché. Individuellement, chaque firme est incitée à vendre en forward pour préempter la demande future. Cependant, plus la proportion de ses ventes en forward est élevée, moins une firme est sensible au risque de faire baisser le prix en vendant de grandes quantités sur le marché spot, puisque ses revenus sont en grande partie déjà fixés ; par conséquent, elle sera plus agressive sur le spot. Les firmes sont donc dans une situation de dilemme du prisonnier, car toutes veulent signer des contrats forward avant leurs rivales, et à mesure que le nombre de périodes d'échanges sur le marché forward s'accroît, le prix spot et le prix forward (qui sont égaux à l'équilibre) tendent vers le niveau de concurrence parfaite. Ainsi, chacun voudrait être le seul à s'engager, mais il vaudrait mieux, pour l'ensemble des vendeurs, qu'il n'existe pas de possibilité d'engagement par des contrats forward.

Si, dans un contexte horizontal, les firmes entretiennent une relation de pure rivalité, la relation entre vendeur et acheteur implique le partage d'un surplus, et donc une tension entre désir de maximiser le surplus total généré et désaccord sur sa répartition (chapitres 1 et 3). Une telle relation fait apparaître un besoin de coopération, qui peut inciter le vendeur à adopter un engagement d'un type différent : au lieu d'un engagement à l'agressivité, caractéristique de la préemption, il choisira un engagement à la modération, visant à rassurer son partenaire. Ainsi, pour l'inciter à investir, il pourra lui proposer une "garantie", notamment au moyen d'un contrat à long terme par lequel il s'empêche à l'avance d'abuser, à l'avenir, de son propre pouvoir de marché. C'est la réponse classique au problème du "holdup" — problème de l'expropriation, par le vendeur, du surplus de l'acheteur une fois que ce dernier a réalisé un investissement spécifique à leur relation bilatérale — identifié dès 1971 par Williamson (voir aussi Klein, Crawford et Alchian, 1978).

Approche de la problématique théorique

Le premier chapitre revisite le problème classique du "holdup" dans un contexte où la capacité investie par l'acheteur détermine la quantité maximale qu'il pourra par la suite acquérir auprès du vendeur. L'investissement dans des capacités de transport par gazoduc entre zones de production et de consommation de gaz naturel est une application directe, mais on peut penser aussi à des équipements consommateurs d'énergie caractérisés par une puissance maximale. Cette auto-limitation de l'acheteur, par le choix d'un volume maximal de consommation, tourne à son avantage, puisqu'elle conduit le vendeur à s'engager lui-même sur des conditions contractuelles protectrices, faute de quoi l'investissement serait trop faible ou inexistant.

Comme dans le contexte traditionnel du holdup, seul l'engagement permet d'empêcher l'échec et le non-investissement. Un engagement de longue durée paraît donc garantir un investissement plus élevé. Mais ici, l'attention portée au mode de tarification permet de nuancer l'analyse. Le modèle distingue deux dimensions dans la capacité d'extraction du surplus par le vendeur : la performance du tarif et la durée de l'extraction.

L'auto-limitation dans la durée d'extraction du surplus du consommateur (puisque le holdup n'intervient qu'après expiration d'un contrat protecteur), liée à l'application ultérieure d'un tarif qui permet une extraction parfaite de ce surplus (par exemple un tarif binôme), permet d'atteindre le niveau d'investissement optimal, à condition toutefois que la durée du contrat soit non nulle ; en l'absence de tout engagement, on retrouve l'échec du marché. La performance de l'instrument de tarification employé par le vendeur peut, dans ce contexte, priver l'acheteur de tout surplus.

On peut concevoir une restriction dans le mode de tarification, par exemple le recours à des tarifs purement linéaires. L'inconvénient est que le niveau d'investissement optimal ne peut plus être atteint, mais l'avantage est de garantir une part du surplus à l'acheteur. L'interaction entre les restrictions portant sur la tarification et la limitation de la durée d'extraction n'est pas triviale. Contrairement à l'intuition, la complexité des tarifs et la durée du contrat sont des compléments stratégiques : si on limite la première par une tarification peu sophistiquée, il convient de réduire la seconde en se limitant à des contrats courts. En effet, le vendeur sera d'autant plus enclin à proposer un prix de contrat stimulant l'investissement qu'il est assuré d'un retour suffisant sur cet effort grâce à une date de fin de contrat précoce. Des contrats de longue durée, s'ils s'appuient sur des tarifs peu performants, s'avèrent protecteurs pour les acheteurs, mais nuisibles pour l'investissement.

Le second chapitre est consacré à l'analyse de l'utilisation du stockage par des firmes dans le but d'améliorer leur position concurrentielle, à la fois par rapport à leurs rivales et par rapport au producteur auprès duquel elles s'approvisionnent. Le stockage étant une caractéristique fondamentale du gaz naturel, il a semblé pertinent de s'intéresser à la possibilité de comportements stratégiques dans ce domaine. Ce chapitre s'appuie sur la modélisation d'un oligopole successif, devenue courante pour représenter le marché européen du gaz naturel, mais qui n'avait jamais été employée pour analyser les comportements de stockage. Ceci permet, tout en adoptant une méthode de résolution classique en économie industrielle, d'obtenir des résultats novateurs dans un jeu où la concurrence horizontale, les relations verticales et l'aspect intertemporel des stratégies sont étroitement liés. Si l'étude met délibérément de côté certains traits de réalisme (notamment par l'hypothèse d'environnement certain qui élimine le stockage de précaution), elle permet, par son caractère stylisé, de mettre en lumière ce qui relève spécifiquement du comportement stratégique.

Ce deuxième chapitre s'inscrit en rupture avec l'argument classique de la préemption selon lequel chaque firme souhaiterait stocker plus que sa rivale pour préempter la demande future. Il montre que cette intuition n'est valable que dans un oligopole simple. Lorsque les firmes s'approvisionnent auprès de producteurs eux-mêmes en concurrence imparfaite (oligopole successif), d'autres effets apparaissent, qui peuvent contrebalancer l'effet initial. On présente ainsi un mécanisme par lequel il est possible qu'une firme souhaite que ce soit sa concurrente qui stocke, ce qui lui procurerait l'avantage de pouvoir s'approvisionner à plus bas prix à l'avenir, la demande future étant réduite. Des conséquences sur la régulation de l'accès des tiers au stockage peuvent être tirées de ces analyses. Ainsi, même si le stockage est une stratégie d'engagement permettant de préempter la demande future, dans le cadre considéré, il peut être pertinent de s'engager à l'avance à ne pas employer cette stratégie, en restreignant soi-même les capacités de stockage dont on pourra disposer, au moyen des réservations de capacité. Dès lors, le leader n'est pas tant celui qui a les moyens d'être le premier à capter la demande, que celui qui a la possibilité de choisir d'être ou non le premier.

Le troisième chapitre se penche à nouveau sur les stratégies d'approvisionnement, en s'intéressant non plus à l'arbitrage entre stockage et achats immédiats, mais à la combinaison entre approvisionnements par contrats à long terme et achats à court terme sur un marché spot, la première possibilité n'étant pas accessible à tous les fournisseurs, mais uniquement à l'opérateur historique. Cet accès exclusif aux engagements en amont renforce en retour sa capacité à s'engager envers les consommateurs en aval, puisqu'il lui est possible de s'appuyer sur des approvisionnements à volume et prix prédéterminés, et d'ajuster sa position sur le marché spot pour minimiser son coût global d'approvisionnement. Pour le régulateur, cette asymétrie d'accès à la ressource est problématique puisqu'elle a un effet désincitatif sur l'entrée de fournisseurs concurrents et met donc en péril le succès de la libéralisation. Cependant, le contrat à long terme ne peut pas en lui-même faire l'objet d'une régulation. Une réponse apportée à ce problème, dans certains pays, a consisté à obliger l'opérateur historique à revendre, selon des modalités fixées par le régulateur, une proportion des volumes de son contrat à long terme dans le cadre de programmes dits de “gas release” (cession de gaz).

Si ces programmes ont été systématiquement peu ambitieux, c'est sans doute parce que leurs objectifs n'ont pas été clairement définis, ou qu'il a pu y avoir confusion entre les objectifs finaux, les moyens à mettre en œuvre pour y parvenir, et les critères d'évaluation des mesures mises en place. Ainsi, se donner pour seul objectif l'augmentation de la part de marché des entrants est illusoire, car l'opérateur historique peut alors choisir de réaliser ses profits en vendant en amont à ses concurrents plutôt qu'en aval aux consommateurs, ce qui est typiquement le cas lorsque les volumes cédés sont vendus aux enchères. L'analyse proposée dans ce chapitre montre que l'objectif global d'augmentation du surplus social se décompose en deux sous-objectifs : stimuler l'entrée, mais aussi garantir des conditions favorables d'approvisionnement par contrat à long terme. En effet, la libéralisation du marché aval a souvent suscité la crainte de voir les fournisseurs européens, désormais plus nombreux et moins puissants, affaiblis par rapport aux grands producteurs auprès desquels ils s'approvisionnent. Le chapitre évalue, par rapport à ces objectifs, la performance des types de programmes qui ont été mis en œuvre en pratique, puis s'efforce de décrire comment les instruments à la disposition du régulateur (l'ampleur du programme, sa durée et le prix de cession du gaz) devraient être calibrés, en fonction des contraintes de faisabilité politique.

Le quatrième et dernier chapitre aborde la problématique du stockage sous un angle différent. Le stockage peut être conçu comme un actif réel de conversion, qui transforme du gaz disponible immédiatement en gaz disponible à une période future. Il permet donc d'exercer des arbitrages entre les deux prix correspondants. L'analyse s'attache à montrer les limites de la valorisation d'un tel actif par des méthodes de pur arbitrage, qui ne tiennent pas compte des fondamentaux du marché puisque toute l'information pertinente est supposée être incluse dans les prix du marché de gros (spot). Deux oublis sont ainsi identifiés. D'une part, le pouvoir de marché sur le spot : l'hypothèse d'acteurs preneurs de prix est contestable pour les marchés de l'énergie, qui sont peu liquides et où des transactions impliquant des volumes importants auront un impact sur les prix. D'autre part, l'existence d'un marché aval : celui-ci ne peut pas être négligé lorsque les acteurs y détiennent un pouvoir de marché qui leur permet d'y voir une source de profit alternative aux arbitrages sur le marché amont. L'analyse montre que ces deux types d'erreur engendrent des biais qui sont de sens opposé. Le biais global révèle une tendance structurelle des méthodes de valorisation traditionnelles à la sous-évaluation des actifs, qui pourrait conduire au sous-investissement.

Une extension propose de prendre en compte la diversité des profils de clientèle des opérateurs. On suppose ainsi que deux fournisseurs sont actifs sur des marchés aval distincts, dont le profil saisonnier de demande diffère, mais qu'ils s'approvisionnent sur le même marché spot. L'analyse révèle qu'il est important, dans la valorisation d'un investissement en capacités de stockage, de tenir compte non seulement de son propre profil de demande, mais de celui des autres opérateurs actifs sur le marché spot, dans la mesure où ils peuvent avoir une influence sur le prix de gros. Si les techniques fondées sur les seuls prix spot présentent des imperfections, des méthodes qui tiendraient compte de l'environnement concurrentiel nécessiteraient une connaissance fine de la demande, de l'offre et des capacités de stockage de tous les autres acteurs présents sur le marché, ce qui limite leur utilisation concrète.

Pour toutes ces problématiques liées au marché du gaz naturel, la thèse s'efforce, à l'aide des outils de l'économie industrielle, de décrire comment les acteurs s'appuient sur des stratégies intertemporelles pour maintenir ou renforcer leur position face à leurs partenaires ou à leurs concurrents. Elle étudie ainsi notamment dans quelle mesure les différentes stratégies d'approvisionnement disponibles modifient le pouvoir de marché des firmes amont et aval, et les conséquences sur les comportements des firmes et sur la structure du marché. Les modèles, très stylisés, ne sont pas destinés à servir de base à des simulations mais doivent permettre de mettre en lumière des aspects spécifiques du marché pour comprendre les incitations et les comportements des acteurs. Ils apportent un regard critique sur les outils et méthodes d'analyse classiques du marché du gaz, pour mesurer leur pertinence et leurs limites. Enfin, ils permettent de formuler certaines recommandations en termes de régulation et de politique énergétique.

Références

Allaz, Blaise and Jean-Luc Vila (1993), "Cournot Competition, Forward Markets and Efficiency", Journal of Economic Theory, 59, 1-16.

Bulow, Jeremy (1982), "Durable Goods Monopolists", Journal of Political, 90, 2, 314-322.

Coase, Ronald (1972) "Durability and Monopoly", Journal of Law and Economics, 15, 1, 143–49.

Fudenberg, Drew and Jean Tirole (1983), "Capital as Commitment : Strategic Investment to Deter Mobility", Journal of Economic Theory, 32.

Gal-Or, Esther (1985), "First-mover and second-mover advantages", International Economic Review, 26, 3, 649-653.

Klein, Benjamin, Robert G. Crawford, and Armen A. Alchian (1978), "Vertical Integration, Appropriable Rents, and the Competitive Contracting Process", Journal of Law and Economics, 21, 2, 297-326.

Schelling, Thomas Crombie (1960), "The Strategy of Conflict", Harvard University Press, Cambridge (Massachussets).

Spence, Andrew Michael (1979), "Investment Strategy and Growth in a New Market", Bell Journal of Economics, 10, 1-9.

Von Stackelberg, Heinrich Freiherr (1934), "Marktform und Gleichgewicht", Springer-Verlag, Vienna and Berlin.

Sun Tzu, "L'art de la guerre", traduit du chinois par Valérie Niquet-Cabestan. Economica, Paris, 1988.

Williamson, Oliver E. (1971) : "The Vertical Integration of Production : Market Failure Considerations", American Economic Review, Papers and Proceedings, 61, 2, 112-123.

Première partie

Stratégies d'engagement : aspects dynamiques

Chapitre 1

Strategic capacity investment under holdup threats : the role of contract length and width

1 Introduction

This paper considers markets in which the short-run demand elasticity is low because demand is largely pre-determined by specific installed capital with which the buyer is caught. Investment decisions involve not only a qualitative choice (specific technology), but also a quantitative one (capacity). Oil and gas pipelines are the paragon of specific investment, where the initial capacity choice acts as a cap on volumes subsequently traded. In the short run, buyers of energy (oil, natural gas, or electricity) are locked into a previously chosen technology or standard (appliances in Balestra's and Nerlove's 1966 terminology), or tied to a specific supplier (in the case of pipelines). In the long run, fuel substitution will follow the path of capital substitution, making the elasticity much higher.

What happens if market power matters ? Markups can rise high with low elasticities, but in the long run price elasticity typically increases.[1] The seller has to be careful to preserve his consumer base over time, and he must adopt reasonable tariffs if he doesn't

This chapter is based on joint work with Professor Bertrand Villeneuve.

[1]See the Le Chatelier principle in Samuelson (1947).

want to kill the goose that lays golden eggs.

The model studies in detail a bilateral relationship in which a potential or actual investment is specific. Commitment is a critical issue : though reasonable prices may be announced to encourage investment in the specific appliances, these announcements are more or less credible. If commitment is limited, buyers may fear hold-up, *i.e.* unilateral price increases that will extract a rent from the installed capital.

Discrete-continuous choice models in the econometric literature on consumer demand (Dubin-McFadden 1984, Hanemann 1984) usually assume that each buyer makes essentially *one* farsighted decision, namely the technology he adopts. Balestra and Nerlove (1966) build a dynamic model where at any given point in time only one fraction of the market, the non-committed consumers (new consumers or those who replace their appliances), can choose their fuel, and once this choice is made, consumption varies freely in response to price. Not only do these models assume that production is competitive and that consumers are price-takers, they also disregard an important feature of the investment decision that constrains future consumption decisions, the capacity choice.

This feature is also neglected by industrial organization literature on standard competition or aftermarket monopolization (Shapiro 1995, Chen *et al.* 1998, Reitzes and Woroch 2008), which focuses on the optimal strategy of firms trying to attract customers who, once locked in, will be at the mercy of their market power. These models make rather extreme assumptions about the link between equipment and complementary goods. Some assume strict complementarity (one primary good for one aftermarket good, see Carlton and Waldman, 2001), so that there is one decision to be made—equipment. Alternatively, others assume independence—demand *ex post* can be adjusted freely (*e.g.* Borenstein *et al.*, 2000, Morita and Waldman, 2004). In our model, complementarity is asymmetric : the buyer cannot consume more than his capacity allows, but he is free to consume less. This is typically the case with energy-consuming appliances.

Examples could also be taken from the R&D sector. Firms investing in specific production lines that need to pay license fees for intellectual property rights gauge their investment according to the intended intensity of license use. Here again, elasticity is asymmetric : it is easier to slow down production than to exceed capacity. Another example is the franchisor/franchisee relationship : when a franchisee chooses an outlet of a given size and location, his investment caps his future sales capacity, then the payment to the franchisor (in addition to a fixed fee) typically consists in royalties calculated as a percentage of his turnover. The main difference with the traditional literature on incomplete contracts, investment and hold-up[2] is that investment itself is a strategy against the seller's potential abuses.

Contract incompleteness affects both the overall performance of the relationship and the distribution of the generated surplus. To pre-empt possible contract failures, some general rules can be agreed on, without compromising future negotiations about contractual details. For example, in their analysis of natural gas contracts, Crocker and Masten (1985) explain how take-or-pay provisions, by allocating discretionary power to the informed party, ensure that the optimal decisions are taken at investment *and* operations stages.[3] In our view, contract length and width can be seen as key features of the "'constitution' governing the ongoing relationship" (Goldberg, 1976, p. 428). The constitution could be either a prior agreement between the parties, or even a general purpose law governing some commercial relationship. This view motivates our comparative statics analysis of contract length in relation with restrictions on the price structure (width).

Complete contracts are, by definition, unlimited; in contrast, contracts with limited width may be optimized with respect to length in compensation. Conventional wisdom has it that long contracts protect investors. Eventually, one would expect the investment level and social welfare to rise as the commitment duration increases,[4] the extra surplus being shared between the parties depending on their bargaining powers.

Clearly, a time limit may be necessary to avoid applying obsolete clauses, especially if some random factor drives the economy away from the initial conditions on the basis of which the contract was calibrated (Crocker and Masten, 1988). However, even in the absence of uncertainty, long incomplete contracts may have undesirable effects.

In our model, as the contract becomes longer, the buyer's incentives to invest regress while the seller's ability to extract rent diminishes. With linear prices, the negative impact

[2] See Williamson (1971) for an early reference.

[3] Hubbard and Weiner (1986) offer an alternative interpretation of take-or-pay provisions in terms of risk sharing. See Creti and Villeneuve (2004) for a survey.

[4] This is the thesis in the empirical study by Joskow (1988). He finds evidence of a positive relationship between asset "specificity" (as measured by different proxies) and contract length. See also Neumann and Hirschhausen (2008).

on social welfare of a longer contract is very unequally shared between the parties : the buyer's surplus increases as he produces less surplus but can keep a much larger part of it, whereas the seller is a net loser.[5] A longer contract actually protects expropriable investors rather than the investment itself.

The paper is organized as follows. Section 2 sets up the model. We analyze various scenarios with two-part tariffs in section 3. Linear contracts are then characterized : we start with simple cases (full commitment, no commitment) in section 4 and we expose the case of partial commitment, *i.e.* with expiry date, in section 5. Most of the proofs are relegated to the Appendix.

2 General setting

2.1 Trade and payoffs

The game involves two players : the seller and the buyer. The model is in continuous time with infinite horizon. At instant t, the seller sells to the buyer a quantity q_t of a commodity produced at a constant unit cost c; he receives in exchange a payment τ_t, expressed in units of the numéraire good.

The instantaneous utility of the buyer is quasi-linear. It can be written (up to some irrelevant constant) $u(q_t) - \tau_t$. We will use the iso-elastic utility function

$$u(q) = \tfrac{\varepsilon d^{\frac{1}{\varepsilon}}}{\varepsilon - 1} q^{\frac{\varepsilon-1}{\varepsilon}}, \tag{1.1}$$

where d is a positive scale parameter and where ε is the price elasticity of demand. We assume that $\varepsilon > 1$.

The seller sets the tariffs $\{\tau_t(\cdot), t \geq 0\}$ where the argument of $\tau_t(\cdot)$ is q_t. Only linear and two-part tariffs are used. The general shape of the total payment at date t to the seller for quantity q_t is therefore $\tau_t(q_t) = m_t + p_t q_t$, where m_t is a per-time-unit fixed fee and p_t is the marginal price.

[5]Castaneda (2006) also finds a negative effect of longer contracts on investment, but in his model both parties are worse off. The contract in his analysis is such that the buyer pays upfront a lump sum and that the seller invests after acceptance. The buyer thus is reluctant to accept long contracts that would establish extortion for a long time, meaning in turn that the seller's return on them is poor, which depresses investment.

Thus, the instantaneous buyer demand $Q(\cdot)$ exhibits constant price elasticity :

$$Q(p_t) = dp_t^{-\varepsilon}. \tag{1.2}$$

The inverse demand function Q^{-1} is denoted P.

The consumption of the commodity requires an equipment with an indefinite service life, installed at date $t = 0$, whose size A determines maximum consumption once and for all. For example if the equipment is a pipeline, imports cannot exceed the pipeline's capacity :

$$q_t = \min\{Q(p_t), A\}. \tag{1.3}$$

Unless otherwise specified, the investment cost (k per unit) is assumed to be borne by the buyer, who chooses non-cooperatively the investment size A (the case where the seller is the investor is also discussed further on). The future is discounted at rate r.

The intertemporal surplus of the buyer is

$$S = \int_0^{+\infty} (u(q_t) - \tau_t(q_t))e^{-rt}\, dt - kA. \tag{1.4}$$

The intertemporal profit of the seller is

$$\Pi = \int_0^{+\infty} (\tau_t(q_t) - cq_t)e^{-rt}\, dt. \tag{1.5}$$

The first best.

The social optimum requires $u'(q_t) = c + rk$, which means constant consumption : $\forall t, q_t = Q(c + rk)$. The term rk is the unit amortization cost of the durable investment. The efficient investment is thus

$$A^* = Q(c + rk). \tag{1.6}$$

2.2 Market power and limited commitment

Trade takes place only after the equipment has been built, however trading terms can be determined beforehand by means of an agreed tariff.

1. At date 0, the seller makes a take-it-or-leave-it offer to the buyer consisting of tariffs $\{\tau_t(\cdot), t \in [0, T)\}$, valid until T. The buyer accepts this offer if it leaves him with a non-negative surplus.
2. The buyer invests A.
3. From $t = 0$ to T, the buyer purchases q_t at each date t.
4. At date T, the contract expires. At each date $t \geq T$, the seller makes a take-it-or-leave-it offer to the buyer consisting of tariff $\tau_t(\cdot)$. The buyer accepts this offer if it leaves him with a non-negative instantaneous surplus, and consumes the corresponding q_t.

Without loss of generality, the seller's pricing strategies can be restricted to constant marginal prices over each period : p_0 during the first period ($0 \leq t < T$) and p_T during the second period (for $t \geq T$). The way the fixed payments are staggered over time within the first period does not matter in the sense that paying m_t at all dates $t \in [0, T)$ is equivalent to an upfront payment[6]

$$M_0 = \int_0^T m_t e^{-rt}\, dt. \tag{1.7}$$

The contract can be summarized by (M_0, p_0).

In the 4$^{\text{th}}$ step, the buyer cannot change his investment, thus whether the seller offers a durable contract or (as we assume) a short-term contract does not make a difference. Indeed, any optimal contract has to implement the same successive identical offers.

The following sections will discuss performance of the market with respect to the first-best allocation. The analysis will focus on a bilateral relationship where the investor is the buyer ; the case where the seller invests will also be discussed.

3 Two-part tariffs

3.1 Unlimited commitment ($T = +\infty$)

Implementation of the first-best is straightforward. If $p_0 = c$ and the fixed fee is reasonable (*i.e.* such that the buyer participates), the buyer invests A^*. To extract the

[6]Liquidity constraints on either player could limit this freedom, which we do not consider.

surplus, the seller must choose

$$M_0 = \frac{1}{r}\left(u(A^*) - (c+rk)A^*\right), \tag{1.8}$$

which is the present value of the perpetual flow $u(A^*) - (c+rk)A^*$. This is the generalization of the well-known static result.

3.2 Limited commitment $(0 < T < +\infty)$

At date T the investment A is sunk and nothing can prevent the seller from exerting hold-up on the buyer by setting at each instant a tariff that captures the entire surplus from the relationship. For $t \geq T$, any tariff scheme (m_t, p_T) such that $p_T \leq P(A)$ (to avoid under-consumption) and $m_t + (p_T - c)A = u(A)$ (to ensure participation) will do. A simple example is $p_T = c$ combined with a fixed fee $m_t = u(A), \forall t \geq T$.

The buyer anticipates that he will obtain no surplus from T on. Assume the price during the first period is constant and denoted by p_0. After rearrangement, the buyer solves :

$$\max_A \tfrac{1-e^{-rT}}{r}\left(u(A) - \left(p_0 + \tfrac{rk}{1-e^{-rT}}\right)A\right) - M_0, \tag{1.9}$$

where the expression reveals that, due to expropriation *ex post*, the investment A has to be amortized during the first period. The equivalent flow cost of investment is thus $\frac{rk}{1-e^{-rT}}$ per unit of equipment.

The buyer will invest

$$A = Q\left(p_0 + \frac{rk}{1-e^{-rT}}\right), \tag{1.10}$$

under the condition that M_0 is small enough to ensure participation.

The seller anticipates that he can obtain the total surplus from T on, whose present value is $\frac{e^{-rT}}{r}(u(A) - cA)$. He solves

$$\begin{aligned}
\max_{M_0,p_0} \Pi(M_0,p_0) = M_0 &+ \tfrac{1-e^{-rT}}{r}(p_0 - c)Q(p_0 + \tfrac{rk}{1-e^{-rT}}) \\
&+ \tfrac{e^{-rT}}{r}\left[u\left(Q(p_0 + \tfrac{rk}{1-e^{-rT}})\right) - cQ(p_0 + \tfrac{rk}{1-e^{-rT}})\right] \\
\text{s.t. } M_0 \leq \tfrac{1-e^{-rT}}{r} &\left[u\left(Q(p_0 + \tfrac{rk}{1-e^{-rT}})\right) - (p_0 + \tfrac{rk}{1-e^{-rT}})Q(p_0 + \tfrac{rk}{1-e^{-rT}})\right].
\end{aligned} \tag{1.11}$$

Clearly, the seller will choose the largest possible fixed fee and the corresponding profit-maximizing price.

Proposition 1.1. *When the seller can commit to a two-part tariff* (M_0, p_0) *for a limited duration* T*, he will set a marginal price below his marginal cost :*

$$p_0 = c - \tfrac{e^{-rT}}{1-e^{-rT}} rk, \tag{1.12}$$

This leads the buyer to undertake the optimal investment $A^* = Q(c + rk)$*. The fixed fee allows the seller to capture the entire first-stage surplus :*

$$M_0 = \tfrac{1-e^{-rT}}{r} \left(u(A^*) - (c + rk)A^* \right). \tag{1.13}$$

Then the following tariff allows him to capture the entire second-stage surplus :

$$\textit{For all } t > T, \; m_t = u(A^*) \textit{ and } p_T = c. \tag{1.14}$$

An interesting feature of this game is that the consumption good is subsidized during the contract : it is priced below its marginal cost, the subsidy being the amortization of capital from date T on, *i.e.* it is an *advance compensation* for the hold-up period. The shorter the contract duration and the larger the investment cost, the more generous the first-stage unit price reduction must be in order to stimulate investment. Remark that p_0 is negative if T is sufficiently short.

The two instruments of the contract play different roles : p_0 is used to give the right investment incentives to the buyer, and M_0 transfers the surplus to the seller. The seller is willing to set a below-cost unit price in order to encourage investment because this does not prevent him from capturing the entire surplus from the relationship, through the fixed fee in the first stage, then by exerting hold-up after expiry of the contract.

3.3 No commitment $(T = 0)$

Suppose now the seller cannot commit to a tariff (M_0, p_0) (in other words, $T = 0$). This is the pure hold-up situation : once the investment is made, the seller will repeatedly set the same tariff (m, p) that captures the entire *ex post* surplus for each period, which means that the buyer cannot recoup his investment costs. As a consequence, the buyer's surplus if he invests is negative. Therefore, if the seller cannot commit to a unit price before the buyer invests, there is no equilibrium with positive investment. No commitment and powerful tools is the worst-case scenario.

3.4 Endogenous duration

The first-best investment level can be attained whatever $T > 0$. The interest of the alternative scenarios with respect to T lie in the timing of transfers and the structure of tariffs. In all cases, the whole surplus goes into the seller's hands. In the analysis, the contract duration T is treated as exogenous. Now suppose the seller or the buyer has the power to determine the contract's duration. All durations $T > 0$ are equivalent for both players, while $T = 0$ is inefficient, thus the choice will be any strictly positive duration.

3.5 Investment by the seller

Suppose the investment is made by the seller. Fixed fees allow a monopolistic seller to capture the entire surplus both during and after the contract, therefore it is optimal for him to choose the first-best investment level A^* and to always set the variable price $p = c + rk$ to induce a consumption equal to A^*. In fact, whether the investment is undertaken by the seller or the buyer has no bearing on the outcome.

4 Linear tariffs : simple cases

Let's recall first a basic characteristic of static monopolistic markets. Let's suppose the fixed part of a two-part tariff is capped by regulation, and let's see what happens when the cap goes down. Obviously, if the cap is high enough, the seller achieves the first-best by setting a price equal to his marginal cost and extracts the entire surplus through the fixed fee (see previous sections). If the cap on the fixed part is lower, the seller must decrease the fixed fee and raise the marginal price above marginal cost (the buyer's surplus is still zero). If the cap on the fixed part falls further, the seller continues to set the highest possible fee but stops raising the marginal price. This happens when the marginal price has attained the optimal linear price, usually called monopoly price.

The latter case is the most important for our point as it can be easily extrapolated : tightly capped two-part tariffs yield the same prices, quantities and investment level as linear tariffs, only the surplus sharing is affected. In other words, the marginal effects of the cap and its inframarginal effects are disconnected if the cap is sufficiently low.

A defense of linear pricing relies on its distributive role : guaranteeing the buyer a share of the surplus is an appealing feature of linear pricing. Linear pricing may emerge as a general rule imposed in the buyer's interest simply because in the absence of information on future costs or preferences, it is extremely robust as a protection against full rent extraction.[7]

In this section, the seller is assumed to use linear tariffs. Before solving the game for any T, the extreme cases $T = +\infty$ and $T = 0$, which provide a useful insight into how the game functions, will be analyzed.

4.1 Unlimited commitment : Model pA

The timing is simplified, hence the name pA :

1. The seller sets a price p.
2. The buyer invests A at a unit cost k.

After this, at each instant, the buyer faces the predefined price p and purchases q. Obviously, there is no point in a buyer overinvesting with respect to his future consumption, therefore after observing p, the buyer will invest so that at equilibrium A equals q. He buys one unit of equipment for each unit of commodity, so the marginal cost of one commodity unit is $p + rk$. Therefore, his demand function is

$$q(p) = Q(p + rk). \tag{1.15}$$

The seller equalizes marginal revenue and cost and thus picks p that solves

$$\partial\left(p\,Q(p + rk)\right)/\partial q = c. \tag{1.16}$$

[7] Linear prices are robust to asymmetric information about the demand parameter d in the sense that linear tariffs do not depend on d at equilibrium (as the following analysis will show).

The corresponding investment is $A = Q(p + rk)$. The results are summarized in the following proposition :

Proposition 1.2. *In game pA the equilibrium price and investment level are*

$$p = \tfrac{\varepsilon c + rk}{\varepsilon - 1}; \tag{1.17}$$

$$A = Q\left(\tfrac{\varepsilon(c+rk)}{\varepsilon-1}\right). \tag{1.18}$$

Remember the optimal investment level is $A^* = Q(c + rk)$. In model pA, since the demand function is $Q(p + rk)$, the welfare-maximizing price is $p = c$. The equilibrium price is always higher than the social optimum, so that the equilibrium investment level is always suboptimal.

4.2 No commitment : Model Ap

The timing is also simplified, hence the name Ap :

1. The buyer invests A at a unit cost k.
2. At each date t, the seller makes a take-it-or-leave-it offer p_t to the buyer. If the buyer accepts, he buys q_t.

Clearly, the same price and quantities (denoted respectively by p and q) will be chosen at all dates.

The buyer anticipates that he will suffer hold-up as soon as the investment is realized. He has no means to obtain more than the unconstrained monopoly quantity. Even this quantity could actually require too much investment : the buyer weighs up the initial investment cost against the subsequent costs of purchasing the good. Depending on the parameters, he might either passively adjust the investment to the monopoly quantity, or deliberately restrict investment, even though this will induce a higher commodity price. These are the two regimes that are described below.

The model is solved by backward induction.

Choice of q.

In the last step, given A and p,

$$\begin{aligned} q &= Q(p) \quad \text{if } p \geq P(A), \\ q &= A \qquad\ \ \text{if } p \leq P(A). \end{aligned} \tag{1.19}$$

Choice of p.

Anticipating this, the seller chooses p. The optimal price is such that

$$\partial(p\,Q(p))/\partial q = c, \tag{1.20}$$

if and only if this price effectively leads the buyer to purchase $q = Q(p)$, *i.e.* if it is higher than $P(A)$. In this case, where the seller is not constrained by the capacity, the optimal price is such that the Lerner index equals the inverse of the elasticity of demand : $\frac{p-c}{p} = \frac{1}{\varepsilon}$. This yields the Ramsey monopoly price

$$\overline{p} = \frac{\varepsilon c}{\varepsilon - 1}. \tag{1.21}$$

This “passive-buyer” regime prevails if and only if $A \geq Q(\overline{p})$. Else, when the buyer has restricted his investment below the monopoly quantity, the seller has to set a higher price in order to equate the corresponding demand to the equipment size : $Q(p) = A$, thus $p = P(A)$. This characterizes the “active-buyer” regime.

To summarize,

$$p = \max\{\overline{p}, P(A)\}. \tag{1.22}$$

.

Choice of A.

Solving backwards, we come to the investment choice of the buyer. See Figure 1.1. We saw that in the “active-buyer” regime the price $P(A)$ decreases with respect to A. Thus as long as this regime prevails, a larger investment yields a bigger price reduction. But when the investment attains the monopoly quantity, this effect stops because the seller would never decrease the price below the monopoly price $\overline{p}$: it is never worth investing more than $\overline{A} = Q(\overline{p})$. Actually, when the investment cost is large, the buyer prefers to invest less.

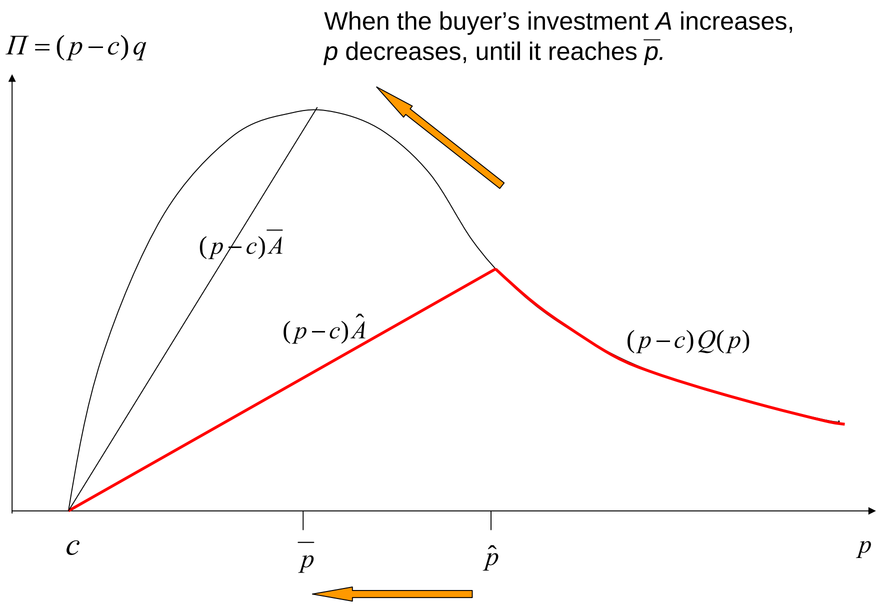

FIG. 1.1: Impact of the investment choice on the price in model Ap.

Thus, the buyers' surplus-maximization program can be expressed as

$$\begin{aligned} &\max_A S(A) = \frac{1}{r}\left(u(A) - (P(A) + rk)A\right) \\ &\text{s.t. } A \leq Q(\overline{p}) \end{aligned} \tag{1.23}$$

The solution A is interior when the "active-buyer" regime prevails : the seller adjusts his price so that $q = A$. The optimal investment level equates marginal benefits $(q/r)dp$ (one more unit of equipment causes a permanent reduction dp in the commodity price) with marginal costs k : $(q/r)\,dp = k\,dA$. As $q = A$, this can be rewritten $\frac{1}{r}\frac{dp}{dq} = -\frac{k}{q}$, which yields $p = \varepsilon rk$, and since by assumption $p = P(A)$, the optimal investment level is $A = Q(\varepsilon rk)$. In response, the seller will set[8]

$$p = \varepsilon rk. \tag{1.24}$$

The seller is constrained by this investment choice if he cannot set his monopoly price $\overline{p}$ because $Q(\overline{p}) > Q(\varepsilon rk)$, or equivalently, $\overline{p} < \varepsilon rk$. This is the case when $\frac{c}{rk} < \varepsilon - 1$.

Conversely, when $\frac{c}{rk} > \varepsilon - 1$ then $\varepsilon rk < \overline{p}$, thus investing $Q(\varepsilon rk)$ will not prevent the seller from setting his monopoly price. The buyer would do better to invest passively $Q(\overline{p})$.

The following proposition summarizes the results.

Proposition 1.3. *In game Ap, the equilibrium price and investment level are*

$$p = \max\{\tfrac{\varepsilon c}{\varepsilon-1}, \varepsilon rk\}, \tag{1.25}$$

$$A = \min\{Q\left(\tfrac{\varepsilon c}{\varepsilon-1}\right), Q(\varepsilon rk)\}. \tag{1.26}$$

Since in both cases the capacity is fully used ($q = A = Q(p)$), the outcome is *ex post* efficient ; however, *ex ante* efficiency is not achieved. Indeed, the equilibrium price is always higher than the social optimum $p = c + rk$, which implies that the equilibrium investment level is always suboptimal.

4.3 Investment by the seller

An alternative assumption could be that the investment is undertaken by the seller. Let us examine the following game :

1. The seller chooses the investment size A and sets price p.

2. The buyer purchases q indefinitely.

Commitment is not relevant here, because the optimal price for the seller does not change over time. The solution of this game is trivial : the buyer will choose $q = \min\{Q(p), A\}$,

[8]This situation combines the features of monopoly and monopsony. In the regime where $p = P(A)$, the buyer chooses A as a monopsonist to maximize $S(A) = \frac{1}{r}(u(A) - P(A)A - rkA)$. The first-order condition can be rewritten $\frac{P(A)+rk-u'(A)}{P(A)} = \frac{-P'(A)A}{P(A)} \equiv \frac{1}{\varepsilon}$. However, while in the monopsony case the price equals the marginal cost, here the seller's market power allows him to set a price equal to the marginal utility of the buyer ($P(A) = u'(A)$). Thus the equation can be rewritten $p(A) = \varepsilon rk$.

and anticipating this, the seller chooses simultaneously A and p. Obviously he will not set $A > Q(p)$ because the capacity would be oversized, nor $A < Q(p)$ because he would forgo profit opportunities (the margin $p - c - rk$ is positive), thus necessarily $q = A = Q(p)$ where p maximizes $\Pi(p) = \frac{1}{r}(p - (c + rk))\, Q(p)$. This is the program of a monopolist whose marginal cost is $c + rk$: the equilibrium is characterized by

$$p = \tfrac{\varepsilon(c+rk)}{\varepsilon-1}, \tag{1.27}$$

$$A = Q(\tfrac{\varepsilon(c+rk)}{\varepsilon-1}). \tag{1.28}$$

This game is essentially equivalent to the game pA with buyer investment : the outcomes (investment level, profit and surplus of the parties) are the same. The seller simply increases the commodity price by rk to pass on his investment cost.

As a matter of fact, the identity of the investor is not crucial. The real issue is whether the game played is essentially a "two-stage game" (like this game or game pA) where the seller plays first and the buyer has the final word, or a "three-stage game" (like game Ap) where in an additional preliminary step the buyer takes a first move by choosing A.

5 Linear tariffs with expiry date

5.1 A general characterization

Now the linear case with positive and finite values of T will be treated. Two stages can be distinguished : in the first stage (from $t = 0$ to T) the price is p_0 and consumption is q_0, while in the second stage (from $t = T$ to $+\infty$) the price is p_T and consumption is q_T.

The contract duration T (*i.e.* the length of the first stage) acts as a weight given to the first stage as opposed to the second stage, so that the basic games Ap and pA seen in the previous section will correspond to extreme values (close to zero or to infinity) of the contract duration in this "pAp" game.

As in game Ap, the buyer can either passively invest the capacity corresponding to the monopoly quantity, or use his investment choice to influence the outcome. In addition, the seller can either passively set p_0 at the anticipated marginal willingness to pay of the buyer, or use p_0 strategically to influence his investment behavior, typically to stimulate investment.

This defines the following alternative behaviors :

Definition 1.1. *The buyer is said to be* active *when his investment choice A induces a response p_T from the seller that differs from the unconstrained monopoly price $\frac{\varepsilon c}{\varepsilon - 1}$. Otherwise he is said to be* passive.

Definition 1.2. *The seller is said to be* active *when his price choice p_0 induces a response A from the buyer that differs from $A = Q(p_0)$. Otherwise he is said to be* passive.

The game is sequential, with successive decisions p_0, A, q_0, p_T, q_T. As usual, it will be solved by backward induction, but first two lemmas will eliminate large classes of strongly dominated strategies.

To begin with, we will prove that the investment is never oversized in the second stage, and that the second-stage price equates demand with capacity :

Lemma 1.1. *When the buyer is active, $p_T = P(A) > \frac{\varepsilon c}{\varepsilon - 1}$.*

Démonstration. If $A > Q(\frac{\varepsilon c}{\varepsilon - 1})$, then A is not constraining in the second stage, and the seller can set the unconstrained monopoly price $\frac{\varepsilon c}{\varepsilon - 1}$. Therefore, $A \leq Q(\frac{\varepsilon c}{\varepsilon - 1})$ and $p_T = p(A) \geq \frac{\varepsilon c}{\varepsilon - 1}$. Since by definition of active buyer, $p_T \neq \frac{\varepsilon c}{\varepsilon - 1}$, the lemma obtains. □

Lemma 1.2. *When the buyer is passive, $p_0 = p_T = P(A) = \frac{\varepsilon c}{\varepsilon - 1}$, and the seller is also passive.*

Démonstration. If the buyer is passive, $p_T = \frac{\varepsilon c}{\varepsilon - 1}$. Since $p_T = \max\{P(A), \frac{\varepsilon c}{\varepsilon - 1}\}$, this implies $A \geq Q(\frac{\varepsilon c}{\varepsilon - 1})$. Suppose $A > Q(\frac{\varepsilon c}{\varepsilon - 1})$. The choice of A only affects the first-stage game, and so does p_0. This game is solved like model pA, the difference being that trade takes place from $t = 0$ to T only : the buyer will equate q_0 with A, so that his program can be rewritten

$$\max_A \frac{1 - e^{-rT}}{r} \left[u(A) - \left(p_0 + \frac{rk}{1 - e^{-rT}} \right) A \right], \tag{1.29}$$

and at equilibrium the buyer's best choice is

$$q_0 = A = Q\left(p_0 + \frac{rk}{1 - e^{-rT}} \right). \tag{1.30}$$

Anticipating this the seller chooses

$$p_0 = \frac{\varepsilon c + \frac{rk}{1-e^{-rT}}}{\varepsilon - 1} > \frac{\varepsilon c}{\varepsilon - 1}. \tag{1.31}$$

But this means that $A = Q(p_0) < Q(\frac{\varepsilon c}{\varepsilon-1})$, which contradicts the assumption. Therefore, $A = Q(\frac{\varepsilon c}{\varepsilon-1})$. Anticipating this, the seller will set p_0 at the monopoly price. □

In words, the investment capacity can never be oversized in the second stage. Otherwise, the seller could slightly adjust his first-period price without affecting the second period ; setting the price p_0 closer to the unconstrained monopoly price would enhance profits.

Now we turn to the first stage. The next lemma proves that the investment can never be oversized in the first stage either :

Lemma 1.3. *At equilibrium, $A \leq Q(p_0)$.*

Démonstration. Assume that $A > Q(p_0)$. In model pA there was no reason to overinvest with respect to demand. Here the capacity could be adjusted to the anticipated second-stage demand and oversized relative to first-stage demand : $A > q_0 = Q(p_0)$, or equivalently $p_0 > P(A)$. Since (from Lemmas 1.1 and 1.2) $p_T = P(A) \geq \frac{\varepsilon c}{\varepsilon-1}$, this requires $p_0 > \frac{ec}{e-1}$. But if the capacity were strictly oversized in the first stage, this would mean that the capacity was chosen according to the second stage, therefore a marginal change in p_0 would not affect the investment size, nor would it affect the second-stage game. Therefore, if $p_0 > \frac{\varepsilon c}{\varepsilon-1}$, the seller would have an incentive to deviate to a lower price, closer to his profit-maximizing price $\frac{\varepsilon c}{\varepsilon-1}$: this would increase his first-stage profits without altering the second-stage game. Consequently, $A > Q(p_0)$ cannot be an equilibrium. □

The lemmas enable us to summarize the four cases in Table 1.1.

Since we are mostly interested in the situation where both players use their opportunities of strategically influencing the other party's behavior, we will concentrate on the case where the seller and the buyer are active.

The other cases are treated in the Appendix.

		Seller	
		Active	Passive
Buyer	Active	$p_0 < p_T$ $p_T > \frac{\varepsilon c}{\varepsilon-1}$ $A = Q(p_T) < Q(p_0)$	$p_0 = p_T$ $p_T > \frac{\varepsilon c}{\varepsilon-1}$ $A = Q(p_0) = Q(p_T)$
	Passive	IMPOSSIBLE	$p_0 = p_T$ $p_T = \frac{\varepsilon c}{\varepsilon-1}$ $A = Q(\frac{\varepsilon c}{\varepsilon-1})$

TAB. 1.1: The 4 types of equilibrium in game pAp.

5.2 When an active seller faces an active buyer

Whenever the buyer is active, he solves :

$$\max_A \tfrac{1-e^{-rT}}{r}\left(u(A) - p_0 A\right) + \tfrac{e^{-rT}}{r}\left(u(A) - P(A)A\right) - kA, \tag{1.32}$$

where the first term is the present buyer utility from the contract, the second term is the present utility for the subsequent period, and the third is investment cost. The fact that the buyer is active enables us to replace p_T with $P(A)$; Lemma 1.3 enables us to replace consumption in the first period by A.

We find

$$A = Q\left(\frac{p_0 + \frac{r}{1-e^{-rT}}k}{1 + \frac{1}{\varepsilon}\frac{e^{-rT}}{1-e^{-rT}}}\right). \tag{1.33}$$

Since the seller is active, $p_0 < p_T$: the seller offers a lower price in the first period so that the buyer is incited to invest more, then once the capacity is fixed he sets a higher price. To choose p_0, the seller solves

$$\max_{p_0}\left[\tfrac{1-e^{-rT}}{r}(p_0 - c) + \tfrac{e^{-rT}}{r}\left(\frac{p_0+\frac{r}{1-e^{-rT}}k}{1+\frac{1}{\varepsilon}\frac{e^{-rT}}{1-e^{-rT}}} - c\right)\right] Q\left(\frac{p_0 + \frac{r}{1-e^{-rT}}k}{1 + \frac{1}{\varepsilon}\frac{e^{-rT}}{1-e^{-rT}}}\right). \tag{1.34}$$

This yields the optimal contract price

$$p_0 = \tfrac{1}{1-e^{-rT}}\left[\left(1 - \tfrac{\varepsilon e^{-rT}}{\varepsilon+e^{-rT}}\right)\tfrac{\varepsilon c}{\varepsilon-1} + \left(1 - \tfrac{\varepsilon^2 e^{-rT}}{\varepsilon+e^{-rT}}\right)\tfrac{rk}{\varepsilon-1}\right]. \tag{1.35}$$

Finally, we need to check under which conditions the buyer and the seller are actually active. To ensure $A < Q(\frac{\varepsilon c}{\varepsilon-1})$ and $A < Q(p_0)$, we calculate from equations (1.33) and

(1.35) that the ratio of the production and investment costs must verify respectively $\frac{c}{rk} < \varepsilon e^{rT}$ and $\frac{c}{rk} < (\varepsilon - 1)e^{rT} - \frac{1}{\varepsilon}$. Clearly the latter inequality implies the former : both players are active if and only if

$$\frac{c}{rk} < (\varepsilon - 1)e^{rT} - \frac{1}{\varepsilon}. \tag{1.36}$$

Therefore, a necessary and sufficient condition for both players to be active *for all* T is

$$\frac{c}{rk} < \varepsilon - 1 - \frac{1}{\varepsilon}. \tag{1.37}$$

Note that for the right hand-side to be positive, the elasticity of demand must exceed $\frac{1+\sqrt{5}}{2} \simeq 1.6$, the Golden Ratio.

Proposition 1.4 (Both players active for any contract duration)**.** *When* $\frac{c}{rk} < \varepsilon - 1 - \frac{1}{\varepsilon}$,

$$\textit{If } T > 0, \begin{cases} p_0 & = & \frac{1}{1-e^{-rT}} \left[\left(1 - \frac{\varepsilon e^{-rT}}{\varepsilon + e^{-rT}}\right) \frac{\varepsilon c}{\varepsilon - 1} + \left(1 - \frac{\varepsilon^2 e^{-rT}}{\varepsilon + e^{-rT}}\right) \frac{rk}{\varepsilon - 1} \right], \\ p_T & = & \frac{\varepsilon^2 (c + rk)}{(\varepsilon + e^{-rT})(\varepsilon - 1}). \end{cases} \tag{1.38}$$

If $T = 0$, p_0 *is irrelevant and* $p_T = \varepsilon rk$*.*

The equilibrium is discontinuous at 0, meaning that no commitment ($T = 0$) and "some" commitment ($T > 0$) are qualitatively different.

5.3 Impact of the contract duration

Since $A = Q(p_T)$ is a decreasing function of p_T, which (from Proposition 1.4) is an increasing function of T, the following paradoxical result obtains.

Proposition 1.5 (Investment)**.** *The equilibrium investment level decreases with respect to the contract duration for all* $T > 0$*.*

In other terms, to encourage investment, the smallest contract is the best, no contract at all is the worst case.

Since the seller cannot commit to refrain from hold-up after contract expiry, his only means to stimulate investment is to offer at $t = 0$, before A is chosen, the guarantee

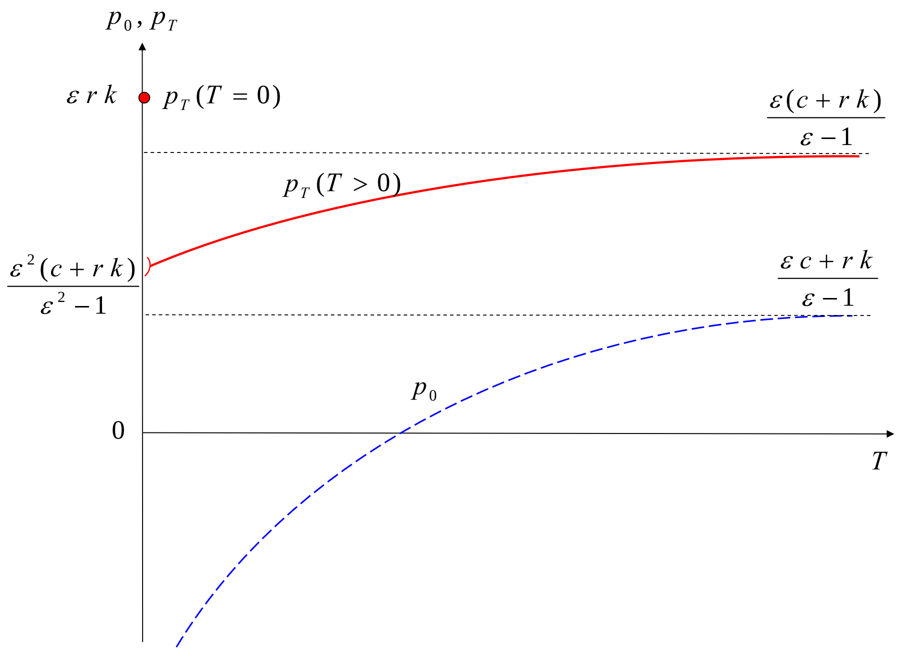

FIG. 1.2: Equilibrium prices as a function of the contract duration (when $\frac{c}{rk} < \varepsilon - 1 - \frac{1}{\varepsilon}$).

of a low price until T. The smaller T, the more generous the bargain must be : p_0 can even be negative, *i.e.* consumption is subsidized during the contract when the contract duration is short. When T is close to zero but still strictly positive, p_0 becomes infinitely negative (see Figure 1.2). But when $T = 0$ the game is radically altered, because the seller has no possibility to induce a higher investment than the level corresponding to the monopoly price : the investment suddenly falls. This is reflected in a discontinuity in the second-stage hold-up price $p_T = P(A)$ (upward jump when the duration goes from $T > 0$ to $T = 0$).

Since social welfare increases with respect to the investment level, Proposition 1.5 implies that welfare decreases with respect to the contract duration. As for the seller's profit and the buyer's surplus, when $\frac{c}{rk} < \varepsilon - 1 - \frac{1}{\varepsilon}$, they read respectively

$$\Pi = \frac{1}{r}\frac{c+rk}{\varepsilon-1} Q\left(\frac{\varepsilon^2(c+rk)}{(e^{-rT}+\varepsilon)(\varepsilon-1)}\right); \tag{1.39}$$

$$S = \frac{1}{r}\frac{1-e^{-rT}+\frac{1}{\varepsilon}e^{-rT}}{\varepsilon-1}\frac{\varepsilon^2(c+rk)}{(e^{-rT}+\varepsilon)(\varepsilon-1)} Q\left(\frac{\varepsilon^2(c+rk)}{(e^{-rT}+\varepsilon)(\varepsilon-1)}\right). \tag{1.40}$$

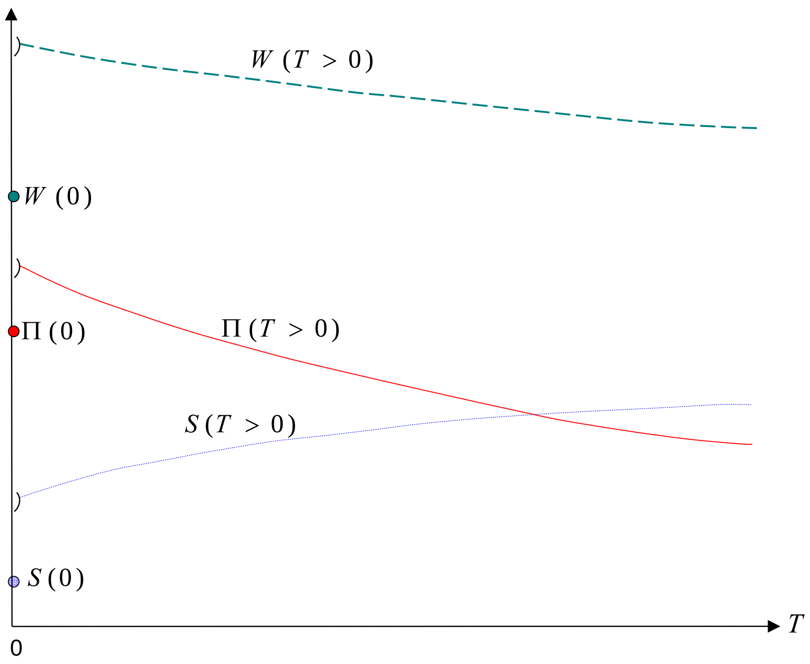

FIG. 1.3: Profit of the seller, surplus of the buyer and social welfare as a function of the contract duration (when $\frac{c}{rk} < \varepsilon - 1 - \frac{1}{\varepsilon}$).

The following proposition summarizes.

Proposition 1.6 (Welfare)**.** *When $\frac{c}{rk} < \varepsilon - 1 - \frac{1}{\varepsilon}$, for all $T > 0$,*

1. *Social welfare decreases with respect to T.*
2. *The seller's profit decreases with respect to T.*
3. *The buyer's surplus increases with respect to T.*

With linear prices, more commitment through longer contracts is detrimental to the seller *and* has the effect of depressing investment.

In a nutshell, the reason is that the first price p_0 serves to push investment whereas p_T serves to extract rents. We have a clear analogy with the static monopoly case recalled at the beginning of Section 4 : the two successive prices approach a two-part tariff, the first price providing the marginal incentives (investment) and the second price the inframarginal ones (participation). Though the performance of these linear prices is imperfect, this view clarifies the effects of T across agents, and for the economy, as we explain now.

The attempt to approach the optimum is less successful with long commitments. As T increases, the hold-up period gets farther away, and pushing investment through price rebates in the first period becomes costly to the seller. Of course the rebate can be smaller if it can be sustained for a longer time ; still, the profitable period is rejected to a farther future, which imposes a clear opportunity cost. As a consequence, a large T induces a smaller A, which means lower social surplus and lower profits.

What about the buyer ? As T increases, the buyer's surplus increases. In other terms, as social surplus decreases by one unit, the buyer's surplus does increase by more than one.

At the beginning of Section 4, we recalled the protective role for the buyer of a cap on the fixed fee. Longer durations are similar to lower (*i.e.* more constraining) caps : the longer the commitment, the more limited the hold-up period. In compensation, as the second price loses impact, the seller has to mix in the first price two objectives (incentives and rent extraction), which is the typical limit of plain static linear prices.

5.4 Investment by the seller

If the seller invests, there is no need to create incentives and extract rents in two separate episodes : he can and will replicate the same price in the first and second stages. This means that contract duration does not matter. The contract in effect necessarily gives the solution of game pA seen in Section 4, which is equivalent to the case $T = +\infty$ in the pAp game.

Does this solve the seller's problem ? In fact, the seller would prefer to let the buyer invest. The reasoning is as follows. If the seller invests, he can invest at the level that he wishes, but the linear prices limit his ability to extract the rent thus generated. Since the investment cost is difficult to recoup, his incentive to invest in the first place is limited. Conversely, if the buyer invests, the linear prices protect his effort (he is able to keep a fraction of the surplus generated). So the incentives that the seller gives to the buyer are leveraged by the buyer's own incentives. This makes the seller's contribution to investment (through subsidies) relatively small and he uses the second price p_T to extract a bigger rent.

6 Conclusion

Long-term contracts on specific assets have been repeatedly under the scrutiny of the competition authorities in Europe. The divide is between the pro-competition line of argument (foreclosure establishes durably abusive market power, *e.g.* Aghion and Bolton, 1987) and the pro-investment line of argument (contracts offer protection against expropriation). The 2007 Energy Sector Inquiry states that “long-term supply agreements seem to foreclose the availability of crucial inputs for actual or potential competition” (p. 66). On the other hand, the 2004 Directive on Security of Natural Gas Supply emphasizes their positive impact on investment, underlining that “long-term contracts have played a very important role in securing gas supplies for Europe and will continue to do so” (recital 11). Though the latter view is largely supported by the energy industry, the link between contract duration and investment incentives in a noncompetitive environment has not been thoroughly established by economic theory. One reason is that duration is not just another parameter in a contract, complete or incomplete. Its interaction with other dimensions can be quite counterintuitive.

In this paper, we have examined a situation where contracts are incomplete in several respects : both the pricing structure and the duration of commitment are restricted.

All the pricing schemes that we have analyzed share the following feature : some commitment ($T > 0$) is always better than none ($T = 0$). The reason is intuitive : the seller can offer a significant rebate that gives the buyer perfect or at least fairly good incentive to invest. The commitment period secures the indispensable thrust.

A longer contract never gives higher investment incentives. Tariffs with a sufficient “width” (such as two-part tariffs) are powerful enough to make the contract length irrelevant (provided $T > 0$). With linear tariffs, the investment level is a strictly decreasing function of the contract length. A shorter subsidy period concentrates the effort, but it doesn’t diminish the incentives that can be conveyed. Moreover, a shorter commitment limits the postponement of the profitable hold-up period, mechanically limiting the opportunity cost. Accordingly, when the contract duration is very short, the seller will choose to subsidize investment heavily to maximize the surplus that will subsequently be extracted. In this sense, length and width of the contract are complements.

With linear tariffs, social welfare, the seller's profit and the buyer's surplus do not vary in parallel when contract length changes. The analogy is the following : in a static monopoly model, it is possible to increase the buyer's surplus by restricting the use of two-part tariffs. One option is to put a cap on the fixed part, or even to eliminate it. Albeit inefficient, pure linear pricing may afford the buyer more surplus than other solutions. In our model, the first period is the one during which investment incentives are set up by the seller. The seller tries to make the buyer invest and consume as if prices were exactly equal to marginal costs. The second period in contrast acts like the fixed part, serving to extract surplus : requiring that the commitment period be long means that there is a cap on the rent extracted by the seller, which benefits the buyer.

The analogy is imperfect, if only because two linear prices cannot strictly replicate nonlinear tariffs. Nevertheless, it simply shows that a rule forcing linear prices and longer commitment on prices could be set up as a "universal" means to protect buyers against sellers' market power. This would be at the expense of investment. Depending on the political game played between the various interest groups in a society, a rule guaranteeing linear prices and forcing a certain commitment will be imposed or opposed.

References

Aghion, Philippe and Patrick Bolton (1987), "Contracts as a Barrier to Entry", American Economic Review, 77(3), 388-401.

Balestra, Pietro and Marc Nerlove (1966), "Pooling, Cross Section and Time Series Data in the Estimation of a Dynamic Model : The Demand for Natural Gas", Econometrica, 34(3), 585-612.

Borenstein, Severin, Jeff Mackie-Mason and Janet Netz (2000), "Exerting Market Power in Proprietary Aftermarkets", Journal of Economics and Management Strategy, 9(2), 157-88.

Carlton, Dennis and Michael Waldman (2001), "Competition, Monopoly, and Aftermarkets", NBER Working Paper 8086.

Castaneda, Marco A. (2006), "The Hold-up Problem in a Repeated Relationship", International Journal of Industrial Organization, 24(5), 953-970.

Chen, Zhiqi, Thomas Wayne Ross and William T. Stanbury (1998), "Refusals to Deal and Aftermarkets", Review of Industrial Organization, 13, 131-151.

Council of the European Union (2004), Council Directive 2004/67/EC of 26 April 2004 concerning measures to safeguard security of natural gas supply.

Creti, Anna and Bertrand Villeneuve (2004), "Long-term Contracts and Take-or-pay Clauses in Natural Gas Markets", Energy Studies Review, 13, 75-94.

Crocker, Keith J. and Scott E. Masten (1985), "Efficient Adaptation in Long-term Contracts : Take-or-Pay Provisions for Natural Gas", American Economic Review, 75, 1083- 1093.

Crocker, Keith J. and Scott E. Masten (1988), "Mitigating Contractual Hazards : Unilateral Options and Contract Length", RAND Journal of Economics, 19(3), 327-343.

Dubin, Jeffrey.A. and Daniel L. McFadden (1984), "An Econometric Analysis of Residential Electric Appliance Holdings and Consumption", Econometrica, 52, 118-131.

European Commission (2007), DG Competition report on energy sector inquiry, SEC(2006) 1724, 10 January 2007.

Goldberg, Victor P. (1976), "Regulation and Administered Contracts", Bell Journal of Economics, 7(2), 426-448.

Hanemann, W. Michael (1984), "Discrete/Continuous Models of Consumer Demand", Econometrica, 52(3), 541-561.

Hubbard, Glenn and Robert Weiner (1986), "Regulation and Long-term Contracting in US Natural Gas Markets", Journal of Industrial Economics, 35, 71-79.

Joskow, Paul (1988) : "Price Adjustment in Long-term Contracts : The Case of Coal", Journal of Law and Economics, 31, 47-83.

Morita, Hodaka and Michael Waldman (2004), "Durable Goods, Monopoly Maintenance, and Time Inconsistency", Journal of Economics and Management Strategy, 13(2), 273-302.

Neumann, Anne and Christian von Hirschhausen (2008), "Long-Term Contracts and Asset Specificity Revisited : An Empirical Analysis of Producer-Importer Relations in the Natural Gas Industry", Review of Industrial Organization, 32(2), 131-143.

Reitzes, James D. and Glenn A. Woroch (2008), "Competition for Exclusive Customers : Comparing Equilibrium and Welfare Under One-Part and Two-Part Pricing", Canadian Journal of Economics/Revue canadienne d'économique, 41(3), 1046-1086.

Samuelson, Paul (1947), *Foundations of Economic Analysis*. Cambridge, MA : Cambridge University Press.

Shapiro, Carl (1995), "Aftermarkets and Consumer Welfare : Making Sense of *Kodak*", Antitrust Law Journal, 63, 483-511.

Williamson, Oliver E. (1971),"The Vertical Integration of Production : Market Failure Considerations", American Economic Review, Papers and Proceedings, 61(2), 112-123.

A Appendix

The case when $\frac{c}{rk} < \varepsilon - 1 - \frac{1}{\varepsilon}$ was detailed in subsection 5.1. Here the general case is treated.

A.1 Linear tariffs with expiry date : general case

From Lemmas 1.1 and 1.2, we can deduce that a necessary and sufficient condition for the buyer to be active is $p_T > \frac{\varepsilon c}{\varepsilon - 1}$. In addition, equation (1.33) tells us that when the buyer is active, he anticipates that the seller will adjust the price to the investment ($p_T = P(A)$). From equation (1.33),

$$p_T = \frac{p_0 + \frac{r}{1-e^{-rT}}k}{1 + \frac{1}{\varepsilon}\frac{e^{-rT}}{1-e^{-rT}}}. \tag{1.41}$$

Conversely, when the buyer is passive, he knows that the seller will set $p_T = \frac{\varepsilon c}{\varepsilon - 1}$. The price prevailing after contract expiry is

$$p_T = \min\left\{\frac{p_0 + \frac{r}{1-e^{-rT}}k}{1 + \frac{1}{\varepsilon}\frac{e^{-rT}}{1-e^{-rT}}}, \frac{\varepsilon c}{\varepsilon - 1}\right\}. \tag{1.42}$$

This enables us to write the following necessary and sufficient condition for having an active buyer :

$$p_0 - \frac{\varepsilon c}{\varepsilon - 1} > \frac{c - (\varepsilon - 1)e^{rT} rk}{(\varepsilon - 1)(e^{rT} - 1)}, \tag{1.43}$$

The buyer is passive if and only if the opposite inequality holds. Since this situation is characterized by $p_0 = \frac{\varepsilon c}{\varepsilon - 1}$, the left hand-side is equal to zero, and the following result obtains : when

$$\frac{c}{rk} \geq (\varepsilon - 1)e^{rT}, \tag{1.44}$$

the buyer is passive—and so is the seller.

Now suppose $\frac{c}{rk} < (\varepsilon - 1)e^{rT}$: the buyer is active. Two subcases have to be analyzed : passive seller and active seller. Let us start with the case where the seller is active. A necessary and sufficient condition for having an active seller is $p_0 < P(A)$. In this case, as computed previously (see equation 1.35),

$$p_0 = \tfrac{1}{1-e^{-rT}} \left[\left(1 - \tfrac{\varepsilon e^{-rT}}{\varepsilon + e^{-rT}}\right) \tfrac{\varepsilon c}{\varepsilon - 1} + \left(1 - \tfrac{\varepsilon^2 e^{-rT}}{\varepsilon + e^{-rT}}\right) \tfrac{rk}{\varepsilon - 1} \right].$$

The condition $p_0 < P(A)$, where A is given by equation (1.33), can now be rewritten $\frac{c}{rk} < (\varepsilon - 1)e^{rT} - \frac{1}{\varepsilon}$, which yields the following necessary and sufficient condition for both parties to be active :

$$\frac{c}{rk} < (\varepsilon - 1)e^{rT} - \frac{1}{\varepsilon}. \tag{1.45}$$

Accordingly, the equilibrium involves an active buyer and a passive seller if and only if $(\varepsilon - 1)e^{rT} - \frac{1}{\varepsilon} \leq \frac{c}{rk} < (\varepsilon - 1)e^{rT}$. In this case, $p_0 = p_T = P(A)$, and combining equations (1.41) and (1.35) yields the equilibrium prices and investment level.

The results are summarized in the following proposition :

Proposition 1.7 (Equilibrium prices in the general case)**.**

ⓐ *If* $\frac{c}{rk} \geq (\varepsilon - 1)e^{rT}$, *both parties are* passive *and*

$$p_0 = p_T = \frac{\varepsilon c}{\varepsilon - 1}.$$

ⓑ *If* $(\varepsilon - 1)e^{rT} - \frac{1}{\varepsilon} \leq \frac{c}{rk} < (\varepsilon - 1)e^{rT}$, *the buyer is* active *and the seller is* passive*, and*

$$p_0 = p_T = re^{rT}\varepsilon k.$$

ⓒ *If* $\frac{c}{rk} < (\varepsilon - 1)e^{rT} - \frac{1}{\varepsilon}$, *both parties are* active *and*

$$\begin{cases} p_0 & = \tfrac{1}{1-e^{-rT}} \left[\left(1 - \tfrac{\varepsilon e^{-rT}}{\varepsilon + e^{-rT}}\right) \tfrac{\varepsilon c}{\varepsilon - 1} + \left(1 - \tfrac{\varepsilon^2 e^{-rT}}{\varepsilon + e^{-rT}}\right) \tfrac{rk}{\varepsilon - 1} \right], \\ p_T & = \tfrac{\varepsilon^2 (c + rk)}{(\varepsilon + e^{-rT})(\varepsilon - 1)}. \end{cases}$$

A.2 pAp : Comparative statics w.r.t. investment cost

Intuitively, one would think that the equilibrium prices are increasing functions of the investment cost, since a higher k tends to dampen investment and consumption. This is true for the hold-up price p_T, but not necessarily for the contract price : it may be worth

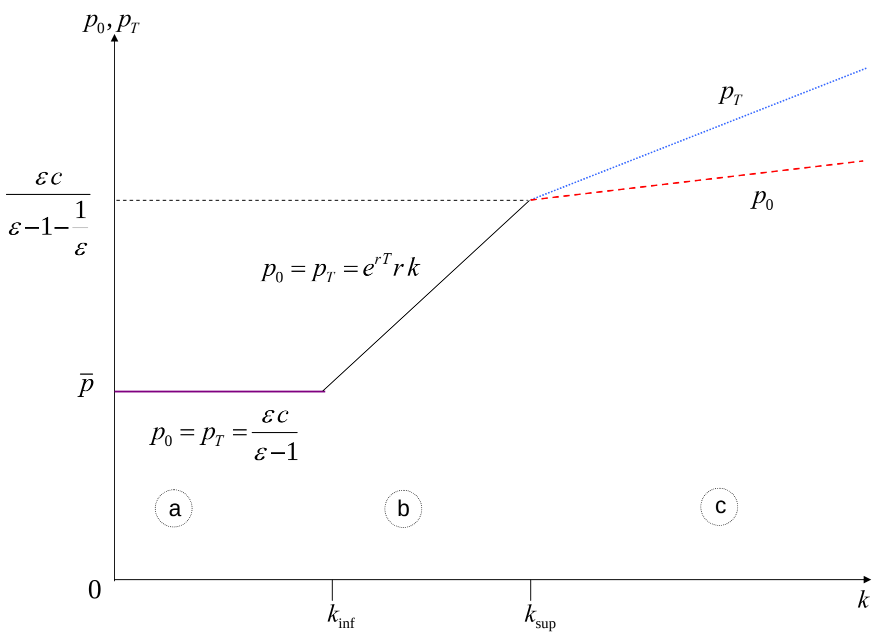

FIG. 1.4: Equilibrium prices as a function of the investment cost.

the seller's while to set a low p_0, thus sacrificing first-stage profits, to induce a higher investment and more second-stage sales at the hold-up price $p_T = P(A)$.

Let

$$\begin{cases} k_{\text{inf}} &= \frac{e^{-rT}}{r} \frac{c}{\varepsilon - 1}, \\ k_{\text{sup}} &= \frac{e^{-rT}}{r} \frac{c}{\varepsilon - 1 - \frac{1}{\varepsilon} e^{-rT}}. \end{cases}$$

For all T, $0 < k_{\text{inf}} < k_{\text{sup}}$. The three cases mentioned in Proposition 1.7 correspond respectively to $k \leq k_{\text{inf}}$, $k_{\text{inf}} < k \leq k_{\text{sup}}$ and $k > k_{\text{sup}}$, and and to zones ⓐ, ⓑ, and ⓒ in Figure 1.4.

ⓐ $k \leq k_{\text{inf}}$: both parties are passive.

In the second stage, the seller will be able to set his unconstrained monopoly price $p_T = \frac{\varepsilon c}{\varepsilon - 1}$ only if the invested capacity is sufficiently large. Therefore, as long as setting his monopoly price $p_0 = \frac{\varepsilon c}{\varepsilon - 1}$ in the first stage induces a sufficiently large investment $A \geq Q(\frac{\varepsilon c}{\varepsilon - 1})$, the seller has no incentive to deviate, and he will set in both stages $p_0 = p_T = \frac{\varepsilon c}{\varepsilon - 1}$. This will be the case when the investment cost k is not too large : the buyer responds passively to the contract price by setting $A = Q(\frac{\varepsilon c}{\varepsilon - 1})$.

When k becomes larger, the buyer compensates the higher unit cost of equipment by reducing his investment to $A < Q(\frac{\varepsilon c}{\varepsilon - 1})$. The seller then necessarily sets in the second stage the corresponding hold-up price $p_T = P(A) > \frac{\varepsilon c}{\varepsilon - 1}$. In the first stage, two possible choices are available to the seller, knowing that $q_0 = \min\{A, Q(p_0)\}$. Either he passively sets p_0 such that at equilibrium $p_0 = p_T = P(A)$ and in particular $p_0 = P(q_0)$ (case ⓑ below), or he strategically sets the contract price below the marginal willingness to pay of the buyer ($p_0 < P(q_0)$) : he forgoes first-stage profits in order to induce the buyer to invest in a larger equipment capacity, thus preserving second-stage profits (case ⓒ below).

ⓑ $k_{\text{inf}} < k \leq k_{\text{sup}}$ **: only the buyer is active.**

For intermediate values of k, the investment level is still close to the seller's preferred level $Q(\frac{\varepsilon c}{\varepsilon - 1})$, therefore setting $p_0 = p_T > \frac{\varepsilon c}{\varepsilon - 1}$ yields only a second-order loss in both stages compared to the initial situation with a low k, whereas setting $p_0 < P(A) = p_T$ would cause a first-order loss $(P(A) - p_0)\, A$.

ⓒ $k > k_{\text{sup}}$ **: both parties are active.**

When k becomes sufficiently large, setting $p_0 < p_T$ in order to increase A becomes worthwhile, since the positive volume effect in both stages offsets the first-stage loss. In this case only, the contract price and the hold-up price differ. The contract price can even be a decreasing function of k, and become negative when k is high, if the contract length is short enough : the seller accepts a loss that will be compensated by larger sales volumes after contract expiry.

A.3 pAp : Comparative statics w.r.t. contract duration

The case where $\frac{c}{rk} < \varepsilon - 1 - \frac{1}{\varepsilon}$ was detailed in Subsection 5.1. Now assume the opposite holds. Let

$$\left\{ \begin{array}{rcl} T_{\text{inf}} & = & \frac{1}{r} \ln\left(\frac{c}{(\varepsilon-1)rk}\right), \\ T_{\text{sup}} & = & \frac{1}{r} \ln\left(\frac{\varepsilon c + rk}{\varepsilon(\varepsilon-1)rk}\right). \end{array} \right. \tag{1.46}$$

The three cases mentioned in Proposition 1.7 correspond respectively to $T \leq T_{\text{inf}}$, $T_{\text{inf}} < T \leq T_{\text{sup}}$ and $T > T_{\text{sup}}$, and to zones ⓐ, ⓑ, and ⓒ in Figure 1.5.

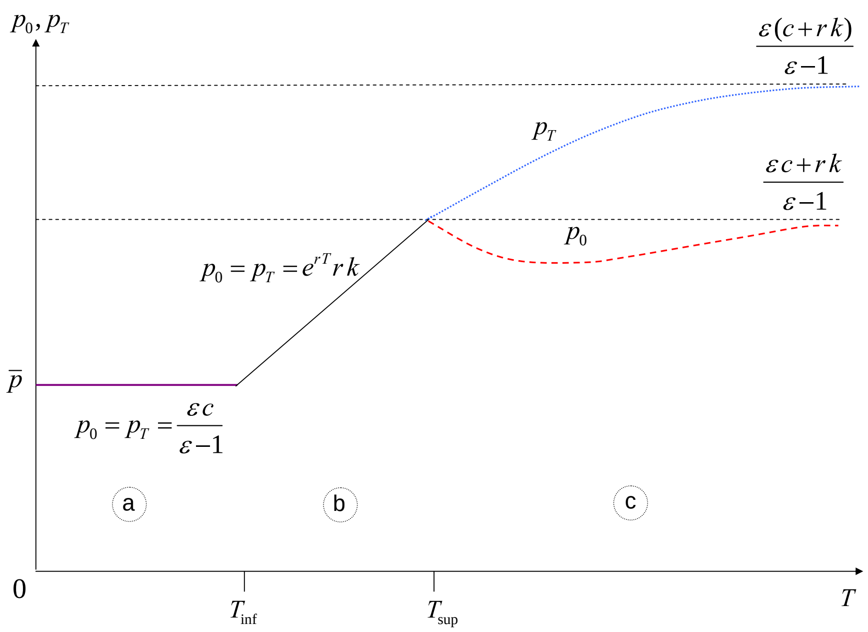

FIG. 1.5: Equilibrium prices as a function of the contract duration (when $\frac{c}{rk} > \varepsilon - 1$).

By assumption, $T_{\sup} > 0$; $T_{\inf}$ is positive when $\frac{c}{rk} > \varepsilon - 1$. In what follows, we assume this is also true (else Case ⓐ is simply empty).

For the buyer, being active, *i.e.* reducing A below the monopoly quantity, implies an immediate benefit (lower investment expenses), and from T on, a cost (higher p_T).

For the seller, being active, *i.e.* reducing p_0 below the marginal willingness to pay of the buyer during the contract, implies an immediate cost (lower first-stage profits), and from T on, a benefit (larger volumes due to increased investment).

ⓐ $T \leq T_{\inf}$: both parties are active.

For the buyer, the cost of being active is coming up too early, and he prefers to stay passive and invest $A = Q(\frac{\varepsilon c}{\varepsilon - 1})$.

ⓑ $T_{\inf} < T \leq T_{\sup}$: only the buyer is active.

The cost of being active is delayed, it is worth reducing A : equalizing marginal cost and marginal benefit ($k = \frac{e^{-rT}}{r}\frac{P(A)}{\varepsilon}$) yields $A = Q\left(re^{rT}\varepsilon k\right)$.

ⓒ $T > T_{\sup}$ **: both parties are active.**

When T becomes large, capacity risks to decrease too much if the seller stays passive. He becomes active and offers a lower p_0 to stimulate investment. Decreasing p_0 is a good strategy as long as T is not too large. But as the contract length approaches infinity, the hold-up period becomes too remote : the seller seeks to preserve profits made during the contract by increasing p_0. When T tends to infinity, the contract price tends to p_{pA} .

A.4 pAp : Profit and surplus analysis

Profit of the seller.

The seller's profit can be expressed as a function of the contract duration :

ⓐ $T \leq T_{\inf}$: $\Pi(T) = \frac{1}{r}\frac{c}{\varepsilon-1}Q\left(\frac{\varepsilon c}{\varepsilon-1}\right)$;

ⓑ $T_{\inf} < T \leq T_{\sup}$: $\Pi(T) = \frac{1}{r}(re^{rT}\varepsilon k - c)Q\left(re^{rT}\varepsilon k\right)$;

ⓒ $T > T_{\sup}$: $\Pi(T) = \frac{1}{r}\frac{c+rk}{\varepsilon-1}Q\left(\frac{\varepsilon^2(c+rk)}{(e^{-rT}+\varepsilon)(\varepsilon-1)}\right)$.

The seller's profit is a non-increasing function of the contract duration : he always prefers shorter contracts, but actually any contract duration between 0 and $T_{\inf}$ is equivalent for him.

Surplus of the buyer.

ⓐ $T \leq T_{\inf}$: $S(T) = \frac{1}{r}\left(\frac{\varepsilon c}{(\varepsilon-1)^2} - rk\right)Q\left(\frac{\varepsilon c}{\varepsilon-1}\right)$;

ⓑ $T_{\inf} < T \leq T_{\sup}$: $S(T) = \frac{1}{r}\frac{1-e^{-rT}+\frac{1}{\varepsilon}e^{-rT}}{\varepsilon-1}re^{rT}\varepsilon kQ\left(re^{rT}\varepsilon k\right)$;

ⓒ $T > T_{\sup}$: $S(T) = \frac{1}{r}\frac{1-e^{-rT}+\frac{1}{\varepsilon}e^{-rT}}{\varepsilon-1}\frac{\varepsilon^2(c+rk)}{(e^{-rT}+\varepsilon)(\varepsilon-1)}Q\left(\frac{\varepsilon^2(c+rk)}{(e^{-rT}+\varepsilon)(\varepsilon-1)}\right)$.

The buyer's surplus function is not monotonous with respect to T : it is first constant, then decreasing, then increasing and it tends to a finite limit. In addition, the thresholds in T are not always positive, so that depending on the value of the parameters, cases ⓐ and ⓑ can be empty.

First suppose $\frac{c}{rk} \leq \varepsilon - 1 - \frac{1}{\varepsilon}$: only case ⓒ exists, and since the surplus is a strictly increasing function of T in this case, the buyer always prefers the longest possible contract.

Now if $\varepsilon - 1 - \frac{1}{\varepsilon} \leq \frac{c}{rk} \leq \varepsilon - 1$, we are either in case ⓑ or in case ⓒ, so the buyer's surplus is highest either for $T = 0$, or when $T \to +\infty$. Comparing the two values yields the following result : the buyer's surplus is highest for $T = 0$ if and only if

$$\frac{c}{rk} \leq (\varepsilon - 1)\varepsilon^{\frac{1}{\varepsilon - 1}} - 1. \tag{1.47}$$

Finally, when $\frac{c}{rk} \geq \varepsilon - 1$, all three cases exist. Clearly the buyer's surplus is maximal either for $T = 0$, or when T tends to infinity. Let $y = \frac{c}{rk}$. After rearrangement, we find that the buyer prefers the shortest possible contract whenever

$$\left(1 - \frac{(\varepsilon - 1)^2}{\varepsilon y}\right)\left(1 + \frac{1}{y}\right)^{\varepsilon - 1} \geq 1. \tag{1.48}$$

The derivative with respect to y of the left hand-side has a unique root $\varepsilon(\varepsilon - 1)$. The LHS is increasing then decreasing, it tends to $-\infty$ when y tends to zero, and to 1 when y tends to $+\infty$, thus it is equal to 1 for a unique value of y. Therefore there is a unique y^* such that the buyer's surplus is maximal when $T \to +\infty$ whenever $y \leq y^*$, and it is maximal for $T = 0$ whenever $y \geq y^*$.

In addition, the LHS is higher than 1 for $y = \varepsilon(\varepsilon - 1)$, which means that $0 < y^* < \varepsilon(\varepsilon - 1)$. As a consequence, when the elasticity parameter ε is close to 1, the threshold y^* is close to zero, so that for all values of the ratio $\frac{c}{rk}$ that are bounded away from zero, the buyer prefers the shortest possible contract.

Chapitre 2

Strategic storage and market power in the natural gas market

1 Introduction

This paper analyzes strategically motivated storage in the presence of imperfect competition at several levels of the supply chain. It shows that the basic intuition according to which storage gives a leadership advantage over rivals by allowing a firm to preempt future demand does not hold unequivocally. The strategic use of storage is described in two different settings : a single-tier oligopoly and a two-tier oligopoly where suppliers buy from a producer with market power. The paper disentangles several purely strategic effects of inventories and analyzes their interaction. Modeling the industry structure as a two-tier oligopoly provides innovative insights into the use of storage by imperfectly competitive firms. In addition to this theoretical contribution, the choice of a market structure with imperfect competition both upstream and downstream provides a framework to understand better the specific features of competition in the European market for natural gas.

Much of the earlier literature devoted to storage considers a competitive environment where storage contributes to matching stochastic supply and demand. The primary focus of this literature is to investigate price dynamics. Kirman and Sobel (1974) show that storage introduces an intertemporal dependence between each period's price-quantity strategies. Williams and Wright (1991) provide a comprehensive analysis of storage in an economy facing random shocks, using stochastic dynamic programming and numerical simulations.

Literature on seasonal storage is rather scarce. Pyatt (1978) analyzes the optimal scheduling of production and storage in continuous time, in a context where demand and supply are both exogenous, stationary and subject to fixed seasonal patterns that might not correspond. He shows that the use of storage is determined not by the demand level, but by the rate at which demand increases, and that it is optimal to hold stock only when production is increasing ; when demand is stationary, any accumulated stocks must be used up within one year of the initial stockpiling. Chaton, Creti and Villeneuve (2005) propose a model encompassing the issues of seasonal storage and resource exhaustibility. In all these models, production and storage are perfectly competitive, and the stock level is characterized by a no-arbitrage condition : when a firm holds positive stocks, it is indifferent between, on the one hand, buying or producing one additional unit in the current period and bearing the storage costs, and on the other hand, buying or producing this additional unit in the following period.

Another stream of literature analyzes the use of storage under imperfect competition and describes how inventories can give a competitive advantage over rivals. First contributions by Saloner (1987) and Pal (1991) consider a Cournot duopoly with two production periods and sales in the second period only. In the first period, firms simultaneously choose quantities (to be stored), then in the second period they simultaneously decide how much more to produce before the market clears. Saloner (1987) shows that any outcome on the outer envelope of the two reaction functions lying inbetween the two Stackelberg outcomes can be sustained as a subgame perfect equilibrium. Pal (1991) generalizes Saloner's analysis by allowing for cost differences across periods. If production costs are smaller in the first period (respectively, much smaller in the second period), both firms produce the Cournot quantities in the first (respectively, second) period ; in the intermediate case where costs are constant or slightly decreasing, the equilibrium is of the Stackelberg type. In other words, an asymmetric outcome obtains where one of the firms carries inventories even though advance production is more costly. Arvan (1985) allows for sales to occur in both periods, and when production costs are linear he finds only asymmetric equilibria where storage is used by one of the firms to gain a leader's position. Moellgaard, Poddar and Sasaki (2000) show that symmetric equilibria where both firms carry inventories can exist when costs are convex, because stocks can help to reduce the marginal cost in a high-demand period (the "smoothing effect" of inventories must be disentangled from their "commitment effect", as explained in Mitraille, 2004). But the game leads to a prisoner's dilemma, since both firms use storage to acquire a leadership advantage, and both of them finally obtain smaller profits. This result is not unrelated to the pro-competitive effect of forward contracts identified by Allaz and Vila (1993) : all firms seek to preempt future demand by selling forward, but this leads them to compete more aggressively in the spot market, which finally brings prices and quantities close to the competitive outcome. In the case of storage, however, there is no unambiguous relationship between the degree of competition and the level and the volatility of prices : Thille (2003) shows in an infinite-horizon model that duopolists hold more inventories than perfectly competitive firms (due to strategic considerations), but they are less willing to use them in response so stochastic shocks.

In a vertical structure, inventories can also be used strategically by a buyer to force the seller to lower his price in future periods (Anand et al., 2008). The case where both upstream and downstream operators are oligopolistic has virtually never been addressed in the storage literature, except by Baranès, Mirabel and Poudou. While in a first paper (2005) they treat storage as a necessary step of the production process, in a second paper (2007) they analyze the arbitrage between carrying inventories and buying on spot, which is an alternative sourcing possibility. In a two-period setting, they show that at equilibrium suppliers always use spot sourcing in addition to storage even if the spot price is higher than the cost of buying in advance and storing. Though their model shares some common features with the present model, the authors assume perfectly competitive production in the first period, whereas we assume that the producer behaves strategically in each period when setting the spot price, which explains why our results are quite different.

The intuition that strategic storage aims solely at preempting future demand does not hold any more in a setting where oligopolistic suppliers do not produce themselves but buy from oligopolistic producers on an intermediate ("spot") market. The spot price is influenced by suppliers' storage decisions : buying an additional unit in the first period and carrying it over into the next period instead of buying it in the second period pushes the first-period spot price up and the second-period spot price down. But since all rival suppliers buy at this spot price, they all benefit from the price changes without incurring the storage costs. Thus, when choosing his level of stocks, a supplier has to take into account two antagonistic effects. First, storage can reduce producers' market power by preventing them from discriminating perfectly between first-period and second-period spot sales, which globally decreases the costs of spot purchasing. Second, storage exerts a positive externality on rival suppliers, who benefit from a lower spot price in the second period, which leads them to compete more aggressively in the second-period downstream market. Overall, whether the strategic yield of storage is positive or negative depends on the demand and cost parameters.

The rest of the paper is organized as follows. Section 2 presents the basic setting with a one-tier oligopoly and retrieves the result of Arvan (1985) stating that the only equilibria with storage are asymmetric (only one supplier carries inventories), then it shows that the "leader" who holds stocks always makes more profits than his rival ; a Stackelberg leader would carry the same level of stocks as the "leader" of this simultaneous game. When storage capacity constraints are introduced with a Stackelberg leadership in capacity reservation, the leader chooses to hold stocks if storage capacity is sufficiently large and storage costs are low, else no stocks are held. Section 3 introduces a two-tier oligopoly, and proves the existence of symmetric equilibria with storage. Section 4 extends the analysis to the case where storage capacities are limited, and where the incumbent can choose his share of capacities. The final section concludes. The proofs of all results are given in the Appendix.

2 Storage in a one-tier oligopoly

This section considers the case of suppliers who produce themselves the quantities they store or sell to their customers. By threatening to flood the market with his stocks, an oligopolistic seller can deter competitors from producing and, by this means, obtain a leader's market share. In this way, storage affects rivals' decisions in future periods.

This advantage can be linked to the leadership obtained through early investment (see Spence, 1979 and Dixit, 1980), but there are some differences : in the short run storage offers a more credible commitment than capacity because quantities previously produced and now in stock can be released to the market at no cost at any moment, however this effect fades in the long run since sales out of inventory deplete the inventory stock.

In a seminal contribution, Arvan (1985) proves with general revenue functions and linear production costs that in a two-period Cournot duopoly there is no equilibrium in pure strategies where both suppliers carry inventories. In a first step we prove this result in the case with a linear demand function, and we compare the equilibrium of the simultaneous game with the equilibrium where one supplier has a Stackelberg leadership in storage. Then we introduce capacity constraints and we analyze the game with reservation of storage capacities.

Consider a two-period duopoly where in the first period, suppliers decide how much to sell and how much to carry as inventories into the next period, and in the second period, they merely sell from their inventories, or decide to produce again in order to sell more than their stocks (we allow for unsold inventory at no cost). We introduce the following notation :

q_i, q'_i	are the production of supplier i in the first and second periods, respectively,
z_i, z'_i	are the sales of supplier i in the first and second periods, respectively,
w_i	denotes the inventories of supplier i.

Since our focus is strategic storage, we eliminate all classical motivations to carry inventories, such as uncertainty, production constraints or non-linearities in costs : we assume that the marginal costs of production (k) and storage (c) are constant and identical in both periods. The suppliers compete *à la Cournot* in each period. Consumer demand is linear, the inverse demand function is :

$$p_z = d - z_i - z_j \quad \text{in the first period,}$$
$$p'_z = d' - z'_i - z'_j \quad \text{in the second period.}$$

Demand in the second period is (weakly) higher than in the first period : $d' \geq d$.

2.1 Second-period downstream subgame

In the second period, suppliers choose their production and their downstream sales, given their inventories. Supplier i maximizes his second-period profit :

$$\begin{aligned} &\max_{z'_i, q'_i} (d' - z'_i - z'_j) z'_i - k q'_i \\ &\text{s.t. } z'_i \geq 0, \\ &\qquad q'_i \geq 0, \\ &\qquad q'_i + w_i \geq z'_i. \end{aligned} \tag{2.1}$$

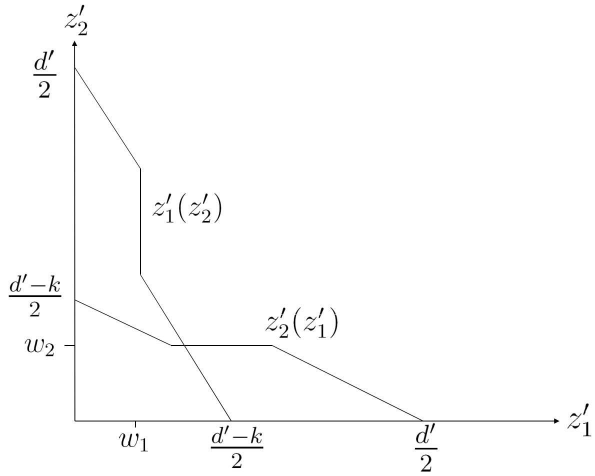

FIG. 2.1: Best responses to the rival's sales in the second period : case of an asymmetric equilibrium where only supplier 1 buys on spot ($z'_1 > w_1$ and $z'_2 = w_2$).

As shown by Arvan, inventories introduce a kink in the suppliers' best responses, since the production cost of units in stock has already been incurred and their marginal cost is now zero. A supplier compares the marginal revenue from his sales $(d' - 2z'_i - z'_j)$ with his marginal cost of selling an additional unit : zero as long as $z_i \leq w_i$, then k if $z_i > w_i$. The best-response function $z'_i(z'_j)$ of supplier i, given his rival's inventories w_j, is continuous but exhibits two kinks (see Figure 2.1) :

$$z_i' = \frac{d' - k - z_j'}{2} > w_i \qquad \text{if } z_j' < d' - k - 2w_i \ (A) \tag{2.2}$$

$$= w_i \qquad \text{if } d' - k - 2w_i \leq z_j' \leq d' - 2w_i \ (B) \tag{2.3}$$

$$= \frac{d' - z_j'}{2} < w_i \qquad \text{if } z_j' > d' - 2w_i \ (C). \tag{2.4}$$

As a consequence, there are nine possible types of Nash equilibria in this subgame.

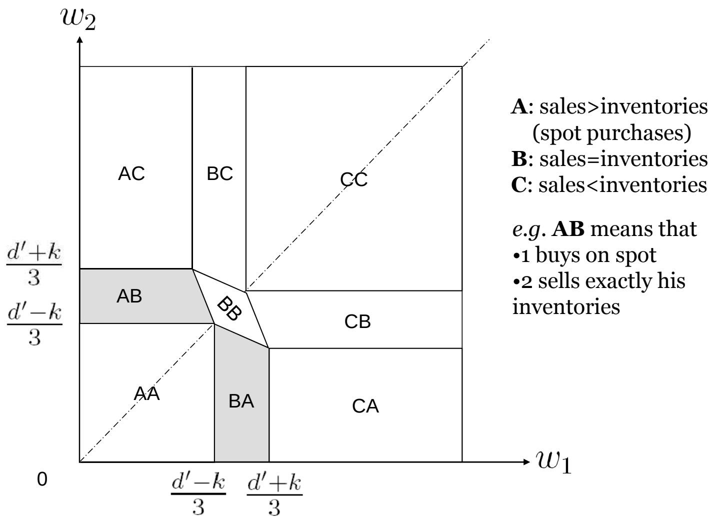

FIG. 2.2: Equilibria of the second-period subgame : mapping of the sales behavior of suppliers 1 and 2 as a function of their inventories w_1, w_2.

Each supplier can buy on the intermediate market to sell more than his inventories (A), exactly exhaust his inventories (B), or sell less than his inventories (C). Let XY denote the equilibrium where supplier 1 is in situation X and supplier 2 in situation Y, where X and Y can be A, B or C. The relevant equilibrium for any pair of inventories (w_1, w_2) is represented in Figure 2.2.

2.2 Equilibrium with no capacity constraints

As proved by Arvan, there is no equilibrium where both suppliers have positive stocks. Let $q_i'^* = q_i'^*(w_i, w_j)$ and $z_i'^* = z_i'^*(w_i, w_j)$ denote the equilibrium values of supplier i's second-period production and sales as a function of inventories. Let $R(z_i, z_j)$ denote the second-period revenue to supplier i when he sells z_i and the rival sells z_j, and $R_1(z_i, z_j), R_2(z_i, z_j)$ its derivatives with respect to the first and second arguments respectively. The second-period value function of supplier i is

$$V_i(w_i, w_j) \equiv R(z_i'^*, z_j'^*) - kq_i'^*. \tag{2.5}$$

As the marginal cost of production is constant, the profit-maximization program of supplier i in the first period is equivalent to :

$$\begin{aligned} &\max_{w_i} -(k+c)w_i + V_i(w_i, w_j) \\ &\text{s.t. } w_i \geq 0. \end{aligned} \tag{2.6}$$

Using the envelope theorem yields

$$\begin{aligned} \frac{\partial V_i}{\partial w_i} &= R_1(z_i'^*, z_j'^*) + R_2(z_i'^*, z_j'^*)\frac{\partial z_j'^*}{\partial w_i} && \text{if } w_i \text{ is not redundant,} \\ &= 0 && \text{if } w_i \text{ is redundant.} \end{aligned} \tag{2.7}$$

In the first period it is never optimal to choose a stock level such that inventories will become redundant (situation C in figure 2.2) : reducing the level of inventories would save storage costs, and the second-period sales of both suppliers would not be affected. Therefore at equilibrium a supplier is necessarily in situation A or B. The gain in the second period from an additional unit of inventories can be decomposed into a direct increase in the second-period revenue due to higher sales and an increase in profits due to the adverse effect of own stocks on the rival's second-period sales. Using our demand specification, the first-order condition of the inventory choice program can be rewritten as

$$-(k+c) + (d' - 2z_i'^* - z_j'^*) = z_i'^* \frac{\partial z_j'^*}{\partial w_i} \text{ if } w_i > 0, \tag{2.8}$$

$$< z_i'^* \frac{\partial z_j'^*}{\partial w_i} \qquad \text{if } w_i = 0. \tag{2.9}$$

The left-hand side in (2.8) is negative whenever $c > 0$. In effect, in the second period the marginal revenue is equal to the marginal cost of production if production takes place, or it is lower than this marginal cost if there are redundant inventories : $(d' - 2z_i'^* - z_j'^*) \leq k$. As a result, the right-hand side is negative : $\partial z_j'^* / \partial w_i < 0$. Supplier i will carry inventory only if, as Arvan puts it, this "grants him some degree of leadership in the second-period subgame", *i.e.*, the rival's sales in the second period are adversely affected. This is possible only if supplier j is in situation A, selling more than his inventories, and supplier i is selling exactly his inventories (B). But since supplier j solves a similar program, by symmetry he would carry positive inventories only if he were in situation B and supplier i were in situation A, which leads to a contradiction : it is impossible that both suppliers use inventories to obtain a leader's position. Therefore if at equilibrium supplier i carries positive inventories, supplier j does not. This allows us to restate Arvan's result :

Lemma 2.1. *Consider a two-period Cournot duopoly where suppliers produce themselves with a constant marginal cost.*

- *There is no equilibrium where both suppliers carry inventories.*
- *If an equilibrium with positive inventories exists, it is necessarily asymmetric : one supplier holds stocks and does not produce again in the second period, while his rival does not store and has a positive production in the second period.*

With linear costs, carrying inventories yields no efficiency gain with respect to producing immediately (contrary to the convex case, where storage can be used for cost smoothing) and it is costly. Therefore a supplier will carry inventories only for strategic reasons, if it gives him the possibility to act as a leader in the second period and obtain a larger market share. But if both suppliers produce again in the second period they face the same marginal cost and they will have identical sales. A supplier can only obtain a higher market share if he ceases producing and sells exclusively from his inventories, because his marginal cost becomes zero. Finally, both suppliers cannot carry positive inventories since both of them would use storage to act as a leader ; symmetric equilibria without storage may exist if storage is too expensive but there is no symmetric equilibrium with storage.

As a result, even though firms are symmetric and play simultaneously, the only possible equilibria with storage are asymmetric equilibria where one supplier holds large inventories and does not produce any more, thereby obtaining a leader's market share in the second period, and the other supplier does not hold any inventories. The game features an extreme specialization in sourcing choices : in the second period one supplier sells exclusively his inventories, and his rival sells exclusively his current production.

As stated in Lemma 2.1 the only equilibria with storage are necessarily of type AB or BA, with the supplier in situation A carrying no inventories. These equilibria require that the storage cost is sufficiently low. Else, no supplier carries inventories and the static Cournot game is repeated in each period. To determine the storage cost threshold, we must determine whether the best response to $w_2 = 0$ is to have $w_1 = 0$ or to have an equilibrium of type (BA) with a positive w_1. In the latter case, provided $c < \frac{d'-k}{2}$, equilibrium inventories and sales are :

$$\begin{aligned} w_1 &= \frac{1}{2}(d' - k - 2c), &(2.10)\\ w_2 &= 0, &(2.11)\\ z_1' &= \frac{1}{2}(d' - k - 2c), &(2.12)\\ z_2' &= \frac{1}{4}(d' - k + 2c). &(2.13)\end{aligned}$$

First-period sales are the usual Cournot quantities :

$$z_1 = z_2 = \frac{1}{3}(d - k). \tag{2.14}$$

The profits of the suppliers are :

$$\begin{aligned} \Pi_1 &= \frac{1}{9}(d-k)^2 + \frac{1}{8}(d' - k - 2c)^2, &(2.15)\\ \Pi_2 &= \frac{1}{9}(d-k)^2 + \frac{1}{16}(d' - k + 2c)^2. &(2.16)\end{aligned}$$

The best response to $w_2 = 0$ is to hold positive inventories if and only if the profit in (2.15) is higher than the profit in the game with repeated Cournot, which is

$$\Pi_1 = \Pi_2 = \frac{1}{9}(d-k)^2 + \frac{1}{9}(d' - k)^2. \tag{2.17}$$

This is true if and only if $c < \tilde{c}$, where

$$\tilde{c} \equiv \frac{1}{3}\left(\frac{3}{2} - \sqrt{2}\right)(d' - k). \tag{2.18}$$

When this inequality holds, the equilibrium is asymmetric with one of the suppliers carrying positive stocks.

Proposition 2.1. *When the storage cost is low relative to second-period demand ($c < \tilde{c}$), there are only two asymmetric equilibria, where one supplier holds inventories and does not produce again in the second period, and the other supplier holds no inventories and produces again in the second period.*
When the storage cost is high relative to second-period demand ($c > \tilde{c}$), no inventories are carried and the equilibrium is the static Cournot equilibrium in each period.

Corollary 2.1. *In the case with positive inventories, the supplier who carries inventories always makes more profit than his rival.*

In effect, $c < \tilde{c}$ implies that the profit of the supplier with positive stocks (given by (2.15)) is higher than the other supplier's profit (given by (2.16)), even though producing in the second period is less costly than producing in advance and bearing the cost of storage. The reason is that the firm with inventories preempts future demand and becomes a leader.

Note that the "leader" in this simultaneous game has no particular commitment power, since both firms are identical at the outset : he is not a Stackelberg leader in the choice of inventories. Nevertheless, the comparison with the Stackelberg variant yields an interesting result : the outcome of the game where supplier i enjoys a Stackelberg leadership on storage is identical to the outcome of the simultaneous game where i carries inventories when storage is cheap enough.

Proposition 2.2. *When the storage cost is low relative to second-period demand ($c < \tilde{c}$), a Stackelberg leader in the choice of storage carries inventories and does not produce again in the second period, whereas his rival carries no inventories.*
When the storage cost is high relative to second-period demand ($c > \tilde{c}$), neither the leader, nor the follower carry inventories.

Proof 2.1. *If the leader holds no stocks, the follower's best response is the stock level in* (2.10)*, and if the leader holds positive stocks, the follower's best response is to hold no stocks. Anticipating this, the leader knows that if he holds no stocks his profit will be given by* (2.16)*. If he decides to hold stocks he should play his best response to zero stocks, which is given by* (2.10)*. He will choose to do so whenever this gives him a higher profit,* i.e.*, when* $c < \tilde{c}$*.*

In general, the equilibrium of a Stackelberg game is not identical to the outcome of a game with no commitment, because Stackelberg leadership usually involves some sort of "regret" : at equilibrium the follower plays his best response to the leader's actions, but the leader does not, in fact he is tempted to deviate. It is precisely his ability to commit that ensures that he will not deviate, so that the Stackelberg outcome is actually an equilibrium. In the present game, however, the leader is not tempted to deviate : the Stackelberg leader needs no commitment power.

To summarize, whether a supplier is the "leader" in an asymmetric equilibrium of the simultaneous game or a Stackelberg leader in the choice of inventories, he will always make more profits if he uses an aggressive stockpiling strategy in order to preempt future demand, unless storage is so expensive that no supplier wants to hold inventories.

2.3 Reservation of storage capacity

Suppose that the total available capacity is W and the incumbent i has a Stackelberg advantage in the reservation of storage capacity : once he has reserved W_i, his rival can only reserve $W_j \leq W - W_i$. To simplify, we assume that the cost of reserving capacity is negligible. Note that reserving capacities is a form of asymmetric commitment : when reserving capacity W_i, supplier i cannot commit to use it entirely, but he commits to store not more than W_i. In addition, since the total capacity is limited, there is also an externality between suppliers : reserving W_i reduces the capacity that is available for the rival.

Introducing storage capacity constraints does not change the fact that only one supplier can carry inventory at equilibrium (there is no room for two leaders). However, the storage cost threshold is not necessarily the same : when the storage capacity constraint of supplier 1 is potentially binding ($W_1 \leq \frac{1}{2}(d' - k) - c$), we must determine in which case his best response to $w_2 = 0$ is actually $w_1 = W_1$ or, alternatively, $w_1 = 0$. In the latter case, supplier 1 makes simply the Cournot profit. In the former,

$$\Pi_1 = \frac{1}{9}(d-k)^2 + \frac{1}{2}(d' - k - 2c - W_1)W_1. \tag{2.19}$$

Facing $w_2 = 0$, supplier 1 will choose $w_1 = W_1$ rather than $w_1 = 0$ whenever $c < \hat{c}(W_1)$, where

$$\hat{c}(W_1) \equiv \frac{9(d' - k - W_1)W_1 - 2(d'-k)^2}{18W_1}. \tag{2.20}$$

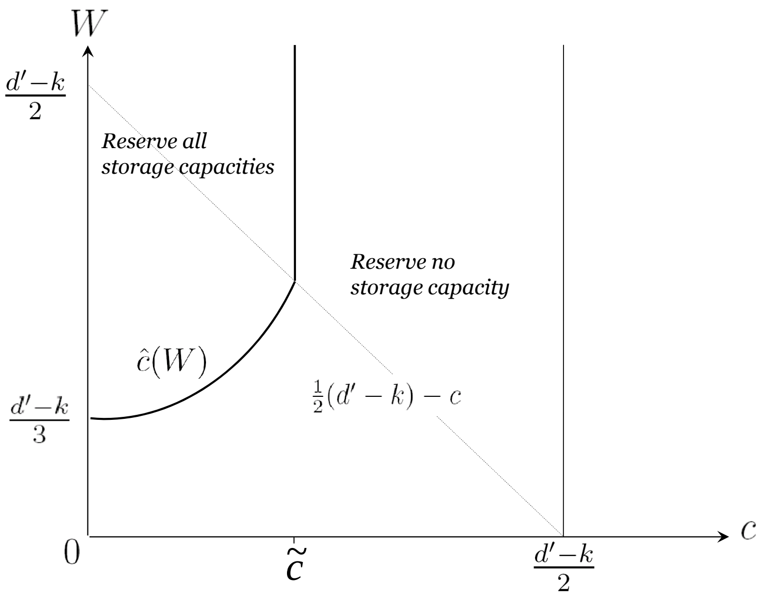

FIG. 2.3: Optimal choice of capacity reservation depending on storage costs and total capacity.

Equilibrium inventories in the case where supplier 1 holds stocks (and necessarily, supplier 2 does not) are :

$$w_1 = \min\left(\frac{1}{2}(d'-k) - c, W_1\right), \tag{2.21}$$

$$w_2 = 0, \tag{2.22}$$

and second-period sales are

$$z'_1 = w_1, \tag{2.23}$$
$$z'_2 = \frac{1}{2}(d' - k - w_1). \tag{2.24}$$

If total capacity is large ($W \geq \frac{1}{2}(d' - k) - c$), the equilibrium is the same as in the previous subsection : when $c < \tilde{c}$, being the supplier who holds stocks yields the highest profit, else no supplier wants to store.

If total capacity is scarce ($W < \frac{1}{2}(d' - k) - c$),

$$\Pi_1 = \frac{1}{9}(d - k)^2 + \frac{1}{2}(d' - k - 2c - W)W, \tag{2.25}$$
$$\Pi_2 = \frac{1}{9}(d - k)^2 + \frac{1}{4}(d' - k - W)^2. \tag{2.26}$$

When $c < \hat{c}$, supplier 1 (who carries inventories) always makes a higher profit than his rival.

Choosing his capacity first allows the incumbent to select the most profitable equilibrium : either he does not want to use storage (and neither does his rival), in which case he will reserve no capacity, or he wants be the only supplier who uses storage, and he will reserve the entire capacity for himself, in order to be sure that his rival cannot hold stocks.

The results can be summarized as follows.

Proposition 2.3. *When the storage cost is low* ($c < \min(\tilde{c}, \hat{c}(W))$)*, the incumbent will reserve* all the available capacity *for himself.*
Conversely, when the storage cost is high ($c > \min(\tilde{c}, \hat{c}(W))$)*, the incumbent will reserve* no capacity*, and no stocks will be held.*

In the first case, when $W > \frac{1}{2}(d' - k) - c$ and $c < (\frac{3}{2} - \sqrt{2})(d' - k)$, capacity hoarding occurs : the incumbent reserves more capacity than what he will actually use.[1] But surprisingly, when capacity is very scarce, the incumbent will not try to keep it for himself : in this case, no supplier is interested in storage. The leadership advantage

[1] If the costs of capacity reservation were significant, the incumbent would face a trade-off between guaranteeing that the rival cannot use storage to acquire a leadership position and saving on reservation costs. Depending on the cost of capacity reservation, hoarding would not necessarily occur.

granted by a small storage capacity is not significant enough, even if the storage cost is zero. Remember that a supplier who holds stocks sells no more than these stocks in the second period. If total capacity is below the Cournot quantity ($W < (d' - k)/3$), using inventories means selling less, and the rival selling more than the Cournot quantity. Therefore even if storage is costless, playing the static Cournot equilibrium is more profitable.

3 Storage in a two-tier oligopoly

This section introduces an additional layer in the industry structure : suppliers cannot produce themselves, they buy from a monopolistic producer in each period in an intermediate market. Even with a single downstream firm (buyer) and a single upstream firm (seller), the impact of storage on the buyer-seller relationship in a dynamic setting is non-trivial. As Anand et al. (2008) show, even though the demand and cost structure is identical across periods, the buyer can carry strategic inventories to force the seller to lower his price in future periods, by inducing competition between the seller and the buyer's inventories. Anticipating this, the seller is tempted to increase his current price in order to deter storage, but this would reduce current profits. The current price results from this trade-off, and at equilibrium it is higher than the price in the next period. This means that inventories are procured at the more costly first-period price, and nevertheless, stocks are positive when the storage cost is low enough. In our model, there are two suppliers and one producer. The effects of inventories held by a supplier are twofold : they affect his competitive position with respect to the rival supplier (horizontal effect), and they mitigate the producer's market power (vertical effect).

The model is as follows. The suppliers have market power in the downstream market, where they compete *à la Cournot*, but they are price-takers with respect to the producer on the intermediate ("spot") market.[2] Suppliers can be spot buyers or spot sellers. The spot position of supplier i is s_i in the first period (s'_i in the second period), where a positive number is for a buying position. The spot price is p in the first period and p' in

[2]This assumption means that in each period, they take the price set by the producer as given ; this does not prevent them from correctly anticipating, when they build inventories, that the future spot market demand will be reduced accordingly, and the spot price will decrease.

the second period.

The demand and cost functions are unchanged with respect to the previous section, and to simplify, the marginal cost of production k is set to zero. As for the cost of storage, we assume $c < d'/12$. The timing is the following :

- First period :
  - the producer sets the spot market price p;
  - the suppliers simultaneously choose their spot market positions s_1, s_2, their downstream sales z_1, z_2 and their inventories w_1, w_2. The storage cost is incurred immediately.
- Second period :
  - the producer sets the spot market price p';
  - the suppliers choose simultaneously their spot market positions s'_1, s'_2 and their downstream sales z'_1, z'_2.

Note two important differences with the one-tier setting. The first one is related to the commitment value of inventories. When suppliers produce themselves, inventories have no value outside the downstream market : when building stocks, a supplier essentially commits to selling them to downstream customers (unless flooding the market with inventories would reduce the price so much that he prefers to keep them unsold). When producers and suppliers are distinct the suppliers can sell on spot in the second period, therefore the commitment effect of inventories is not as strong : there is an alternative to selling downstream, namely selling to the rival supplier in the spot market. Therefore, situations where a supplier's second-period downstream sales do not depend on the current spot price cannot occur in such a model. The second difference relates to the link between the two periods. In the one-tier model there was no link between first-period downstream sales and inventories. However, when the producer is a monopoly who plays strategically, when choosing the first-period price he takes its impact both on first-period sales and on inventories into account. One the one hand, he is tempted to increase this price in order to discourage inventories, but on the other hand, this would jeopardize his first-period sales. The first-period spot price results from this trade-off between current and future profits.

3.1 Second-period subgame

Suppliers compete à la Cournot in the downstream market, taking the spot price p' as given. They choose their spot market position (for $i = 1, 2$, $s'_i > 0$ if i is a buyer) and their downstream sales, given their inventories. Supplier i maximizes his second-period profit :

$$\begin{aligned}
&\max_{z'_i, s'_i} (d' - z'_i - z'_j)z'_i - p's'_i \\
&\text{s.t. } z'_i \geq 0, \\
&\quad\;\; s'_i + w_i \geq z'_i.
\end{aligned} \tag{2.27}$$

Since suppliers arbitrate between the upstream and downstream markets, whatever their inventories, both of them sell the same amount

$$z'_1 = z'_2 = \max\left(\frac{d' - p'}{3}, 0\right). \tag{2.28}$$

The producer cannot be a spot buyer, therefore the suppliers' spot positions necessarily satisfy $s'_1 + s'_2 \geq 0$. As long as this inequality holds, for $i = 1, 2$ $s'_i = z'_i - w_i$: depending on his inventories a supplier can be a spot buyer or a spot seller. The demand faced by the producer is $s'_1 + s'_2 = z'_1 + z'_2 - (w_1 + w_2)$. To choose p', the producer solves

$$\max_{p'} \quad p'\left(\tfrac{2}{3}(d' - p') - (w_1 + w_2)\right). \tag{2.29}$$

Accordingly, he sets

$$p' = \frac{1}{2}d' - \frac{3}{4}(w_1 + w_2). \tag{2.30}$$

The resulting spot positions and downstream sales are

$$s'_1 = \frac{1}{6}d' - \frac{1}{4}(3w_1 - w_2), \tag{2.31}$$

$$s'_2 = \frac{1}{6}d' - \frac{1}{4}(3w_2 - w_1), \tag{2.32}$$

$$z'_1 = z'_2 = \frac{1}{6}d' + \frac{1}{4}(w_1 + w_2). \tag{2.33}$$

The inequality $s'_1 + s'_2 \geq 0$ holds if and only if suppliers' stocks satisfy $w_1 + w_2 \leq \frac{2}{3}d'$.

If this is not the case, at least one supplier has redundant inventories and the spot price is zero. Reducing marginally his stocks would achieve cost savings (including a decrease in the first-period spot price) without affecting the second-period subgame, therefore keeping stocks that will be left unsold cannot be part of an equilibrium strategy.

3.2 First-period subgame

In the first period there are no initial stocks, so both firms face the same marginal cost p. Both suppliers simultaneously choose their first-period sales and their inventories. Supplier i chooses w_i to maximize his intertemporal profit, which amounts to solving :

$$\begin{aligned} &\max_{w_i} (p' - p - c)w_i + (d' - z_i' - z_j' - p')z_i' \\ &\text{s.t. } w_i \geq 0. \end{aligned} \tag{2.34}$$

where the second-period spot price and downstream sales are given by equations (2.30) and (2.33). Using the envelope theorem, when suppliers choose their optimal sales given the spot price p the marginal effect on profits of carrying an additional unit of inventories is :

$$\frac{\partial \Pi_i'}{\partial w_i} = (p' - p - c) - \frac{\partial p'}{\partial w_i} s_i' - \frac{\partial p'}{\partial w_i}\frac{\partial z_j'}{\partial p'} z_i'. \tag{2.35}$$

- The first term (*arbitrage effect*) is the direct effect on purchasing costs of buying one additional unit in the first period and storing it instead of buying it in the second period.
- The second term (*countervailing power effect*) is the effect on the spot price, which affects all units bought by supplier i in the second-period spot market.
- The third term (*reducing rival's costs effect*) is the effect on own downstream sales z_i' of a more aggressive competition by the rival supplier, who benefits from the reduction in the spot price.

These effects rely on the assumption of imperfect competition at both levels, production and supply. When suppliers can carry inventories they can arbitrate between spot prices, so that the producer cannot charge the monopoly price in each period ; he has to decrease his second-period spot price with respect to the first-period price. Storage mitigates the producer's market power, which is beneficial for the firm that holds stocks.

But storage exerts an externality on the rival supplier by affecting the spot market price, which is equally charged to all suppliers. When making his storage choice, a supplier has to arbitrate between these effects. Note, by contrast, that the preemption effect of inventories that was identified as the rationale for strategic storage in the one-tier setting has disappeared : as can be seen from (2.28) inventories have no direct effect on second-period sales (this is due to the possibility to arbitrate between the upstream and downstream markets), their impact is only indirect through the spot price variation.

Definition 2.1 (**Strategic yield of storage).** *The strategic yield of storage σ_i for a supplier i who holds positive inventories can be defined as the sum of the "countervailing power effect" and the "reducing rival's costs effect"of his inventories :*

$$\sigma_i \equiv -\frac{\partial p'}{\partial w_i}\left(s_i' + \frac{\partial z_j'}{\partial p'} z_i'\right).$$

When suppliers are not capacity-constrained the strategic yield of storage is identical for all suppliers (and shall be denoted as σ) since at equilibrium $\sigma = p + c - p'$. The strategic yield of storage is positive when at equilibrium the marginal cost of purchasing and storing one unit in the first period is higher than the cost of buying it in the second period, which means that there is also a strategic motive for carrying inventories.

Note that in the case of perfectly competitive producers, where the spot price is not affected by inventories, $\sigma = 0$ and we retrieve the classical no-arbitrage condition : $p + c = p'$ when stocks are positive. If the cost of production does not change between the two periods there will be no storage : inventories grant no leadership advantage, and with perfectly competitive production they yield no cost reduction either (in both periods the spot price is equal to the marginal production cost and does not depend on inventories).

By contrast, if producers are oligopolistic the second and third terms on the right-hand side of equation (2.35) are not equal to zero : in our setting, this equation can be rewritten as

$$\frac{\partial \Pi_i'}{\partial w_i} = (p' - p - c) + \frac{3}{4} s_i' - \frac{1}{4} z_i', \tag{2.36}$$

so that

$$\sigma_i = \frac{3}{4}s_i' - \frac{1}{4}z_i' \tag{2.37}$$
$$= \frac{d'}{12} - \frac{1}{8}(5w_i - w_j). \tag{2.38}$$

As will be proved in this section, equilibria with positive inventories do exist.

Since both suppliers face the same spot price and storage cost and there are no capacity constraints, their storage choices are necessarily identical : the first-order conditions of program (2.34) yield :

$$w_1 = w_2 = \frac{7}{24}d' - \frac{1}{2}(p+c) \quad \textbf{if} \quad p \leq \frac{7}{12}d' - c, \tag{2.39}$$
$$w_1 = w_2 = 0 \quad \textbf{if} \quad p > \frac{7}{12}d' - c. \tag{2.40}$$

First-period sales are the usual Cournot quantities :

$$z_1 = z_2 = \frac{1}{3}(d-p) \quad \textbf{if} \quad p \leq d, \tag{2.41}$$
$$z_1 = z_2 = 0 \quad \textbf{if} \quad p > d. \tag{2.42}$$

We introduce the following notation to characterize the equilibrium of the subgame where suppliers face the first-period price p : **Z** denotes an equilibrium with positive downstream sales in the first period but no inventories, **W** denotes an equilibrium with positive inventories but no sales, **ZW** (respectively, **O**) denotes the case where inventories and sales are both positive (respectively, zero). Table 2.1 summarizes the type of equilibrium for a given value of the first-period spot price.

$p < \min(d, \frac{7}{12}d' - c)$	**ZW**
$d \leq p < \frac{7}{12}d' - c$	**Z**
$\frac{7}{12}d' - c \leq p < d$	**Z**
$p \geq \max(d, \frac{7}{12}d' - c)$	**O**

TAB. 2.1: Type of equilibrium in the first period.

Finally, the first-period spot price is obtained by maximizing with respect to p the producer's profit

$$\Pi_p = p(z_1 + z_2 + w_1 + w_2) + \frac{1}{24}(2d' - 3(w_1 + w_2))^2. \tag{2.43}$$

The optimal price is computed for each of the four cases, then to determine the equilibrium we identify among the cases that are possible given the demand and cost parameters the case where the producer makes the largest profit. The details are given in the Appendix.

Proposition 2.4. *In a two-period Cournot duopoly where suppliers buy in each period from a monopolistic producer, there is a unique equilibrium, where both suppliers are spot buyers in the second period. This equilibrium is symmetric : inventories and sales in both periods are identical for the two suppliers. With $c < \frac{d'}{12}$, stocks are always positive and first-period sales can be positive or zero.*

It appears that when $c < \frac{d'}{12}$ storage cannot be blockaded, and deterring storage is possible in theory but the producer never chooses to do so.

When $d' > (1 + \sqrt{2})d$, the equilibrium involves

- positive inventories and positive first-period sales (**ZW**) if the demand swing is moderate ($d' - 12c < \frac{4}{31}(23d - 90c)$) ;
- positive inventories and no first-period sales (**W**) if the demand swing is large ($d' - 12c \geq \frac{4}{31}(23d - 90c)$, which is always satisfied for high storage costs, *i.e.* $c \geq \frac{23}{90}d$).

Similarly, when $d' \leq (1 + \sqrt{2})d$, the equilibrium is of type

- **ZW** if $c < \frac{d}{6}$ and $d' - 12c < \frac{60}{31}(d - 6c)$, or if $c \geq \frac{d}{6}$;
- **W** if $c < \frac{d}{6}$ and $d' - 12c \geq \frac{60}{31}(d - 6c)$.

The inventories in cases **ZW** and **W** are, respectively :

$$w_1^{\mathbf{ZW}} = w_2^{\mathbf{ZW}} = \frac{1}{186}(24(d' - d) + 7(d' - 12c)), \tag{2.44}$$
$$w_1^{\mathbf{W}} = w_2^{\mathbf{W}} = \frac{1}{30}(d' - 12c). \tag{2.45}$$

Note that suppliers carry inventories even when there is no seasonal swing ($d' = d$) : the only rationale for holding stocks is the strategic motive. Let us compute the strategic yield of storage in each type of equilibrium :

$$\sigma^{\mathbf{ZW}} = \frac{1}{31}(2d + 7c) \tag{2.46}$$

$$\sigma^{\mathbf{W}} = \frac{1}{15}(d' + 3c) \tag{2.47}$$

In both cases, the strategic yield of storage is positive : suppliers hold stocks even though second-period spot purchases are cheaper. This means that the vertical "countervailing-power" effect dominates the horizontal "reducing rival's costs" effect. As we shall see in the next section, this is not always the case when storage capacity is limited.

4 Storage with capacity constraints

In this section we introduce constraints on the maximum quantity that can be stored by the suppliers. Let W_1, W_2 be the storage capacities available to suppliers 1 and 2, respectively. To simplify the analysis, in this section we assume that $c = 0$.

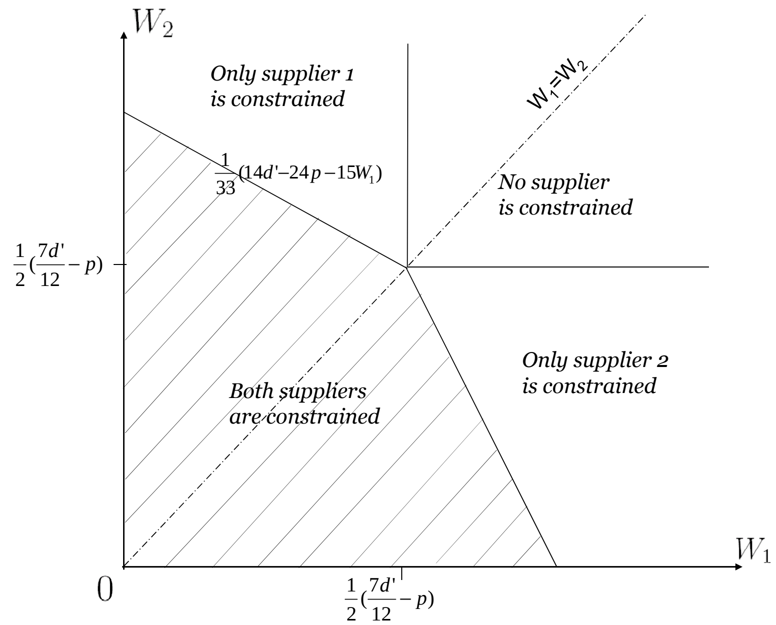

FIG. 2.4: Mapping of the areas where both suppliers, only one or no supplier is constrained, for a given first-period spot price.

When choosing his inventories, each supplier plays his best response to the other supplier's inventories : for $i = 1, 2$,

$$w_i = \max\left(\min\left(\frac{1}{33}\left(14d' - 24p - 15w_j\right), W_i\right), 0\right). \tag{2.48}$$

It is assumed that the supplier with higher storage capacity is supplier 2 ($W_2 \geq W_1$). Clearly, $p > \frac{7}{12}d' - 2W_1$ is a sufficient condition to guarantee that both suppliers are unconstrained. Figure 2.4 represents the type of equilibrium as a function of the inventories and the first-period spot price.

In the general case equilibria with no first-period sales cannot be ruled out and the producer's optimal choice of the first-period price depends on the demand parameters and the capacity constraints of both suppliers. To be able to characterize explicitly the equilibrium, in the rest of the analysis, we shall focus on the case with a moderate demand swing :

$$d' \leq \frac{5}{3}d, \tag{2.49}$$

which is a sufficient condition to have positive first-period downstream sales in any equilibrium.

4.1 Equilibrium

The analysis is detailed in the Appendix. The results can be summarized as follows (see Figure 2.5 and Figure 2.6).

If $W_2 < \frac{1}{51}(-12d + 14d' - 33W_1)$,

both suppliers are constrained. The first-period spot price is

$$p = \frac{1}{4}(2d + 3(W_1 + W_2)). \tag{2.50}$$

If $\frac{1}{51}(-12d + 14d' - 33W_1) \leq W_2 < \frac{1}{651}(-132d + 166d' - 345W_1)$,

the producer adjusts the first-period price so that both suppliers are constrained (see Figure 2.5) :

$$p = \frac{1}{24}(14d' - 15W_1 - 33W_2). \tag{2.51}$$

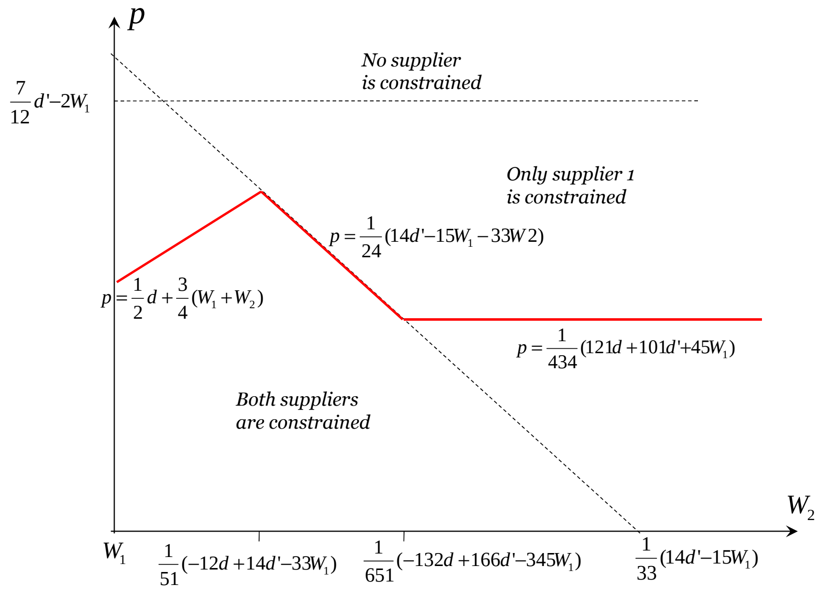

FIG. 2.5: First-period spot price as a function of supplier 2's inventories, in the case where $W_1 < \frac{1}{42}(-6d + 7d')$.

If $W_2 \geq \frac{1}{651}(-132d + 166d' - 345W_1)$ **and** $W_1 < \frac{1}{498}(-66d + 83d')$**,**

only supplier 1 is constrained. The first-period price is

$$p = \frac{1}{434}(121d + 101d' + 45W_1). \tag{2.52}$$

If $W_1 \geq \frac{1}{498}(-66d + 83d')$**,**

no supplier is constrained. The first-period price is

$$p = \frac{1}{124}(32d + 31d'). \tag{2.53}$$

4.2 Comparison of the profits of the suppliers

The profits of the suppliers can be easily compared. In effect, in any equilibrium the downstream sales of suppliers are identical in both periods and the difference in profits

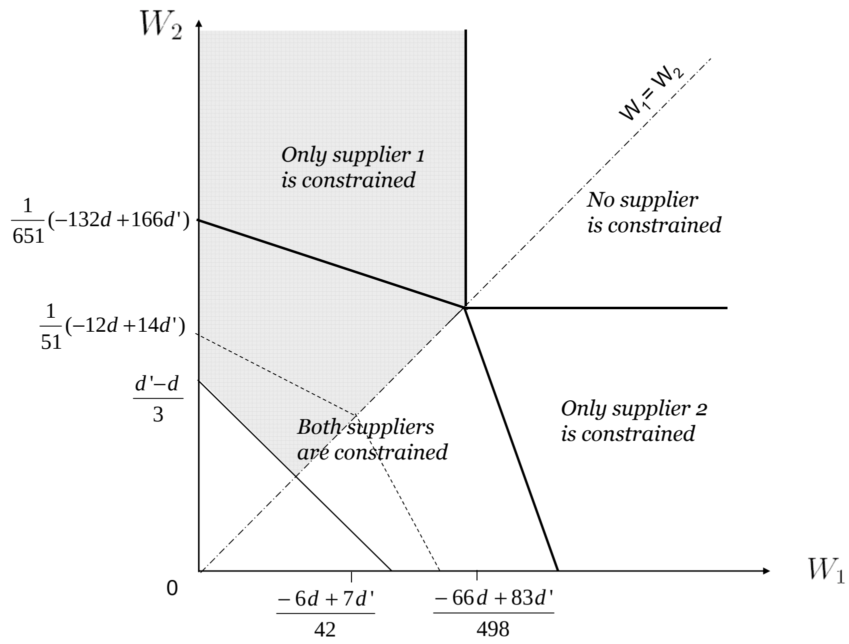

FIG. 2.6: Mapping of the areas where both, only one or no supplier is constrained (case where $d' \leq \frac{5}{3}d$). In the grey area supplier 2 has a larger storage capacity but he makes less profits.

results from the difference in purchasing costs, *i.e.*, in the use of inventories :

$$\Pi_2 - \Pi_1 = (w_2 - w_1)(p' - p). \tag{2.54}$$

The supplier with larger inventories (or equivalently, with a larger storage capacity) makes more profit if and only if $p' - p$ is positive.

Note that when supplier i is not capacity-constrained, the strategic yield of storage satisfies $\sigma_i = p' - p$. However, if he is capacity-constrained, $w_i = K_i$ and $\frac{\partial \Pi_i'}{\partial w_i} < 0$, therefore $\sigma_i < p' - p$. Accordingly, $p' - p < 0$ implies that the strategic yield of storage is negative.

Remember that from (2.30) $p' = \frac{1}{2}d' - \frac{3}{4}(w_1 + w_2)$.

When both suppliers are constrained,

two cases must be distinguished. If $W_2 < \frac{1}{51}(-12d + 14d' - 33W_1)$,

$$p' - p = \frac{1}{2}\left(d' - d - 3(W_1 + W_2)\right). \tag{2.55}$$

The strategic yield of storage is negative when $W_1+W_2 > \frac{d'-d}{3}$: in this case, the supplier with a larger storage capacity makes smaller profits than his rival.

If $\frac{1}{51}(-12d+14d'-33W_1) \leq W_2 < \frac{1}{651}(-132d+166d'-345W_1)$,

$$p'-p = \frac{1}{24}\left(-2d'-3W_1+15W_2\right). \tag{2.56}$$

The strategic yield of storage is negative when $W_2 < \frac{1}{15}(2d'+3W_1)$, which is always true in the interval considered when $d' \leq \frac{5}{3}d$.

When only supplier 1 is constrained,

$$p'-p = \frac{11}{434}\left(-5d+3d'-18W_1\right). \tag{2.57}$$

Since $d' \leq \frac{5}{3}d$, the strategic yield of storage is negative. The supplier with larger inventories, who is not constrained by his storage capacities, makes smaller profits than his rival.

The results can be summarized as follows.

Proposition 2.5. *Suppose that $W_1 \leq W_2$ and $d' \leq \frac{5}{3}d$. One supplier at least is capacity-constrained if and only if*

$$W_1 \leq \frac{1}{498}(-66d+83d'). \tag{2.58}$$

In this case, the price spread (and consequently the strategic yield of storage for both suppliers) is negative if and only if

$$W_1+W_2 > \frac{1}{3}(d'-d). \tag{2.59}$$

When this condition is satisfied, the supplier with a larger storage capacity, which is also the firm with larger inventories, makes a smaller profit than his rival.

The intuition is the following. When storage capacity is very scarce, the spot price will remain higher in the second period than in the first period. The supplier with larger storage capacity is able to buy more in the first period at a cheaper price, therefore he makes more profits. When storage capacity is more abundant, the producer cannot maintain a high second-period spot price due to the competition of inventories, and he increases the price in the first period to restrict stockpiling, so that the first-period price becomes higher than the second-period price. Accordingly, the supplier with larger stocks makes less profits than his rival. In fact, when the price spread is negative, the supplier who carries less inventories because he is capacity-constrained makes more profit than his rival because he buys large volumes in the second-period spot market where he benefits from a lower price resulting from the rival's large stocks. Note that the higher price in the first period does not prevent the rival from holding stocks : remember that even with no capacity constraints the price spread is always negative, and still, stocks are positive. The rival holds stocks because of the "countervailing power" effect : they allow him to obtain a lower average purchasing price from the producer.

5 Choice of storage capacity by an incumbent supplier

This section analyzes the situation where one supplier has a leadership advantage over his rival for the reservation of storage capacities. This can be the case when an incumbent supplier owns a storage installation and offers the remaining capacities to a new entrant after having determined his own needs. In the European Union most existing natural gas storage sites are owned by the incumbent supplier or one of his subsidiaries. Under the current legal framework, new entrants must be granted a non-discriminatory access to storage facilities at a transparent price that can be regulated or negotiated depending on the choice of each member state (see Cavaliere, 2009, for a description of the different regulatory designs). In the latter case, the incumbent could theoretically charge a very high storage fee to deter his rivals from using storage if this is in his interest, but this behavior would be detected immediately since storage fees are public, and such an abuse could lead the authorities to switch to regulated third-party access. In practice, storage users complain less about expensive fees than about the lack of transparency regarding storage availability (CRE, 2005). The storage operator can easily design rules that give to his supply affiliate a preferential access to capacity reservation, and it can also easily pretend that no storage capacity is available for rival suppliers, alleging some technical constraint.[3]

For these reasons, we abstract here from any manipulation of the storage fee, which is treated as exogenous (assume, for example, that it is regulated) and we examine the incentive for an incumbent supplier to reserve a large share of the available storage capacity. In particular, we shall determine whether it is in his interest to reserve more capacities than he actually intends to use (capacity hoarding) and to foreclose access to storage by competitors. To simplify the analysis, the capacity reservation is assumed to be costless.

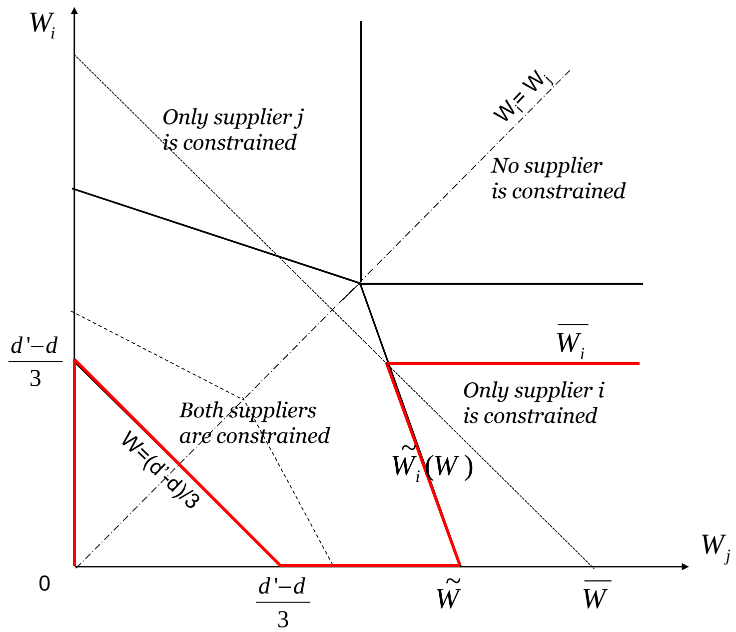

FIG. 2.7: Optimal choice of capacity reservation depending on total capacity (when $d' \leq \frac{5}{3}d$).

In the region where $W_i < \frac{-12d+14d'-33W_j}{51}$ and $W_j < \frac{-12d+14d'-33W_i}{51}$, both suppliers are capacity-constrained and the first-period spot price depends only on the total capacity

[3] The incumbent can also benefit from a preferential access to storage due to the regulatory design. In Italy, for example, access to storage is regulated but in a recent report (AGCM and AEEG, 2009) the national antitrust autority and the energy regulator stated that the current method to allocate scarce storage capacity, which gives priority to suppliers of domestic customers, favors the incumbent who is dominant in the domestic market segment : he can choose to use some or all of the capacities he is entitled to, and his rivals get only what is left.

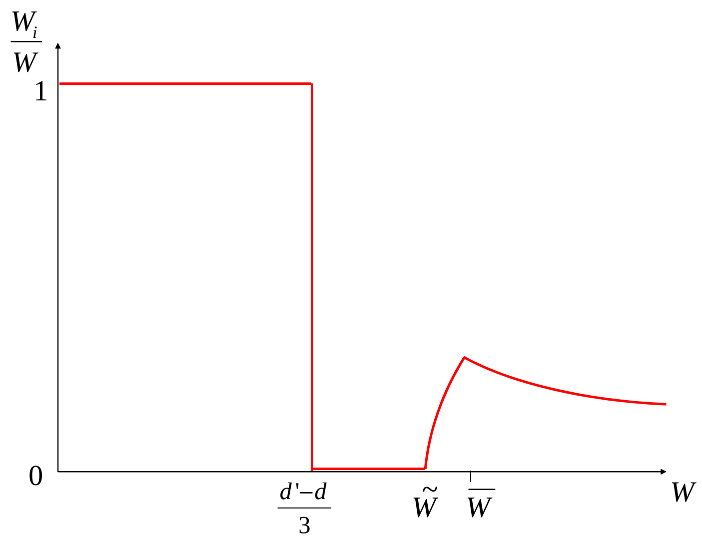

FIG. 2.8: Proportion of total capacity optimally reserved by the incumbent.

W. The profit of the incumbent is

$$\Pi_i = (p_z - p)z_i + (p'_z - p')z'_i + (p' - p)W_i. \tag{2.60}$$

The only term that depends on his storage capacity is the last term, and $(p' - p)$ depends only on the total capacity W. From Proposition 2.5, it is immediate that the incumbent will choose to reserve all the available capacity if $W < \frac{d'-d}{3}$, and to reserve no capacity if $W > \frac{d'-d}{3}$. When $W = \frac{d'-d}{3}$ he is indifferent between any W_i.

The detailed analysis of the other regions is given in the Appendix. Let

$$\tilde{W}_i(W) \equiv \frac{1}{306}(132d - 166d' + 651W), \tag{2.61}$$

$$\tilde{W} \equiv \frac{1}{651}(132d - 166d'), \tag{2.62}$$

$$\overline{W_i} \equiv \frac{1}{41553}(-7311d + 6383d'), \tag{2.63}$$

$$\overline{W} \equiv \frac{2}{13851}(-1977d + 2266d'). \tag{2.64}$$

The results can be summarized as follows.

Proposition 2.6. *The optimal capacity choice by the incumbent when $d' \leq \frac{5}{3}d$ consists in*

- *taking all storage capacities for himself if* $W \leq \frac{d'-d}{3}$ *;*
- *reserving no capacity if* $\frac{d'-d}{3} \leq W \leq \tilde{W}$ *;*
- *taking a smaller share than his rival if* $W > \tilde{W}$ *:*

$$\begin{aligned} W_i &= \max(\tilde{W}_i(W), 0) \text{ if } W < \overline{W}, \\ W_i &= \max(\overline{W_i}, 0) \text{ else.} \end{aligned}$$

When storage capacity is scarce and the demand swing is large ($W \geq \frac{d'-d}{3}$), the incumbent is incited to reserve all the available capacity for himself, thereby preventing his rival from accessing to storage.

However, when seasonal fluctuations of demand are less marked or when storage capacity become more abundant, the incumbent has just the opposite incentive. He will reserve for himself less capacities than he offers to his rival. If storage capacity is still relatively scarce so that both suppliers are constrained, he even prefers to leave all the available storage capacity to his competitor. When total capacity becomes larger, reserving nothing would lead to capacity under-utilization because the rival would not use all that is left, therefore the incumbent reserves a small but positive amount of capacity (if the demand swing is not too small, so that $\overline{W_i} > 0$). As total capacity increases the incumbent faces a trade-off between increasing his capacity reservation to maintain full utilization of storage capacity, which implies building large inventories that are more costly than second-period purchases, and free-riding on the rival's stocks by limiting his own inventories, which implies that total stocks will decrease and the producer will be able to charge a higher price. In fact, when total capacity becomes very large, the incumbent will never reserve more than a fixed quantity $\overline{W_i}$.

Note that capacity hoarding never occurs at equilibrium : in all cases either all the available storage capacity is fully used, or the incumbent reserves a smaller share of the available capacity and fully uses it, while some of his rival's capacity is left idle.

6 Conclusion

The strategic use of storage by Cournot competitors was examined in two different settings : when suppliers produce themselves and when they buy in each period in a spot market from a producer with market power. Novel results with respect to the literature were established.

First, in a single-tier oligopoly we retrieved the classical result that the only equilibria feature extreme purchasing specialization, with one supplier selling only from his stocks in the second period, and one supplier building no stocks. Inventories are a means to acquire a leadership in the second-period market : being the one who stores is always an advantage. We proved that Stackelberg leader would behave exactly as the firm that carries inventories in the simultaneous game. However, when total storage capacity is scarce it is better not to hold stocks because it would mean not producing again in the second period (since equilibria are asymmetric) and having too little to sell.

In a two-tier oligopoly, the story is different. Since stocks can be sold to the rival supplier in the second-period spot market, a supplier who builds inventories does not commit himself to sell them to downstream customers. The asymmetric equilibria of the previous setting disappear. Conversely, there are symmetric equilibria where both suppliers hold stocks and sell the same quantities in each period. In this setting, the purpose of storage is not any more preemption of future demand but rather limiting the producer's market power, by putting a bound on the spot price differential he can maintain between the two periods. The problem is that lowering the future spot price benefits the rival and intensifies competition in the second period. The strategic yield of storage, which accounts for these two effects, is shown to be positive when there are no capacity constraints : suppliers hold inventories even though waiting until the second period to buy on spot would be cheaper. However when capacity constraints are introduced it can be better to have more stocks, or less stocks, than the rival, depending on whether total capacity is scarce or large.

Accordingly, if a supplier has a preferential access to capacity reservation, he is not always incited to take it all for himself. Typically, he will reserve all the available capacity when it is scarce, and only a small share of it (possibly nothing) when it is large. This result contrasts with the one-tier case, where a supplier uses storage only when capacity is large. This is due to the positive externality exerted by a supplier's stocks on his rival in a two-tier setting. By lowering the second-period spot price, inventories have a twofold effect : they lower the own costs of purchasing additional quantities and they lower the rival's costs. At some point, building large inventories ceases to be advantageous because the additional quantities purchased in the second period become insufficient to compensate for the cost advantage given to the rival and it is better to let the rival store, buy more in the second-period spot market and benefit from the price decrease.

In the European natural gas market, new entrants often complain about a lack of transparency as regards availability of storage capacities : incumbent suppliers owning storage facilities allegedly reserve more capacities than they actually need, or in any case, leave little capacity left for them. Our model shows that this behavior is optimal when storage capacities are scarce, which seems to be currently the case in Europe. However, if market conditions change so that storage capacity becomes abundant, the incentives of an incumbent supplier could be radically altered : he could prefer to encourage storage by his competitors, in his own interest. In this case, observing a larger use of storage by entrants would not necessarily mean that they compete on an equal foot with incumbents : the incumbent would simply make a larger profit by free-riding on entrants' stocks.

References

Allaz, Blaise and Jean-Luc Vila (1993), "Cournot Competition, Forward Markets and Efficiency", Journal of Economic Theory, 59, 1-16.

Anand, Krishna, Anupindi, Ravi and Yehuda Bassok (2008), "Strategic Inventories in Vertical Contracts", Management Science, 54, 10, 1792-1804.

Autorità Garante della Concorrenza e del Mercato (AGCM) and Autorità per l'Energia Elettrica e il Gas (AEEG), (2009), "Indagine Conoscitiva sull'Attività di Stoccaggio di Gas Naturale", available at http ://www.agcm.it.

Arvan, Lanny (1985), "Some Examples of Dynamic Cournot Duopoly with Inventory", Rand Journal of Economics 16, 4, 569-78.

Baranès, Edmond, Mirabel, François and Jean-Christophe Poudou (2005), "Storage and Competition in Gas Market", Economics Bulletin, 12, 19, 1-9.

Baranès, Edmond, Mirabel, François and Jean-Christophe Poudou (2007), "Concurrence et stockage stratégique sur le marché gazier", Economie et Prévision, 178-179, 25-40.

Cavaliere, Alberto (2009), "The Regulation of Access to Gas Storage", in Anna Creti (ed.), The Economics of Natural Gas Storage A European Perspective, Springer Berlin Heidelberg.

Chaton, Corinne, Creti, Anna and Bertrand Villeneuve (2008), "The Economics of Seasonal Gas Storage", Energy Policy 36, 11, 4235-4246.

Commission de Régulation de l'Energie (CRE) (2005), "Synthèse des réponses à la consultation publique sur les tarifs et conditions d'utilisation des stockages souterrains de gaz naturel en France", available at http ://www.cre.fr.

Dixit, Avinash (1980), "The Role of Investment in Entry Deterrence", Economic Journal, 90, 95-106.

Kirman, Alan P. and Matthew J. Sobel (1974), "Dynamic Oligopoly with Inventories", Econometrica, 42, 2, 279-288.

Mitraille, Sébastien (2004), "Storage Behavior of Cournot Duopolists over the Business Cycle", University of Bristol, Working Paper, January 2004.

Moellgaard, H. Peter, Poddar, Sougata and Dan Sasaki (2000), "Strategic Inventories in Two-Period Oligopoly", Discussion Paper No. 00/17, University of Exeter.

Pal, Debashis (1991), "Cournot Duopoly with Two Production Periods and Cost Differentials", Journal of Economic Theory, 55, 2, 441-448.

Poddar, Sougata and Dan Sasaki (2002), "The strategic benefit from advance production", European Journal of Political Economy, 18(3), 579-595.

Pyatt, Graham (1978), "Marginal Costs, Prices and Storage", Economic Journal, 88, 749-762.

Saloner, Garth (1987), "Cournot Duopoly with Two Production Periods", Journal of Economic Theory, 42, 1, 183-187.

Spence, Andrew Michael (1979), "Investment Strategy and Growth in a New Market", Bell Journal of Economics, 10, 1-9.

Thille, Henry (2006), "Inventories, market structure, and price volatility", Journal of Economic Dynamics and Control, Elsevier, 30, 7, 1081-1104.

Williams, Jeffrey C., and Brian D Wright (1991), "Storage and Commodity Markets", Cambridge University Press.

A Appendix

A.1 Proof of Proposition 2.4

Case ZW

Suppose that the producer sets a price that leads to an equilibrium with positive sales and positive inventories. Maximizing equation (2.43) with respect to p when stocks and first-period downstream sales are given by (2.39) and (2.41), respectively, yields

$$p^{\mathbf{ZW}} = \frac{1}{4}(d' - 12c) + \frac{2}{31}(4d + 45c). \tag{2.65}$$

In this case we have an interior solution and the corresponding inventories, downstream sales and producer's profit are

$$z_1 = z_2 = \frac{1}{372}(92d - 31d' + 12c), \tag{2.66}$$

$$w_1 = w_2 = \frac{1}{186}(24(d' - d) + 7(d' - 12c)), \tag{2.67}$$

$$\Pi^{\mathbf{ZW}} = \frac{1}{12}(d + d')^2 + \frac{1}{372}(d - 12c)^2. \tag{2.68}$$

With this price, stocks are necessarily positive and inventories are effectively positive if

$$d' - 12c < \frac{4}{31}(23d - 90c). \tag{2.69}$$

If d' does not satisfy this condition, the highest profit in an equilibrium of type **ZW** will be attained with a corner solution, where either $w_1 = w_2 = 0$, or $z_1 = z_2 = 0$. Then the producer would do better to choose the optimal price that corresponds to regime **Z** or **W**.

Case W

Suppose that the producer sets a price that leads to an equilibrium with positive inventories and no first-period downstream sales. Maximizing equation (2.43) with respect to p when stocks are given by (2.39) and first-period downstream sales are zero yields

$$p^{\mathbf{W}} = \frac{1}{60}(31d' - 12c). \tag{2.70}$$

In this case we have an interior solution and the corresponding inventories and producer's profit are

$$\begin{aligned} w_1 = w_2 &= \frac{1}{30}(d' - 12c), && (2.71)\\ \Pi^{\mathbf{W}} &= \frac{1}{6}d'^2 + \frac{1}{360}(d' - 12c)^2. && (2.72) \end{aligned}$$

With this price, stocks are effectively positive if $d' > 12c$, which is an assumption of the model, and downstream sales are effectively zero if

$$d' - 12c \geq \frac{60}{31}(d - 6c). \tag{2.73}$$

Else, this price will not prevent downstream sales by the suppliers in the first period. The producer could deter downstream sales by increasing p (at least to $p = d$), but the resulting profit would be lower than if he accomodates and sets $p^{\mathbf{W}}$: with $p = d$, the profit is

$$\Pi_p = \frac{3}{8}(\frac{1}{12}d' + d + c)^2 + d(\frac{7}{12}d' - d - c), \tag{2.74}$$

which is strictly lower than the profit in (2.72).

Case Z

Suppose that the producer sets a price that leads to an equilibrium with positive first-period downstream sales and no inventories. Maximizing equation (2.43) with respect to p when first-period downstream sales are given by (2.41) and stocks are zero yields $p = \frac{1}{2}d$. With this price, first-period sales are necessarily positive, but having zero stocks requires $d' - 12c \leq \frac{6}{7}(d - 12c)$. This is clearly impossible, since $d' \geq d$: storage cannot be *blockaded.*

However, the producer can *deter* storage by adjusting the first-period price upwards to bring inventories down to zero :

$$p^{\mathbf{Z}} = \frac{7}{12}d' - c. \tag{2.75}$$

In this case, first-period sales will be positive only if $p < d$, which requires

$$d' - 12c < \frac{12}{7}(d - 6c). \tag{2.76}$$

In this case, first-period sales and the producer's profit are :

$$z_1 = z_2 = \frac{1}{3}(d + c - \frac{7}{12}d'), \tag{2.77}$$

$$\Pi^{\mathbf{Z}} = \frac{1}{6}d'^2 + \frac{2}{3}(d + c - \frac{7}{12}d')(\frac{7}{12}d' - c). \tag{2.78}$$

Finally, if $d' - 12c \geq \frac{12}{7}(d - 6c)$, there can be no equilibrium of type **Z** : deterring storage without deterring downstream sales is impossible.

Case O

Any first-period price such that $p \geq \max(d, \frac{7}{12}d' - c)$ leads to an equilibrium of type **O** : an equilibrium with no inventories and no first-period sales is always realizable, provided the producer sets a sufficiently high spot price. The producer's profit in this case is

$$\Pi^{\mathbf{O}} = \frac{1}{6}d'^2. \tag{2.79}$$

Summary

Depending on the demand and cost parameters, only some of the four types of continuation equilibria for a given p are possible :

- If $d' - 12c < \frac{12}{7}(d - 6c)$, the possible equilibria are **ZW**, **Z** and **O** ;
- If $\frac{12}{7}(d - 6c) \leq d' - 12c \leq \frac{60}{31}(d - 6c)$, the possible equilibria are **ZW** and **O** ;
- If $\frac{60}{31}(d - 6c) \leq d' - 12c \leq \frac{4}{31}(23d - 90c)$, the possible equilibria are **ZW**, **W** and **O** ;
- If $d' - 12c \geq \frac{4}{31}(23d - 90c)$, the possible equilibria are **W** and **O**.

The producer chooses the one that gives him the largest profit. In all cases, $\Pi^{\mathbf{ZW}} > \Pi^{\mathbf{Z}}$, whereas $\Pi^{\mathbf{ZW}} > \Pi^{\mathbf{W}}$ if $d' > (1+\sqrt{2})d$. Finally **O** is always dominated when another equilibrium is possible.

When $c < \frac{d}{6}$,

in the case where $d' > (1+\sqrt{2})d$,

- if $d' - 12c < \frac{4}{31}(23d - 90c)$, the producer chooses $p^{\mathbf{ZW}}$;
- if $d' - 12c \geq \frac{4}{31}(23d - 90c)$, the producer chooses $p^{\mathbf{W}}$.

In the case where $d' \leq (1+\sqrt{2})d$ the outcome is similar, but the threshold is attained when $d' - 12c = \frac{60}{31}(d - 6c)$.

When $\frac{d}{6} \leq c < \frac{23}{90}d$,

- if $d' - 12c < \frac{4}{31}(23d - 90c)$, the producer chooses $p^{\mathbf{ZW}}$;
- if $d' - 12c \geq \frac{4}{31}(23d - 90c)$, the producer chooses $p^{\mathbf{W}}$.

When $c \geq \frac{23}{90}d$,

the producer chooses $p^{\mathbf{W}}$.

A.2 Equilibrium with capacity constraints

A.2.1 When both storage capacity constraints are binding

Assume that for a given p, both suppliers are constrained by their storage capacities : $w_1 = W_1$ and $w_2 = W_2$. A single condition is sufficient to ensure that both suppliers are constrained :

$$W_2 < \frac{2}{3}d - \frac{2}{33}(23d - 7d') - \frac{15}{33}W_1. \tag{2.80}$$

The producer chooses the first-period price to maximize his profit :

$$\max_p p(W_1 + W_2 + z_1 + z_2) + \frac{1}{24}(2d' - 3(W_1 + W_2))^2. \tag{2.81}$$

To determine the optimal price, we must distinguish between the cases with positive downstream sales and with no downstream sales in the first period. Remember that downstream sales of supplier i in the first period are $z_i = \max\left(\frac{d-p}{3}, 0\right)$.

Positive first-period downstream sales

Maximizing the producer's profit with respect to p when $z_1 = z_2 = \frac{d-p}{3}$ yields

$$p = \frac{1}{2}d + \frac{3}{4}(W_1 + W_2) \tag{2.82}$$

With this price, first-period sales are effectively positive and both suppliers are constrained by their storage capacities) if the following conditions are satisfied (the first condition is sufficient when $d' \geq \frac{23}{7}d$) :

$$\begin{aligned} W_2 &< \frac{2}{3}d - W_1, & (2.83)\\ W_2 &\leq \frac{2}{3}d - \frac{2}{51}(23d - 7d') - \frac{33}{51}W_1. & (2.84) \end{aligned}$$

The producer's profit is

$$\Pi_p = \frac{1}{12}\left((d' - d - 3(W_1 + W_2))^2 + (d' + d)^2\right). \tag{2.85}$$

No first-period downstream sales

In an equilibrium where both suppliers are constrained, if the demand swing is moderate ($d' \leq 3d$), first-period downstream sales are always positive.

Suppose there are no downstream sales in the first period. The volumes sold by the producer on spot simply fill the inventories. The producer's profit increases strictly with p, and since we assume that storage capacity constraints remain binding, the price must meet condition (2.80), so the producer will set

$$p = \frac{1}{24}(14d' - 15W_1 - 33W_2). \tag{2.86}$$

By construction, this price ensures that storage capacity constraints are binding. As for first-period sales, they are indeed equal to zero if $p > d$, or equivalently,

$$W_2 < \frac{1}{33}(14d' - 24d - 15W_1). \tag{2.87}$$

The producer's profit is

$$\Pi = \frac{1}{12}\left(2d'^2 + (W_1 + W_2)(d' - 3W_1 - 12W_2)\right). \tag{2.88}$$

When $d' \leq \frac{23}{7}d$, both types of equilibria are possible when $W_2 < \frac{2}{3}d - \frac{2}{33}(23d - 7d') - \frac{15}{33}W_1$, and only an equilibrium with positive sales is possible when $\frac{2}{3}d - \frac{2}{33}(23d - 7d') - \frac{15}{33}W_1 \leq W_2 < \frac{2}{3}d - \frac{2}{51}(23d - 7d') - \frac{33}{51}W_1$.

When $d' \geq \frac{23}{7}d$, both types of equilibria are possible when $W_2 < \frac{2}{3}d - W_1$, and only an equilibrium with no sales is possible when $\frac{2}{3}d - W_1 \leq W_2 < \frac{2}{3}d - \frac{2}{33}(23d - 7d') - \frac{15}{33}W_1$.

The profit when first-period sales are positive (2.85) is higher than the profit with no first-period sales (2.88) if and only if

$$(W_1 + W_2)(7d' - 6d - 12W_1 - 21W_2) < 2d^2. \tag{2.89}$$

When $d' \geq \frac{23}{7}d$, the producer always prefers the equilibrium with no sales, except for very low values of W_1 and W_2. Conversely, when $d' \leq \frac{6+2\sqrt{33}}{7}d \approx 2.5d$, the producer always prefers the equilibrium with positive sales.

A.2.2 When only one constraint is binding

Now suppose supplier 2 is not constrained, but supplier 1 is : supplier 2 plays his best response to his rival's inventories, so that

$$w_1 = W_1, \tag{2.90}$$
$$w_2 = \max\left(\frac{1}{33}(14d' - 24p - 15W_1), 0\right). \tag{2.91}$$

Positive first-period downstream sales

The price that maximizes the producer's profit when $w_1 = W_1$, W_2 is given by (2.91) and $z_1 = z_2 = \frac{d-p}{3}$ is

$$p = \frac{1}{434}(121d + 101d' + 45W_1). \tag{2.92}$$

With this price, supplier 1 is constrained by his storage capacity, supplier 2 is not and first-period sales are positive) if the following conditions are satisfied :

$$\begin{aligned} W_1 &< \frac{1}{498}(-66d + 83d'), & (2.93)\\ W_2 &\geq \frac{1}{651}(-132d + 166d' - 345W_1), & (2.94)\\ W_1 &< \frac{1}{45}(313d - 101d'). & (2.95) \end{aligned}$$

Note that the first condition implies $w_2 \geq W_1$.

The producer's profit is

$$\Pi_p = \frac{1}{1302}(121d^2 + 113d'^2 + 202dd' + 18W_1(9W_1 - 3d' + 5d)). \quad (2.96)$$

No first-period downstream sales

The price that maximizes the producer's profit when $w_1 = W_1$, $w_2 = W_2$ and $z_1 = z_2 = 0$ is

$$p = \frac{1}{192}(101d' + 45W_1) \quad (2.97)$$

With this price, supplier 1 is constrained by his storage capacity, supplier 2 is not and first-period sales are zero if :

$$\begin{aligned} W_1 &< \frac{d'}{39}, & (2.98)\\ W_2 &\geq \frac{1}{24}(d - 15W_1), & (2.99)\\ W_1 &> \frac{1}{45}(192d - 101d'). & (2.100) \end{aligned}$$

Conditions (2.98) and (2.100) can be simultaneously satisfied only if $d' > \frac{156}{83}d$.

The producer's profit is

$$\Pi_p = \frac{1}{6}d'^2 + \frac{1}{576}(d' + 9W_1)^2. \quad (2.101)$$

The profit is higher in the case with no downstream sales if

$$W_1 < \frac{1}{45}(4(24 + \sqrt{1302})d - 101d'). \quad (2.102)$$

If the demand swing is moderate, with $d' \leq \frac{5}{3}d$, then

- in an equilibrium where both storage capacity constraints are binding, first-period downstream sales cannot be zero : an equilibrum with positive sales is always possible and it will be preferred to an equilibrium with no sales.
- in an equilibrium where only one storage capacity constraint is binding, first-period downstream sales cannot be zero, since conditions (2.98) and (2.100) are not compatible.
- for a given range of parameter values, only one of the equilibria with an interior optimum (price given by (2.82) or (2.92)) is possible.

When no interior optimum is possible, the optimum is a corner solution : the producer adjusts the price so that both suppliers are just constrained, as long as this is possible (*i.e.* $W_1 < \frac{-66d+83d'}{498}$).

A.3 Proof of Proposition 2.6

In any equilibrium, the profit of supplier i can be expressed as a function of the first-period spot price and his own inventories as :

$$\Pi_i = \frac{1}{9}(d-p)^2 + \frac{1}{144}(2d' - 3(w_i + w_j))^2 + \frac{1}{4}w_i(2d' - 4p - 3(w_i + w_j)). \qquad (2.103)$$

We shall distinguish between several regions. Remember that for a given W the first-period price is a continuous function of W_i, and so is the profit of supplier i.

A.3.1 Scarce storage capacity

In the region where $W_i \geq W_j$ and $\frac{-12d+14d'-33W_j}{51} \leq W_i \leq \frac{-132d+166d'-345W_j}{651}$, both storage capacity constraints are binding and as can be seen in Figure 2.4 the incumbent i has a larger capacity and he makes less profit than his rival. For a given W his profit will necessarily be higher in the symmetric region where $W_i \leq W_j$ and $\frac{-12d+14d'-33W_i}{51} \leq W_j \leq \frac{-132d+166d'-345W_i}{651}$. In this region the incumbent has a smaller capacity than his rival, so the first-period price is given by (2.51) where $i = 1$ and $j = 2$. The incumbent's profit is a decreasing function of W_i if and only if

$$W_i > \frac{-24d + 2d' + 57W_j}{42}. \tag{2.104}$$

By assumption in the relevant interval $W_j < \frac{-132d+166d'}{651}$, so that a sufficient condition is $W_i > \frac{2(-643d+299d')}{1519}$. This inequality is always satisfied when $d' \leq \frac{5}{3}d$, since the right-hand side is negative. Therefore the incumbent's profit is highest when $W_i = 0$.

A.3.2 Intermediate storage capacity

Now we analyze the cases where only one supplier is capacity-constrained. If $W_i > \frac{-132d+166d'-345W_j}{651}$ and $W_j < \frac{-66d+83d'}{498}$, only supplier j is capacity-constrained. By the same reasoning as already exposed, the incumbent's profit is smaller than his rival's and his profit will necessarily be higher in the symmetric region where $W_j > \frac{-132d+166d'-345W_i}{651}$ and $W_i < \frac{-66d+83d'}{498}$. In this region only supplier i is capacity-constrained and he makes more profit than his rival. The first-period price is $p = \frac{1}{434}(121d + 101d' + 45W_i)$ and the incumbent's profit increases with W_i if and only if $W_i \leq \frac{-7311d+6383d'}{41553}$. When W_i is smaller than this value, the optimum is the highest W_i in the area, which is $W_i = \frac{-132d+166d'-651W}{306}$. This will be the optimum as long as $W \leq \frac{2}{13851}(-1977d + 2266d')$. When total capacity is larger, the incumbent's optimal choice is $W_i = \frac{-7311d+6383d'}{41553}$.

A.3.3 Large storage capacity

Finally, when $\min(W_i, W_j) \geq \frac{-66d+83d'}{498}$ no supplier is constrained. The incumbent's profit in this area is the same whatever W_i. In particular, it is the same as on the frontier with the area analyzed just before, where it was proved that this frontier is not the optimal choice. Therefore the incumbent will never choose W_i in this area.

The results are summarized in Proposition 2.6.

Deuxième partie

Asymétries dans l'accès au marché et spécialisation des acteurs

Chapitre 3

Gas release : how to weaken incumbent suppliers without strengthening foreign producers

1 Introduction

The energy policy of the European Union is organized around three pillars : security of supply, competitiveness and protection of the environment. In the last decade, much attention has been paid to the second pillar, with the liberalization of the electricity and natural gas markets, but the results so far are not satisfactory, with most national markets still dominated by incumbent suppliers. The case of natural gas is specific : while electricity can be produced anywhere, Europe has to rely increasingly on gas imports from countries located outside the European Union, and therefore beyond the control of EU legislation and regulation.[1] This constitutes a challenge for the liberalization of the downstream market. Historically, natural gas was imported under long-term contracts between incumbent monopolists and large foreign producers. The recent years have seen

This chapter is based on joint work with Corinne Chaton.

[1] The EU's main external suppliers are Russia, Norway and Algeria. Russian gas alone, which is sold by the export monopolist Gazprom, represents more than 20 % of the EU's total consumption of natural gas. This import dependency is expected to grow in the future. In 2008 the European Union produced only two fifths of its needs and from 2020 on it will rely on imports for almost 80 % of its consumption (European Commission, 2008).

the emergence of wholesale markets, where new entrants can source their gas.[2] However, these markets are still underdeveloped and the European Commission recognized in its Energy sector inquiry in 2007 that volumes traded on continental hubs are, in general, not sufficient to be the main source of gas to build a supply business. As for long-term contracts, they are still dominated by incumbent suppliers.

The E.ON/MOL merger case provides an illustration of these concerns.[3] The Commission's investigation revealed the existence of significant barriers to entry on the Hungarian gas market, mainly due to the difficulty for entrants to have access to competitive sources of gas and the lack of liquidity of the Hungarian gas wholesale market. The investigation suggested that the Russian producer Gazprom (who covers most of Hungary's needs) would have no incentives to sign contracts with new entrants in parallel to existing contracts with the incumbent MOL as the quantities would simply displace the quantities it already sells for the Hungarian market. In addition, selling gas to the incumbent's competitors could weaken the producer's bargaining position when he renegotiates his long-term contracts with his traditional partner. In fact, foreign producers typically prefer to extend existing contracts with incumbents rather than sign long-term contracts with companies that have just entered the market. As a result, new entrants are condemned to remain niche players and have little chance to develop into the large and reliable suppliers who could be attractive partners for foreign producers.

Long-term contracts as such are not expected to disappear. The EU Commission, after having criticized them for being a barrier to entry, explicitly acknowledged their contribution to the first pillar of its energy policy — security of supply.[4] Indeed, they seem indispensable to obtain financing for heavy investments into natural gas production and transportation. However, if new entrants have no access to them, a competitive downstream market is not likely to develop. Solving the problem is not easy. The re-

[2]In practice, new entrants also source their gas directly from incumbent suppliers. We do not model explicitly bilateral contracts between incumbents and new entrants, but we allow for incumbents to resell part of their long-term contracts on the wholesale market.

[3]In this case, the European Commission accepted the remedies offered by E.ON, which consisted in a combination of unbundling measures, contract release and gas release programs (European Commission, 2005).

[4]The 2004 Council directive on security of natural gas supply states that "long-term contracts have played a very important role in securing gas supplies for Europe and will continue to do so. (...) it is believed that such contracts will continue to make a significant contribution to overall gas supplies as companies continue to include such contracts in their overall supply portfolio" (recital 11).

gulatory measures adopted to guarantee access to transportation networks (third-party access rules, regulated tariffs, unbundling) were based on the essential facilities doctrine. The regulatory framework for storage, where tariffs may be negotiated and unbundling requirements are less stringent, reveals the hesitations as to whether it constitutes an essential facility (see Cavaliere, 2009, for a discussion). A first question is : are long-term contracts essential facilities ? The answer is complex : new entrants have alternative possibilities to source their gas but the spot market alone does not allow them to develop a supply activity on a large scale. A second question is : what can regulators do about private right contracts signed with producers from non-EU countries ? In EU member states, antitrust authorities have required the break-up of long-term contracts between suppliers and their large customers.[5] However, there is no way to force a major foreign producer such as Gazprom to modify his contracts with his European partners.

A solution is to grant new entrants access to this precious resource by obliging the incumbent to resell it, as has been done for base load in the electricity market. In this market, new entrants commonly build their own semi-base load or peak load plants, but they cannot easily build their own base load (hydraulic or nuclear) plants. Yet access to base load production is necessary to compete effectively in the downstream market. On several occasions, regulatory authorities have required that the incumbent integrated electricity firm sells either long-term contracts for base load electricity at a regulated price[6], or "Virtual Power Plants" (VPPs).[7] Transposing these measures to natural gas involves some difficulties. A forced divestiture of long-term contracts could give incumbents poor incentives in the future to negotiate efficiently their contracts with foreign producers or even to buy gas under long-term contracts at all ; it could also weaken their negotiating position towards these producers and eventually weaken Europe's security of supply (DRI-WEFA, 2001). These uncertainties might explain why gas release programs

[5]The European Commission obliged in 2007 Distrigas to reduce the duration of its long-term contracts with large customers, and to reduce the gas volumes tied in those contracts. A similar decision was taken in 2010 concerning EDF.

[6]See the Direct Energie decision of the French competition authority (Conseil de la concurrence, 2007), which is based on an auction mechanism. In France, under the new electricity law that is currently under discussion, new entrants should obtain access to nuclear base load electricity at a regulated price.

[7]Virtual Power Plants are call options that allow their buyer to obtain electricity at a price and under conditions that reflect a power plant's operational constraints. VPPs have been used as remedies in merger cases (EDF/EnBW, Nuon/Reliant) and antitrust proceedings (AGCM vs. ENEL), and have sometimes be applied by national regulators to enhance competition in the domestic market (Endesa, Iberdrola). See Ausubel and Cramton (2009).

have been so far very limited in scope.[8]

Gas release programs impose the resale by the incumbent of a share of the gas bought under long-term contracts, for a limited number of years, generally at a regulated price. But there is no common understanding on the right duration, the right volume, and the right way to set the price of released gas, maybe because there is no consensus on how to assess whether the liberalization is a success. Does a high market share of new entrants mean that the market has become competitive ? Is the increase of entrants' market shares the very objective of liberalization ? Regulatory measures often reveal a confusion between final goals, secondary objectives and mere indicators. Such misunderstandings can lead to inappropriate policies.[9]

Moreover, gas release is not only a form of asymmetric regulation that places obligations on the incumbent monopolist to advantage his competitors, it also encompasses some aspects of strategic trade policy. Indeed, creating a competitive downstream market is not the only objective of the regulator : he must also ensure that the incumbent, who remains the only commercial partner of the foreign producer, will buy sufficient volumes and will obtain them at a reasonable price. The literature on strategic trade policy usually analyzes the incentives for using trade instruments such as tariffs or subsidies to extract rents from imperfectly competitive foreign firms. In a seminal contribution, Brander and Spencer (1981) showed that a country that imports goods from a foreign monopolist can use tariffs to extract some of its monopoly rent, without reducing the level of imports. Nese and Straume (2007) developed a successive oligopoly model and analyzed the use of strategic taxation to shift rents up or down the vertical value chain. They described the impact of market concentration on the policy maker's optimal choice, but increasing competition in itself was not part of the regulatory objectives. The combination of strategic trade policy and asymmetric regulation to promote competition in the domestic market, as in the present paper, is novel in the literature.

The paper models the liberalization of the natural gas market. Section 2 describes the

[8] The main gas release programs are described in the Appendix.

[9] In Italy, the government tried to introduce competition by limiting the gas incumbent's market share. A reduction of ENI's share of total imports to 70% was initially imposed, to be followed by another reduction to 61% by 2010. The resulting decrease in ENI's market share did not really improve the competitive situation, as this measure simply led the incumbent to sell the gas to his competitors before it reaches the Italian border (Cavaliere, 2007).

basic setting : the incumbent supplier, who is initially a monopolist, signs a long-term contract with a foreign producer, then the downstream market is opened to competition, but new entrants only have access to a spot market and they are at a disadvantage compared to the incumbent, who remains dominant. The following sections analyze the implementation of a gas release program by a regulator who maximizes the domestic welfare, which excludes the profit of the foreign producer. Not only the effect of gas release on entry, but also its consequences on the renegotiation of the long-term contract between the incumbent and the foreign producer, who act cooperatively, must be taken into account. Section 3 describes the equilibrium outcome for a given gas release scheme, and briefly comments on gas release auctions. Sections 4 and 5 analyze, respectively, gas release at a predetermined price, and gas release at a price that is adjusted to the average purchasing cost of contract volumes, before discussing the optimal policy. Section 6 concludes.

2 Benchmark model : case without regulation

Before the opening of the downstream natural gas market to competition, the incumbent supplier (indexed by i) is a monopolist in his domestic market. He signs a long-term, take-or-pay contract with a foreign producer for a constant quantity y over the future years. This long-term contract allows the producer to undertake the heavy investments in production and transmission required for supplying his client (capacity $Y \geq y$). The contract can be renegotiated if there is an important change in market conditions. The incumbent complements these supplies with purchases s_i from a domestic producer on a short-term ("spot") market, where available quantities can be smaller but supply is more flexible.[10]

When the downstream market is opened to competition, n new suppliers (indexed by j, $j = 1$ to n) enter the market and incur fixed costs to start their activities and establish their brands. Unless a gas release program is implemented, they have no access to long-term contracts with the foreign producer, however they can buy on the short-term

[10] This additional sourcing possibility can be valuable to face unexpected changes in demand, or to complement storage as a seasonal flexibility tool. To simplify the analysis, however, we leave aside uncertainty and seasonal variations. Nevertheless, due to the convexity of production costs, it is efficient to have both producers active.

market.[11]

2.1 Assumptions

Consumers :

Consumers buy z_i from the incumbent and z_j from entrant j ($j = 1$ to n) at price p_z. Their inverse demand function is

$$p_z = d - z_i - \sum_j z_j. \tag{3.1}$$

Suppliers :

The incumbent is already present in the market. To enter the market, new suppliers must incur a fixed cost that is assumed to decrease with the number of suppliers. In effect, entrants exert a number of positive externalities on each other, and some of the entry costs are shared between new suppliers. Establishing a business model in a new, liberalized context requires inevitable trials and errors, which can be observed and avoided by the competitors ; it may also require lobbying or litigation to obtain the effective possibility to ship and market the gas (*e.g.* access to the network or storage sites, more favorable balancing rules), after which the resulting rules apply to all suppliers. Access to customers in the downstream market may also entail litigation costs (*e.g.* obtaining a ban on long-term contracts between the incumbent and downstream consumers, as in the Distrigas case), as well as expenses to increase consumers' awareness of the possibility to change suppliers. The entry cost for each of the n new entrants is modeled as follows :

$$E(n) = \frac{F}{n}, \tag{3.2}$$

where $F > 0$. All suppliers compete in quantities in the downstream market.

[11] This is typically the case in the natural gas market. Despite the liberalization process leading to the emergence of a number of new entrants, major gas producers are rarely willing to enter into long-term relationships with them. This could have several explanations : lack of confidence in the business prospects of entrants or in their survival, bargaining with the incumbent for better contract conditions in exchange for the refusal to supply his rivals, etc.

Producers :

To simplify, there are only two producers : the foreign producer, who is a strategic player and sells only under long-term contracts that are not flexible in the short run, and the spot producer, who is a price taker and whose sales are flexible. Both producers have the same cost function : producing quantity q costs

$$C(q) = \frac{1}{2}q^2 + bq. \tag{3.3}$$

The spot producer chooses his sales (s) to maximize his current profit, while taking the spot price (p) as given. Accordingly, his sales are determined by the following inverse supply function :

$$p = b + s. \tag{3.4}$$

The spot positions of the suppliers are s_i for the incumbent and s_j for entrant j, where a positive (negative) number is for a buying (selling) position. In particular, the incumbent is allowed to resell a part of his long-term contract on the spot market. The spot market equilibrium is

$$s = s_i + \sum_j s_j. \tag{3.5}$$

The foreign producer signs with the incumbent a long-term contract covering his entire future production before he builds the corresponding capacity. The producer and the incumbent cooperatively choose the contract volume y so as to maximize the joint net surplus generated each period by the contract, which is denoted $V(y)-C(y)$. Each period, the incumbent shall receive y against a lump-sum payment M. Let $\alpha \in [0,1]$ represent the producer's bargaining power. M is adjusted to leave the producer with

$$\Pi_p = M - C(y) = \alpha(V(y) - C(y)), \tag{3.6}$$

therefore

$$M = \alpha V(y) + (1-\alpha)C(y). \tag{3.7}$$

r is the per-period discount rate. The timing is as follows.

Before the market opening

1 The incumbent signs a long-term contract (y_0, M_0) with the foreign producer : he commits to buy each year a volume y_0 against a fixed payment M_0. The producer makes the necessary investment (capacity Y, which cannot be expanded).

2 At the beginning of each period, the incumbent commits to sell z_i to his customers at price p_z. Then he receives y_0 under the long-term contract and he buys an additional volume s_i on the spot market to meet his customers' demand.

Opening of the downstream market to competition

1 The regulator opens the downstream market to competition and, if appropriate, he announces the details of a gas release program.

2 n new suppliers enter the market and incur the fixed entry costs.

3 The incumbent and the foreign producer renegotiate the long-term contract : they sign a new contract (y, M).

4 The entrants choose to participate or not in the gas release program.

5 Each period, all suppliers compete in quantities in the downstream market : the incumbent and entrant j (for $j = 1$ to n) commit to sell z_i and z_j, respectively. The resulting price is p_z.

6 The incumbent receives the long-term contract volume y, if a gas release program is implemented he resells y_j at the gas release price p_r to each participating entrant j, then all suppliers adjust their spot positions (s_i, s_j) to supply their customers according to their commitments.

7 Once the gas release program has expired, the incumbent renegotiates the long-term contract, entrants have no longer access to contract gas and all suppliers compete as before.

2.2 Monopolistic incumbent

Initially, the incumbent is in a monopoly position. After having committed to buy y_0 under the long-term contract he complements these volumes with spot purchases

$s_i = z_i - y_0$ to meet his customers' demand. The incumbent chooses his downstream sales z_i to maximize his profit :

$$\Pi_i = \sum_{t=0}^{\infty} \frac{1}{(1+r)^t} \left((d - z_i - (b + z_i - y_0))z_i + (b + z_i - y_0)y_0 - M_0\right). \tag{3.8}$$

The downstream sales and price are

$$z_i = \frac{d-b}{4} + \frac{y_0}{2}, \tag{3.9}$$

$$p_z = \frac{3d+b}{4} - \frac{y_0}{2}, \tag{3.10}$$

and the incumbent's profit can be expressed as

$$\Pi_i = \frac{1}{r}\left(\frac{(d-b)^2}{8} + \frac{y_0}{2}(d+b-y_0) - M_0\right). \tag{3.11}$$

The second term is the revenue V generated by the long-term contract with the producer :

$$V(y_0) = \frac{y_0}{2}(d+b-y_0). \tag{3.12}$$

The net surplus from the long-term contract has to be shared out among the parties in proportion to their bargaining powers :

$$\Pi_p = \frac{1}{r}\alpha(V(y_0) - C(y_0)), \tag{3.13}$$

$$\Pi_i = \frac{1}{r}\left((1-\alpha)(V(y_0) - C(y_0)) + \frac{(d-b)^2}{8}\right). \tag{3.14}$$

Accordingly, the lump-sum transfer to the producer is

$$M_0 = \frac{y_0}{2}\left(\alpha d + (2-\alpha)b + (1-2\alpha)y_0\right). \tag{3.15}$$

Reasoning backwards, we come to the contract choice : y_0 is chosen by the parties so as to maximize the net surplus generated by the contract $V(y_0) - C(y_0) = \frac{y_0}{2}(d - b - 2y_0)$. The optimal contract volume is

$$y_0 = \frac{d-b}{4}. \tag{3.16}$$

Accordingly, the producer invests $Y = \frac{d-b}{4}$. The transfer to the producer is

$$M_0 = \frac{d-b}{4}\left(\alpha\frac{d-b}{4} + \frac{d+7b}{8}\right). \tag{3.17}$$

The downstream sales and downstream price are

$$z_i = \frac{3(d-b)}{8}, \tag{3.18}$$
$$p_z = \frac{5d+3b}{8}. \tag{3.19}$$

Finally, equilibrium profits are :

$$\Pi_p = \alpha\left(\frac{d-b}{4}\right)^2, \tag{3.20}$$
$$\Pi_i = (3-\alpha)\left(\frac{d-b}{4}\right)^2. \tag{3.21}$$

2.3 Liberalized downstream market

After the downstream market has been opened to competition, n new suppliers enter the market. This change in market conditions allows the incumbent to ask for a renegotiation of the contract, which is modeled simply as the repealing of the previous contract and the signature of a new contract (y, M), where $y \leq Y$. Then all suppliers compete each period in the downstream market, and they use the spot market to meet their customers' demand. In particular, if the volumes obtained by the incumbent under the take-or-pay contract exceed the needs of his downstream customers, he can sell the surplus on spot. We assume that he cannot commit in advance to refuse to sell to his rivals the volumes he does not need : once the downstream market shares for the coming period have been determined it is always profitable for him to sell these quantities on the spot market rather than not taking the volumes that he must anyway pay for.

2.3.1 Downstream sales

In the general case where all suppliers have access (possibly through gas release) to gas from long-term contracts, each supplier k (incumbent or new entrant : $k = i, 1, .., n$) receives a contract volume y_k, and the total contract volume is $y = \sum_k y_k$. At the beginning of each period he chooses his downstream sales z_k to maximize his profit in the coming period, and since the payment for contract gas is sunk, he simply solves

$$\max_{z_k}(p_z - p)z_k + py_k. \tag{3.22}$$

The first-order condition is

$$z_k - y_k = \frac{1}{2}(d - b - z_{-k} + y_{-k}). \tag{3.23}$$

Combining the first-order conditions of all $(n+1)$ suppliers yields the optimal downstream sales of supplier k :

$$z_k = \frac{d-b}{2(n+2)} + \frac{y_k}{2}. \tag{3.24}$$

For each additional unit of contract gas, an additional half unit is sold downstream, and half a unit less (more) is bought (sold, depending on the supplier's net position) in the spot market. Therefore, the mark-up over the spot price $(p_z - p)$ is the same whatever the long-term contract. Accordingly, the revenue from downstream sales and spot transactions in each period can be expressed as the sum of a term that is solely related to spot transactions, and the additional revenue due to long-term contract purchases, which depends on the average of spot and downstream prices :

$$(p_z - p)z_k + py_k = \frac{(d-b)^2}{2(n+2)^2} + \frac{p_z + p}{2}y_k \tag{3.25}$$

$$= \frac{(d-b)^2}{2(n+2)^2} + y_k\frac{d+b-y}{2}. \tag{3.26}$$

In the rest of this section we shall focus on the case where only the incumbent has access to contract gas : $y_i = y$ and $y_j = 0$ for all j.

2.3.2 Long-term contract

The intertemporal profit of the incumbent if no gas release measure is to be expected can be expressed as

$$\Pi_i = \frac{1}{r}\left(\frac{(d-b)^2}{2(n+2)^2} + \frac{y}{2}(d+b-y) - M\right). \tag{3.27}$$

Interestingly, the presence of new suppliers, when they have no access to long-term contracts, does not affect the value of the contract relationship between the incumbent and the producer. Since new entrants simply resell to final consumers the quantities they purchased on spot, the decrease in the downstream price is exactly compensated by an increase in the spot price, so that the average $(p_z + p)/2$ does not depend on n. Therefore, as before, $V(y) = \frac{y}{2}(d + b - y)$, and the contract volume and the corresponding payment remain the same as in the monopoly case :

$$y = \frac{d-b}{4}, \tag{3.28}$$

$$M = \frac{d-b}{4}\left(\alpha\frac{d-b}{4} + \frac{d+7b}{8}\right). \tag{3.29}$$

In other words, entry in itself does not weaken the former monopolist's position when negotiating his long-term contracts, nor does it reduce his incentives to buy gas under long-term contracts. Computing the sales of the suppliers, we see that the incumbent's privileged access to long-term contracts allows him to make more sales than new entrants in the downstream market :

$$z_i = \frac{(n+6)(d-b)}{8(n+2)}, \tag{3.30}$$

$$z_j = \frac{d-b}{2(n+2)}. \tag{3.31}$$

The incumbent is a spot seller ($s_i \leq 0$) if the number of entrants is at least two :

$$s_i = \frac{-(n-2)(d-b)}{8(n+2)}, \tag{3.32}$$

which means that the volume y bought under the long-term contract exceeds the demand of his customers and he sells some of this gas to his rivals in the spot market. The intertemporal profits of the incumbent and of entrant j can be rewritten as

$$\Pi_i = \omega^2\left(\frac{1}{(n+2)^2} + \frac{1-\alpha}{8}\right), \tag{3.33}$$

$$\Pi_j = \frac{\omega^2}{(n+2)^2} - \frac{F}{n}, \tag{3.34}$$

where

$$\omega \equiv \frac{d-b}{\sqrt{2r}}. \tag{3.35}$$

2.3.3 Entry decision

The equilibrium number of entrants with no gas release $\overline{n}$ is the largest integer n such that $\Pi_j \geq 0$, or equivalently

$$\omega^2 \geq \frac{(n+2)^2}{n} F. \tag{3.36}$$

The number of entrants is positive only if the entry cost is sufficiently low :

$$\overline{n} = \left[4 \left(1 - \sqrt{1 - 8\frac{F}{\omega^2}} \right)^{-1} \right] - 2 \text{ if } F < \frac{\omega^2}{8}, \tag{3.37}$$

$$\overline{n} = 0 \text{ if } F \geq \frac{\omega^2}{8}. \tag{3.38}$$

where for any real number x, $[x]$ denotes its integer part. Note that if $\overline{n} > 0$, then it is at least two ($\overline{n} = 1$ never occurs).

2.4 Domestic welfare

The regulator seeks to maximize the domestic welfare, which is defined as the sum of the surplus of the consumers, the profits of all suppliers and the profit of the spot producer, and excluding the profit of the foreign producer. When there is no gas release, the intertemporal domestic welfare from the moment the downstream market is opened to competition is

$$DW = \frac{\omega^2}{2} \left(\frac{21 - 4\alpha}{16} - \frac{1}{(\overline{n}+2)^2} \right) - \hat{F}, \tag{3.39}$$

where $\hat{F} = F$ if $\overline{n} > 0$, else $\hat{F} = 0$. The domestic welfare can also be expressed as

$$DW = \frac{\omega^2}{2} \left(1 - \frac{1}{(\overline{n}+2)^2} \right) - \hat{F} + \frac{y}{r} \left((1-\alpha)\frac{d-b}{2} + \frac{4\alpha - 3}{4} y \right). \tag{3.40}$$

Both the equilibrium contract volume $y = \frac{d-b}{4}$ and the equilibrium number of entrants $\overline{n}$ can differ from the optimum. In fact, as the contract volume does not depend on the number of entrants (see (3.28)), the domestic welfare can be optimized with respect to each variable separately.

Is entry desirable at all ? The domestic welfare is higher with n entrants than under monopoly if and only if

$$\frac{F}{\omega^2} < \frac{1}{8} - \frac{1}{2(n+2)^2}. \tag{3.41}$$

A first consequence is that if $\frac{F}{\omega^2} \geq \frac{1}{8}$, which characterizes the no-entry case ($\overline{n} = 0$), the fixed costs associated to entry are so high that entry is actually not desirable. Now consider the case where $\overline{n} = 2$ or $\overline{n} = 3$ (remember that $\overline{n}$ is never equal to one) : this happens when $\frac{1}{9} < \frac{F}{\omega^2} \leq \frac{1}{8}$. It can easily be checked that the right-hand side in (3.41) is lower than $\frac{F}{\omega^2}$ in the relevant intervals, which means that the domestic welfare would have been higher under monopoly. In effect, to compensate for the fixed cost F that is incurred whatever the number of entrants, the positive impact on downstream competition must be sufficiently large. In fact, whenever $\frac{F}{\omega^2} < \frac{1}{8}$, the domestic welfare would be maximized with an infinite number of entrants. In other words, whenever the fixed cost is small enough for some entry to take place even with no regulatory intervention, the regulator should promote entry, but only provided he can attract a sufficiently large number of entrants.

Now let us focus on the contract volume. Absent any regulatory intervention, the volume of the long-term contract can be inefficiently low, but it can also be inefficiently high, depending on the foreign producer's bargaining power. In effect, the optimal contract volume (obtained by maximizing DW with respect to y) would be $y = \frac{1-\alpha}{3-2\alpha}(d-b)$, whereas the equilibrium is $y = \frac{d-b}{4}$. Accordingly, if the producer has more bargaining power than the incumbent ($\alpha > 1/2$), the equilibrium contract volume is larger than the optimum, and vice versa. Intuitively, if the foreign producer gets most of the joint surplus, it would be preferable to have the incumbent buy less from him and more from the domestic spot producer.

3 Model with gas release

The inability for entrants to have access to gas under long-term contracts impedes them to compete on equal terms with the incumbent, which can lead to insufficient entry if no additional measure is taken when the market is opened to competition. To attract more entrants (which we assume to be desirable), the regulator can decide to implement a gas release program, under which the incumbent will have to resell a fraction of the volumes purchased under the long-term contract.

The main characteristics of the program are its duration, the proportion of contract volumes involved and the price paid to the incumbent. The regulator can optimize the program with respect to all three parameters. However, there seems to be no consensus on the optimal design. The European Federation of Energy Traders (EFET, 2003) considers that a gas release program can be successful only if the gas release price is low enough : "as a guide, the price must not be higher than the average price paid by the incumbent (...). [It] must not be higher than that offered in the wholesale market, even if this implies a financial loss to the incumbent." Conversely, the French union of private gas companies UPRIGAZ (2004) expressed the view that the mechanism should be "financially neutral for the incumbent." As for the quantities involved, EFET considers that the volumes released need to be significant compared with the incumbent's portfolio size, whereas the relevant criterion for UPRIGAZ is the market share of new entrants, which should attain at least $20-25\%$ as a result of the gas release. In their opinion, the program should not last too long, so that entrants are incited to find other sourcing possibilities.

Real-world gas release programs, as described in Appendix 1, have involved relatively small volumes for a short duration, and different designs have been used to determine the price. A first option for the regulator is to use an auction mechanism, as was done in most of the recent gas release programs. A second option is to commit in advance to the price that shall be paid by the entrants to the incumbent for the released volumes. Finally, a third option is to set the gas release price equal to price paid by the incumbent under the long-term contract, so that at first sight, the program is "cost neutral" for him (this design was chosen in England in 1992 and in Spain in 2001) : in other words, the regulator commits to adjust the gas release price p_r to the incumbent's average purchasing cost of contract gas M/y, which is (or at least could be) observed *ex post*.

This section presents the equilibrium outcome for a given gas release scheme and the social optimum, and finally it briefly comments on the use of gas release auctions.

3.1 Resolution in the general case

After expiry of the gas release program, the producer and the incumbent are placed in the same situation as in the case with no gas release, except that there are more entrants : the contract renegotiation obviously leads them to choose $y^{exp} = (d-b)/4$, with the same lump-sum payment M as in (3.29). From this moment on, the intertemporal profits of the incumbent and of entrant j are

$$\Pi_i^{exp} = \omega^2 \left(\frac{1}{(n+2)^2} + \frac{1-\alpha}{8} \right), \tag{3.42}$$

$$\Pi_j^{exp} = \frac{\omega^2}{(n+2)^2}. \tag{3.43}$$

Solving backwards, we come to the analysis of the gas release program. The incumbent resells a volume y_j to each entrant j ($j = 1$ to n) and he is left with $y_i = y - \sum_j y_j$. The downstream sales of the suppliers are given by (3.24). As a result, the intertemporal profit of the incumbent at the beginning of the program is

$$\begin{aligned} \Pi_i &= \frac{\tau}{r}((p_z - p)z_i + py_i + p_r \sum_j y_j - M) + (1-\tau)\Pi_i^{exp} & (3.44) \\ &= \frac{\omega^2}{(n+2)^2} + \frac{\tau}{r} \left(\frac{y_i}{2}(d+b-y) + p_r \sum_j y_j - M \right) + (1-\tau)\frac{(1-\alpha)\omega^2}{8}. & (3.45) \end{aligned}$$

where

$$\tau \equiv 1 - (1+r)^{-T}. \tag{3.46}$$

Now we come to the entrants' choice to participate or not in the gas release program. Since the incumbent is committed to buying y under the long-term take-or-pay contract, the entrants know that whether they participate or not in the gas release program, the volume y will be sold to downstream customers and total downstream sales will be :

$$z_i + \sum_j z_j = \frac{n+1}{2(n+2)}(d-b) + \frac{y}{2}. \tag{3.47}$$

As a consequence, neither the spot price p, nor the downstream price p_z depend on their participation in the program.

The profit of entrant j is

$$\Pi_j = \frac{\tau}{r}((p_z - p)z_j - (p_r - p)y_j) + (1-\tau)\Pi_j^{exp} - \frac{F}{n} \tag{3.48}$$
$$= \frac{\omega^2}{(n+2)^2} + \frac{\tau}{r}(\frac{d+b-y}{2} - p_r)y_j - \frac{F}{n}. \tag{3.49}$$

Entrant j will participate in the gas release program whenever

$$p_r \leq \frac{d+b-y}{2}, \tag{3.50}$$

or equivalently, $p_r \leq (p_z + p)/2$: the gas release price must not exceed the average of the spot and downstream prices. The right-hand side of (3.50) is unaffected by the participation choice. As a consequence, depending on the level of the gas release price, either all entrants are willing to participate in the gas release program and they buy the entire quantity offered for sale, or they buy nothing. In case they choose to participate we assume that each of them obtains an equal share of the released volume :

$$y_j = \frac{\beta y}{n} \text{ for all } j,\ j = 1 \text{ to } n. \tag{3.51}$$

In this case, the profit of the incumbent can be rewritten as

$$\Pi_i = \frac{\omega^2}{(n+2)^2} + \frac{\tau}{r}\left(((1-\beta)\frac{d+b-y}{2} + \beta p_r)y - M\right) + (1-\tau)\frac{(1-\alpha)\omega^2}{8} \tag{3.52}$$

The contract-related revenue is the sum of the revenues from downstream sales and from gas release :

$$V(y) = \frac{p_z + p}{2}y_i + p_r(y - y_i) \tag{3.53}$$
$$= ((1-\beta)\frac{d+b-y}{2} + \beta p_r)y, \tag{3.54}$$

therefore the transfer to the foreign producer is

$$M = y\left(\alpha(1-\beta)\frac{d+b-y}{2} + \alpha\beta p_r + (1-\alpha)(\frac{y}{2} + b)\right), \tag{3.55}$$

and finally the incumbent's profit is

$$\begin{aligned}\Pi_i &= \frac{\omega^2}{(n+2)^2} + \frac{\tau}{r}(1-\alpha)y\left((1-\beta)\frac{d+b-y}{2} + \beta p_r - \frac{y}{2} - b\right) \\ &\quad +(1-\tau)\frac{(1-\alpha)\omega^2}{8}. \qquad (3.56)\end{aligned}$$

3.2 Domestic welfare

When the gas release program expires, the domestic welfare is the same as in the case with no gas release, except that there are now n entrants, and all entry costs are sunk :

$$DW^{exp} = \frac{\omega^2}{2}\left(\frac{21-4\alpha}{16} - \frac{1}{(n+2)^2}\right). \qquad (3.57)$$

If a gas release program is implemented, the domestic welfare per period dw during the gas release program, once entry costs are sunk, is

$$dw = \left(1 - \frac{1}{(n+2)^2}\right)\frac{(d-b)^2}{4} + Q, \qquad (3.58)$$

where Q depends on the long-term contract volume :

$$Q \equiv y\left((1-\alpha)\frac{d-b-2y}{2} + \alpha\beta\left(\frac{d+b-y}{2} - p_r\right) + \frac{y}{4}\right). \qquad (3.59)$$

The first two terms in brackets correspond to the effect of contract gas on the profits of all suppliers. The first term is the incumbent's share of the contract-related revenue when there is no gas release. The second term is related to the gas release program, which is not a pure transfer between the incumbent and the entrants. In effect, since the foreign producer shares the contract revenues with the incumbent in proportion to his bargaining power α, he will compensate for the incumbent's possible losses by adjusting the lump-sum payment downwards, so that the larger α, the larger is the net domestic surplus stemming from the gas release program. Finally, the third term is the global positive effect of the long-term contract on the sum of the domestic producer's profit and the surplus of consumers. The intertemporal domestic welfare computed at the date when the program begins is

$$DW = \frac{\tau}{r}dw + (1-\tau)DW^{exp} - \hat{F} \tag{3.60}$$

$$= \frac{\tau}{r}Q + \frac{\omega^2}{2}\left(1 - \frac{1}{(n+2)^2} + \frac{(1-\tau)(5-4\alpha)}{16}\right) - \hat{F}. \tag{3.61}$$

It is a sum of three terms. The first term, proportional to Q, corresponds to the temporary effect of the gas release program on the contract volume ; this expression does not depend on n. The second term is related to the long-term impact of the program on the intensity of competition in the downstream market ; it increases with the number of entrants, but it does not depend on y. The last term is the sum of the entry costs of the n new suppliers.

A gas release program has two objectives : optimizing the volume of the long-term contract in the short run (as long as the program is in force), and optimizing the number of entrants. We shall prove later that, as in the case with no gas release, the contract volume y chosen by the parties does not depend on the number of entrants. Therefore, the optimal number of entrants and the optimal contract volume can be computed separately.

The regulator compares the outcome of the downstream market liberalization with the optimal outcome. A regulatory intervention can be desirable if the equilibrium number of entrants absent any gas release measure ($\overline{n}$, given by (3.37)) is lower than the optimum. As explained before, this is not the case when $F/\omega^2 \geq 1/8$ (there is no entry, but inducing entry would not increase the domestic welfare), whereas it is the case when $F/\omega^2 < 1/8$: with no intervention there would be some entry, but it would be insufficient, and an intervention is beneficial provided it attracts enough entrants.

Finally, a regulatory intervention that succeeds in increasing the number of entrants does not necessarily improve the domestic welfare. In effect, it could change the incentives of the incumbent and the foreign producer and result in an inefficient renegotiation of the long-term contract for the period where the gas release program is implemented (remember, however, that after expiry of the program the contract is renegotiated again). The contract volume could be too high or too low, and the bargaining position of the domestic incumbent could be affected. This effect could be significant if the program lasts for a long time.

3.3 Gas release auctions

Suppose the gas release program is organized as an ascending-clock auction with no reserve price as in the recent gas release programs subsequent to mergers (see Appendix 1) or any other mechanism that succeeds in maximizing the seller's revenue. Auctions where bidders are competitors are often complex to analyze because the bidders' valuations for the good that is sold are usually not independent from each other : a bidder typically expects his rivals to compete more aggressively when they obtain a large quantity of the good (see Ausubel, 2004). However, this difficulty does not arise in our model. As explained before, due to the incumbent's commitment under the long-term take-or-pay contract, there is no externality between the bidders : whether sold by new entrants or by the incumbent, the volume y will be brought to the market and the downstream price will be the same in any case. From (3.50), the entrants are willing to buy contract gas as long as $p_r \leq (d+b-y)/2$, therefore they will all bid for the entire volume that is offered as long as the gas release price is below this threshold, then they will drop out. In the end, each of them will obtain a quantity $\beta y/n$ at price $p_r = (d+b-y)/2$.

The renegotiation of the long-term contract, which is assumed to occur before the auction takes place, appears to be unnecessary. In effect, since the buyers' surplus is entirely extracted by the seller, the incumbent's profit is identical to the case without gas release (see (3.27)). Gas release auctions do not change the incentives of the incumbent and the foreign producer when they negotiate the long-term contract. The equilibrium contract volume is again $y = \frac{d-b}{4}$ and the lump-sum transfer is unchanged. The gas release price is

$$p_r = \frac{3d+5b}{8}. \tag{3.62}$$

Note that the gas release price is always higher than the incumbent's average purchasing cost of contract volumes ($p_r - \frac{M}{y} = (1-\alpha)\frac{d-b}{4}$) : the gas release program is profitable for the incumbent and a reserve price to prevent him from making losses is not needed.

Since the gas release price is equal to the entrants' willingness to pay, they make no more profit than without gas release. Anticipating this, no new firm will decide to enter the market after the gas release program is announced. As a result, this program has no effect on entry.

The only impact of β is on market shares. The entrants' combined market share in the period where the gas release program is implemented increases with β :

$$\frac{\Sigma z_j}{z_i + \Sigma z_j} = \frac{4n + \beta(n+2)}{5n+6}. \tag{3.63}$$

However, even if the market shares of the entrants increase, their additional profits are captured by the incumbent at the auction stage. The rebalancing of the suppliers' market positions is only apparent. To conclude, revenue-maximizing gas release auctions, due to the very fact that they leave the buyers with no rent, have no positive effect whatsoever on domestic welfare : both the long-term contract characteristics and the number of entrants are left unchanged.

4 Ex ante regulation

Now assume that the regulator optimizes the program with respect to all three available instruments (β, T and p_r).

4.1 Equilibrium for a given gas release scheme

4.1.1 Long-term contract

Once entry has taken place, the incumbent and the producer choose y (so that it does not exceed the installed capacity : $0 \leq y \leq (d-b)/4$) to maximize their joint surplus, taking β, T and p_r as given. Since they can always renegotiate the contract when the gas release program expires, they simply maximize the joint surplus per period during the gas release program (see (3.54)) :

$$V(y) - C(y) = y\left((1-\beta)\frac{d+b-y}{2} + \beta p_r - \frac{y}{2} - b\right), \tag{3.64}$$

and they choose

$$y = \min\left(\frac{d-b}{4}, \max(\frac{d-b}{4} - \frac{\beta}{2-\beta}(\frac{d+3b}{4} - p_r), 0)\right). \tag{3.65}$$

The number of entrants has no impact on the volume of the long-term contract. If $p_r \geq \frac{d+3b}{4}$, $y = \frac{d-b}{4}$ and from condition (3.50) the entrants participate in the gas release program if and only if $p_r \leq \frac{3d+5b}{8}$. If $p_r \leq \frac{d+3b}{4}$, the entrants' participation condition can be rewritten as

$$p_r \leq \frac{3d+5b}{8} + \frac{\beta}{2(2-\beta)}(\frac{d+3b}{4} - p_r), \tag{3.66}$$

which is always satisfied. To summarize,

if $p_r \leq \frac{d+3b}{4}$, the entrants participate in the gas release program and y is

$$y = \max\left(\frac{d-b}{4} - \frac{\beta}{2-\beta}\frac{d+3b}{4} - p_r, 0\right); \tag{3.67}$$

if $\frac{d+3b}{4} \leq p_r \leq \frac{3d+5b}{8}$, the entrants participate and $y = \frac{d-b}{4}$;

if $p_r > \frac{3d+5b}{8}$, the entrants do not participate and $y = \frac{d-b}{4}$.

4.1.2 Entry decision

The profit of entrant j if he participates in the gas release program (in which case he obtains $y_j = \beta y/n$), is :

$$\Pi_j = \frac{\tau}{r}\frac{\beta y}{n}(\frac{d+b-y}{2} - p_r) + \frac{\omega^2}{(n+2)^2} - \frac{F}{n} \tag{3.68}$$

where y is given by (3.65). The equilibrium number of entrants is the largest integer n such that $\Pi_j \geq 0$. This number is a non-decreasing function of T, because an entrant can never be worse off under a gas release program than after its expiry : if the gas release conditions were not attractive enough he would have declined the offer to participate and all the other entrants would have done so. The impact of p_r is more complex : on the one hand, a cheaper gas release price means higher profits for the entrants, but on the other hand, a high price gives better incentives to the the incumbent to buy long-term contracts, which means larger gas release volumes for the entrants.

4.2 Optimal *ex ante* gas release scheme

The regulator chooses β, T and p_r to maximize the domestic surplus :

$$DW = \frac{\tau}{r}Q + \frac{\omega^2}{2}\left(1 - \frac{1}{(n+2)^2} + \frac{(1-\tau)(5-4\alpha)}{16}\right) - \hat{F}, \tag{3.69}$$

where Q is given by (3.59). As explained before, the regulator's global objective (maximizing the domestic welfare) can be decomposed into two secondary objectives : increasing the number of entrants and obtaining sufficient volumes of gas under the long-term contract at a favorable price. At first sight these objectives seem conflicting because a low gas release price and a large gas release proportion are supposedly good for entry but might depress imports under the long-term contract. But actually, fostering entry does not require setting the smallest possible p_r : if the incumbent and the foreign producer were completely discouraged from signing a long-term contract, new entrants would have nothing to buy under the gas release program. The regulator must be careful to give the incumbent good incentives to buy gas from the foreign producer as he is the only supplier to be able to do so. What simplifies the problem is that although y is readjusted after the entry of new suppliers, it does not depend on n. The two objectives of increasing n and maximizing Q can therefore be analyzed separately. But first, a general result can be stated :

Lemma 3.1. *The optimal p_r is necessarily such that $p_r \leq \frac{d+3b}{4}$.*

In effect, if the gas release price exceeded $\frac{d+3b}{4}$, a slight reduction in p_r would leave the contract volume at its maximum level $y = \frac{d-b}{4}$, and it would increase both Q and n. Consquently, the contract volume is given by (3.67) :

$$y = \max\left(\frac{d-b}{4} - \frac{\beta}{2-\beta}(\frac{d+3b}{4} - p_r), 0\right). \tag{3.70}$$

4.2.1 Maximizing the number of entrants

First we concentrate on the objective of inducing new entry ; we assume that entry is desirable, *i. e.* $F/\omega^2 < \frac{1}{8}$. We shall prove that the gas release parameters that maximize the number of entrants adversely affect contract volumes. The intertemporal profit of entrant j is

$$\Pi_j = \frac{\omega^2}{(n+2)^2} + \frac{\tau}{r}\frac{\beta y}{n}(\frac{d+b-y}{2} - p_r) - \frac{F}{n}. \tag{3.71}$$

Since the entrants' participation condition requires $p_r < (d+b-y)/2$, it is immediate that the entry-maximizing duration and proportion of gas release are $T = \infty$ and $\beta = 1$. This means forcing the incumbent to resell the entire volume of the long-term contract to new entrants, at a price p_r that he will take as given. In this case, the producer and the incumbent will choose the contract volume so that the marginal cost of production $b + y$ equals p_r : equation (3.65) becomes $y = p_r - b$, which allows us to compute the optimal gas release price.

Proposition 3.1. *When the gas release price is determined* ex ante *the number of entrants is maximum when*

$$\beta = 1, \tag{3.72}$$

$$\tau = 1, \tag{3.73}$$

$$p_r = \frac{d+5b}{6}. \tag{3.74}$$

Is this gas release price higher than the average cost of gas under the long-term contract ? Since the cost function is convex, p_r, which equals the marginal cost of production, is higher than the average cost of production. The long-term contract therefore generates a surplus that is shared between the parties through an adequate transfer M, leaving both of them with a positive surplus. As a consequence, the incumbent makes profits, on average, on the units sold under the gas release program.

The contract volume and Q are, respectively :

$$y = \frac{d-b}{6}, \tag{3.75}$$

$$Q = (9-2\alpha)\frac{(d-b)^2}{144}. \tag{3.76}$$

The gas release program causes a reduction in contract volumes, but this is not necessarily bad news. In effect, without gas release $Q = (5-4\alpha)\frac{(d-b)^2}{64}$ (see (3.59)). If the bargaining power of the foreign producer is sufficiently high ($\alpha > \frac{9}{28} \approx 0.32$), the impact on Q is actually positive.

The number of entrants $\hat{n}$ is the highest integer satisfying $\Pi_j \geq 0$ if such an integer exists, else $\hat{n} = 0$. The profit of entrant j is :

$$\Pi_j = \omega^2 \left(\frac{1}{(n+2)^2} + \frac{\tau}{12n} \right) - \frac{F}{n}. \tag{3.77}$$

If $\frac{F}{\omega^2} \leq \frac{\tau}{12}$, $\hat{n}$ is infinite. If $\frac{F}{\omega^2} > \frac{\tau}{12}$, $\hat{n}$ is strictly positive and finite :

$$\hat{n} = \left[4 \left(1 - \sqrt{1 + \frac{2\tau}{3} - 8\frac{F}{\omega^2}} \right)^{-1} \right] - 2. \tag{3.78}$$

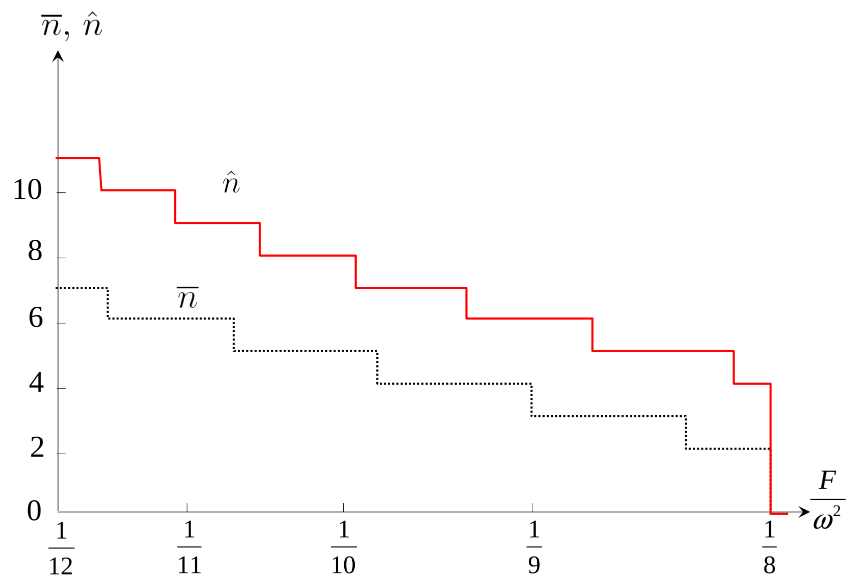

FIG. 3.1: Number of entrants with no gas release ($\overline{n}$) and with a gas release program at a predetermined price, designed to maximize the number of entrants (n), when $\beta = 1$ and $\tau = 0.25$.

For a given gas release program, the positive impact on entry is all the larger as the entry cost is small, which means that the corresponding $\overline{n}$ if there were no gas release would be large : the more entrants with no intervention, the more additional entrants with the gas release measure. To illustrate, consider the case where $\beta = 1$ and $\tau = 0.25$

(for example, $r = 0.05$ and T is around 6 years). As can be seen from figure 3.1, when the number of entrants with no gas release $\overline{n}$ is at most 7 the gas release program typically attracts no more than 3 or 4 additional suppliers.

Finally, the domestic welfare when $\beta = 1$ is

$$DW = \frac{\omega^2}{2}\left(1 - \frac{1}{(n+2)^2} + \frac{(1-\tau)(5-4\alpha)}{16} + \frac{\tau(9-2\alpha)}{36}\right) - \hat{F}. \tag{3.79}$$

Now suppose that for some reason it is not possible to implement $\beta = 1$ and the regulator has to restrict the gas release proportion to some lower level β. Injecting the contract volume (3.67) into the profit of entrant j (3.71) and maximizing with respect to p_r allows us to state the following result.

Proposition 3.2. *When p_r is determined* ex ante*, for a given β, the number of entrants is maximum when*

$$p_r = \frac{d+b}{2} - \frac{d-b}{\beta(4-\beta)}. \tag{3.80}$$

Proof 3.1. *See Appendix.*

Paradoxically, this price can be negative if β is sufficiently small (at least below $2-\sqrt{2} \approx 0.59$) : to attract more entrants, if the gas release proportion cannot be very large, the regulator should set a very attractive p_r and even possibly let the incumbent pay the entrants to buy gas from him (however, it would be more efficient to set a higher β). The long-term contract volume is

$$y = \frac{d-b}{2(4-\beta)}. \tag{3.81}$$

In any case, the contract volume is strictly lower than without gas release (in particular, even when β tends to zero y does not tend to the value of the no-release case because p_r tends to $-\infty$). Note that y increases with β : the more volumes are to be resold to rival suppliers, the more volumes will be bought by the incumbent.

The profit of entrant j when the contract price is given by (3.80) is

$$\Pi_j = \omega^2\left(\frac{1}{(n+2)^2} + \frac{\tau}{4(4-\beta)n}\right) - \frac{F}{n}. \tag{3.82}$$

If $\frac{F}{\omega^2} \leq \frac{\tau}{4(4-\beta)}$, the number of entrants $\hat{n}$ is infinite. If $\frac{F}{\omega^2} > \frac{\tau}{4(4-\beta)}$, it is

$$\hat{n} = \left[4 \left(1 - \sqrt{1 + \frac{2\tau}{4-\beta} - 8\frac{F}{\omega^2}} \right)^{-1} \right] - 2. \tag{3.83}$$

Strikingly, even with a small gas release proportion such as $\beta = 0.1$ the number of additional entrants is not much smaller than when $\beta = 1$; however, this implies setting a negative p_r, which is probably impossible to implement.

4.2.2 Optimizing the long-term contract

Now we determine the parameters that optimize the long-term contract, *i.e.* maximize Q. First, let us determine the optimal gas release price for a given gas release proportion β.

Proposition 3.3. *When p_r is determined* ex ante*, for a given β, the gas release price that maximizes Q is*

$$p_r = \min\left(b + \frac{(1+\beta-2\alpha(1-\beta)(2-\beta))}{\beta(3+2\alpha(2-\beta))}\frac{d-b}{2}, \frac{d+3b}{4} \right). \tag{3.84}$$

This price is always higher than the value of p_r that maximized entry (see (3.80)). The corresponding contract volume is

$$y = \min\left(\frac{d-b}{3+2\alpha(2-\beta)}, \frac{d-b}{4} \right). \tag{3.85}$$

The optimal gas release price decreases with α : if the foreign producer receives a large share of the contract-related surplus, the regulator will favor new entrants by setting a low gas release price, even if it implies a reduction in the contract volume.

The value of p_r that maximizes Q does not depend on τ because the contract volume can always be renegotiated after expiry of the gas release program. It depends on β. A low p_r and a high β both tend to depress y; whether this is problematic depends on the share of the contract-related surplus that is extracted by the foreign producer. If $\alpha \leq \frac{1}{4}$, a large contract volume is desirable because a significant share of this surplus goes to the incumbent, therefore the regulator will set p_r so as to maintain y at his maximum level

$y = \frac{d-b}{4}$. If $\alpha > \frac{1}{4}$, a smaller value of y could be preferable. If for some reason only small values of β can be chosen, the importer is tempted to buy large contract volumes, and to prevent him from doing so the regulator should set a small p_r, possibly even negative.

To summarize, for a given β,

$$Q = \frac{(d-b)^2}{4(3+2\alpha(2-\beta))} \text{ if } \beta \leq 2 - \frac{1}{2\alpha}, \tag{3.86}$$

$$Q = \frac{(5-2\alpha(2-\beta))(d-b)^2}{64} \text{ if } \beta \geq 2 - \frac{1}{2\alpha}. \tag{3.87}$$

Proposition 3.4. *When p_r is determined* ex ante, *Q is maximal when the gas release proportion is $\beta = 1$. The optimal choice of p_r depends on the foreign producer's bargaining power, as summarized in Table 3.1.*

α	p_r	y	Q
$\alpha \leq \frac{1}{2}$	$\frac{d+3b}{4}$	$\frac{d-b}{4}$	$\frac{(5-2\alpha)(d-b)^2}{64}$
$\alpha \geq \frac{1}{2}$	$b + \frac{d-b}{3+2\alpha}$	$\frac{d-b}{3+2\alpha}$	$\frac{(d-b)^2}{4(3+2\alpha)}$

TAB. 3.1: Optimal choice of p_r to maximize Q, with corresponding values of y and Q.

Proof 3.2. *See Appendix.*

Accordingly,

$$DW = \frac{\omega^2}{2}\left(1 - \frac{1}{(n+2)^2} + \frac{5-4\alpha+2\tau\alpha}{16}\right) - F \text{ if } \alpha \leq \frac{1}{2}, \tag{3.88}$$

$$DW = \frac{\omega^2}{2}\left(1 - \frac{1}{(n+2)^2} + \frac{(1-\tau)(5-4\alpha)}{16} + \frac{\tau}{3+2\alpha}\right) - F \text{ if } \alpha \geq \frac{1}{2}. \tag{3.89}$$

Finally, since n is weakly increasing in T, the domestic welfare increases with T : the optimal duration of the gas release program is infinite ($\tau = 1$).

Of course, the profit of entrant j is lower than in the case where the regulator maximized n but higher than without gas release :

$$\Pi_j = \omega^2 \left(\frac{1}{(n+2)^2} + \frac{1}{16n} \right) - \frac{F}{n} \text{ if } \alpha \leq \frac{1}{2}, \tag{3.90}$$

$$\Pi_j = \omega^2 \left(\frac{1}{(n+2)^2} + \frac{1}{n(3+2\alpha)^2} \right) - \frac{F}{n} \text{ if } \alpha \geq \frac{1}{2}. \tag{3.91}$$

4.2.3 Summary of results

Whether the regulator focuses on the objective of inducing entry or on optimizing the long-term contract, the optimum always requires that the entire contract volume be resold to the entrants ($\beta = 1$) for the longest possible time ($T = \infty$). As to the optimal gas release price, however, there is no common optimum. To maximize the number of entrants the regulator will set a low gas release price that depresses long-term contract volumes. To maximize Q, the optimal scheme depends on the respective bargaining powers of the incumbent and the foreign producer : if the incumbent receives a large share of their joint surplus the regulator will give the priority to maintaining the contract volume, whereas in the opposite case Q will give more weight to the profits of new entrants and the regulator will set a low gas release price.

What is the global optimum when p_r is set *ex ante* ? When $\beta = 1$ and $\tau = 1$ the optimal gas release price will satisfy $\frac{d+5b}{6} \leq p_r \leq \frac{d+3b}{4}$. Depending on the foreign producer's bargaining power, the optimal price implies either slightly reducing, either maintaining the volume of long-term contracts. With this price, the incumbent makes profits on the units resold under the gas release program. When the gas release program has to be more limited in duration, strikingly, the optimal gas release price does not change : reducing p_r would not foster entry because the volume to be released would be jeopardized. Finally, when the gas release proportion cannot be as large as $\beta = 1$, the gas release price should generally be reduced, especially if the foreign producer's bargaining power is large : on the one hand, setting a low p_r is a means to attract entrants in spite of a small gas release proportion, and on the other hand, it leads the incumbent to switch to domestic spot supplies.

5 Gas release at a price that is adjusted to purchasing costs

5.1 Equilibrium in the *adjusted* design

In this section we assume that the regulator announces in advance the value of β and commits to adjust *ex post* the gas release price so that it will be exactly equal to the average cost of quantities purchased by the incumbent under the long-term contract : $p_r = M/y$. A first, striking result is that whatever β, the contract volume will remain unchanged with respect to the case $\beta = 0$ (no gas release). To see why, let us compute the net surplus from the contract, which is the sum of the net surplus from the incumbent's downstream sales and the net surplus from gas release. When $p_r = M/y$, it can be expressed as

$$V(y) - C(y) = (\frac{p_z + p}{2} - \frac{C(y)}{y})y_i + (p_r - \frac{C(y)}{y})(y - y_i) \quad (3.92)$$

$$= (\frac{p_z + p}{2} - \frac{C(y)}{y})(1 - \beta)y + \beta(M - C(y)). \quad (3.93)$$

Since M is adjusted so that the producer's profit is equal to a share α of the contract-related surplus, $M - C(y) = \alpha\,(V(y) - C(y))$: the surplus generated by gas release sales is proportional to the total contract-related surplus, so that

$$V(y) - C(y) = \frac{1 - \beta}{1 - \alpha\beta}(\frac{p_z + p}{2} - \frac{C(y)}{y})y. \quad (3.94)$$

Clearly, the optimal contract volume does not depend on β :

$$y = \frac{d - b}{4}. \quad (3.95)$$

This allows us to compute the lump-sum payment to the producer, which is all the larger as α is large (the producer gets a large share of the surplus) and β is small (the surplus is not too much affected by the gas release measure) :

$$M = \frac{(3d + 5b)(d - b)}{32} - \frac{1 - \alpha}{1 - \alpha\beta}\frac{(d - b)^2}{16}. \quad (3.96)$$

This is also true for the adjusted gas release price p_r :

$$p_r = b + \left(\frac{3}{2} - \frac{1-\alpha}{1-\alpha\beta}\right)\frac{d-b}{4}. \tag{3.97}$$

Since y is unchanged whatever β, the number of entrants always increases with β : a larger β means more gas release quantities, and at the same time a lower price for these quantities. As for Q, it is also an increasing function of β and a decreasing function of p_r (see (3.59)). Therefore, the domestic welfare always increases with the gas release proportion.

Proposition 3.5. *When the gas release price is adjusted to the average cost of quantities purchased under the long-term contract, the optimal gas release proportion is*

$$\beta = 1. \tag{3.98}$$

The resulting equilibrium gas release price is

$$p_r = \frac{d+7b}{8}. \tag{3.99}$$

This gas release price is equal to the average production cost of contract gas (recall that $C(y)/y = b + \frac{y}{2}$). In other words, the entire contract volume is resold at its average production cost, so that the contract-related surplus (and the foreign producer's profit) is zero. To understand why, remember that the foreign producer has to adjust the transfer M to leave the incumbent with a share $1-\alpha$ of the contract surplus, which is equivalent to maintaining the following equality :

$$(1-\beta)y(\frac{p_z+p}{2} - \frac{M}{y}) = (1-\alpha)\left((1-\beta)y(\frac{p_z+p}{2} - \frac{M}{y}) + M - C(y)\right), \tag{3.100}$$

where the left-hand side is the incumbent's contract revenue when $p_r = M/y$, *i. e.* the revenue from downstream sales only. If the regulator increases β, the incumbent's revenue falls because his downstream sales volume decreases. But he should bear only a share α of this loss, therefore the producer has to require a smaller M. The larger β, the smaller the lump-sum transfer, until M falls down to the production cost when $\beta = 1$.

The resulting value of Q is

$$Q = \frac{5}{64}(d-b)^2, \tag{3.101}$$

and the profit of entrant j is

$$\Pi_j = \omega^2 \left(\frac{1}{(n+2)^2} + \frac{\tau}{8n} \right) - \frac{F}{n}. \tag{3.102}$$

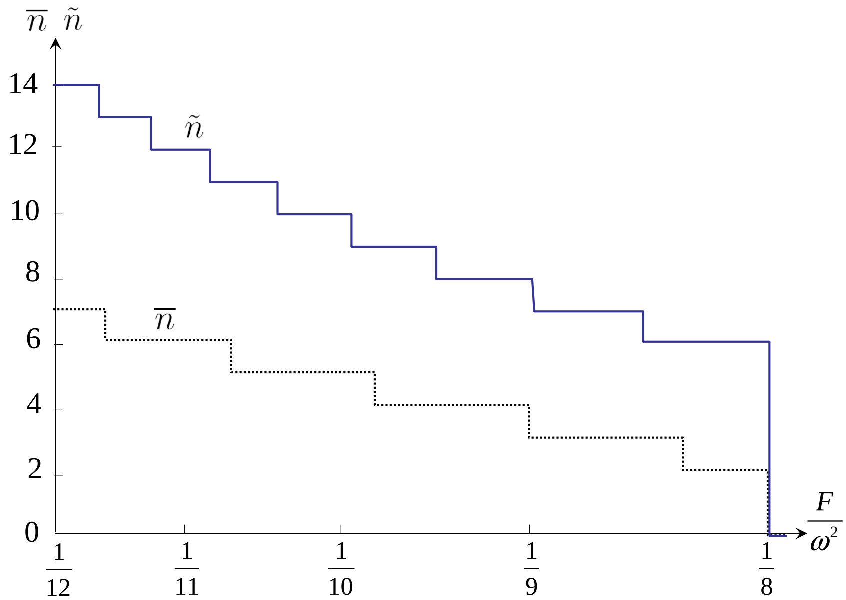

FIG. 3.2: Number of entrants with no gas release program ($\overline{n}$) and after a program where the price is adjusted to the incumbent's purchasing costs ($\tilde{n}$), when $\beta = 1$ and $\tau = 0.25$.

The equilibrium number of entrants $\tilde{n}$ is such that $\Pi_j \geq 0$ when $n = \tilde{n}$ and $\Pi_j < 0$ when $n = \tilde{n} + 1$. :

$$\tilde{n} = \left[4 \left(1 - \sqrt{1 + \tau - 8\frac{F}{\omega^2}} \right)^{-1} \right] - 2. \tag{3.103}$$

The intertemporal domestic welfare is

$$DW \quad = \quad \frac{\omega^2}{2} \left(\frac{21 - 4(1-\tau)\alpha}{16} - \frac{1}{(\tilde{n}+2)^2} \right) - F. \tag{3.104}$$

The term $4(1-\tau)\alpha$ has an interesting interpretation : an increase in τ (gas release duration) has the same positive effect on the domestic welfare as would have a decrease in the foreign producer's bargaining power α in a context with no gas release. To put it differently, in addition to its positive long-term effect on entry (increase in n) such a gas release program is a means to curb the foreign producer's bargaining power in the short run (during the program) and to transfer the contract-related surplus to domestic suppliers and consumers. The optimal duration is unlimited : if the gas release measure is permanent, $\tau = 1$, which is equivalent to a full annihilation of the producer's bargaining power (he is left with just enough to cover his production costs).

This gas release programme implies a transfer of profits from the incumbent to new entrants. The effect of β on the suppliers' profits per period during the program (denoted π_i, π_j) is clear :

$$\pi_i = \left(\frac{1}{2(n+2)^2} + \frac{(1-\alpha)(1-\beta)}{16(1-\alpha\beta)}\right)(d-b)^2, \tag{3.105}$$

$$\pi_j = \left(\frac{1}{2(n+2)^2} + \frac{(1-\alpha)\beta}{16n(1-\alpha\beta)}\right)(d-b)^2. \tag{3.106}$$

But globally, β has a direct, positive impact on the sum of the suppliers' profits (apart from its indirect impact through its possible impact on n) :

$$\pi_i + \Sigma_j \pi_j = \left(\frac{n+1}{2(n+2)^2} + \frac{1-\alpha}{16(1-\alpha\beta)}\right)(d-b)^2. \tag{3.107}$$

This is due to a transfer of profits from the foreign producer to the downstream industry. This positive impact is all the larger as α is high : when the incumbent has anyway a small share of the contract-related surplus, forcing him to resell all the contract volumes at their purchasing cost does not harm him much, whereas this measure is extremely beneficial for new entrants.

However, observing a short-term increase in new entrants' profits or market shares is not necessarily indicative of a long-term success : there is no benefit for consumers (even in the short run) unless n increases. In effect, from (3.47), since y is unchanged (whatever β), total downstream sales increase only if n increases, *i. e.* if β is large enough. Consequently, consumers and the spot producer benefit from the measure only if it leads to additional entry.

5.2 Comparison with the *ex ante* design

When $\beta = 1$, the design considered in this section (*adjusted* design) is superior to the *ex ante* design in all respects. The value of Q in the current design (see (3.101)) is always higher than in the case where p_r is determined *ex ante* to maximize Q (see Table 3.1). As regards entry promotion, again, this gas release design with $\beta = 1$ is the most efficient : the profit of an entrant (see (3.102)) is even higher than in the case where p_r is determined *ex ante* to maximize entry (see (3.77)).

When $\beta = 1$ is not possible to implement, the *adjusted* design still preserves the contract volume but the gas release price is now given by (3.97).

Consider the case where α is relatively small : maintaining a significant contract volume is desirable. In this case, remember that unless β has to be very small, the best choice in an *ex ante* design was to set $p_r = \frac{d+3b}{4}$, which maximizes Q and gives fairly good (though not optimal) incentives for entry. With the *adjusted* design,

$$Q = \left(\frac{1}{4} + \frac{1-\alpha}{1-\alpha\beta}\right)\frac{(d-b)^2}{16}. \tag{3.108}$$

This is higher than the corresponding value of Q in the *ex ante* design (see (3.87)) if and only if

$$\alpha(2-\beta) < 1, \tag{3.109}$$

which is always satisfied if $\alpha < \frac{1}{2}$. As for the profit of entrant j, it is

$$\Pi_j = \omega^2\left(\frac{1}{(n+2)^2} + \frac{\tau(1-\alpha)\beta}{8n(1-\alpha\beta)}\right) - \frac{F}{n}, \tag{3.110}$$

which is higher than the corresponding profit in the *ex ante* design we consider (see (3.90)) if and only if the same condition (3.109) is satisfied.

To summarize, even if β cannot be very large, as long as the producer does not have more bargaining power than the incumbent, a gas release design where the price is adjusted *ex post* to the cost of contract gas is preferable because it does not reduce the contract volume and it results in a moderate gas release price.

If α is large, however, the *adjusted* design is not necessarily the best choice. First, in this case, a decrease in the contract volume can be desirable. Second, if the foreign producer's bargaining power is large, he can require a significant transfer from the incumbent, and the gas release price based on this transfer will remain relatively expensive. If the regulator cannot set a high β in compensation, such a gas release program is likely to be less attractive for potential entrants than an *ex ante* scheme. In fact, since in the *adjusted* design the instrument p_r cannot be adjusted downwards in favor of new entrants to compensate for a low gas release proportion, the level of β becomes a crucial element for the success of the program.

6 Conclusion

The opening of the electricity and natural gas markets to competition has required a number of measures to facilitate entry and growth of new suppliers, such as unbundling and third-party access rules. Access to the resource can however remain a problem for new entrants. In electricity, measures such as electricity auctions, virtual power plants or regulated access to base load have been implemented. The issue is more complex for natural gas because most of the gas resource is sold by non-EU producers under long-term contracts with the former national monopolists. This leads to an apparent trade-off between two pillars of the EU energy policy, namely market liberalization and security of supply. European decision-makers are increasingly concerned about their countries' dependency on foreign producers with market power, and they fear that weakening their national champions could lead to strengthening foreign producers at the expense of European suppliers and consumers. The European Commission advocated in a Green Paper on security of supply (European Commission, 2006) the development of a common external energy policy to be able to negotiate on equal terms with the EU's partners, and some even suggested setting up a single buyer that would be in charge of negotiating contracts with producers on behalf of European suppliers. This solution has been criticized (see Finon and Locatelli, 2008), especially because it would mean interfering with commercial deals between private companies. In addition, foreign producers prefer to deal with their traditional partners, and breaking up these relationships is not necessarily efficient.

Our analysis shows that letting the incumbent negotiate the long-term contracts himself is not necessarily a problem if some guarantees are taken so that he cannot use this advantage to remain dominant in the downstream market. Gas release programs that oblige the incumbent to resell at a regulated price a large proportion of the gas purchased from the foreign producer can have a positive effect both on entry of new suppliers in the incumbent's home market and on the terms of the contract negotiated with the producer.

If the regulator is willing to take strong action and let the incumbent resell a large proportion of his long-term contract, a gas release program designed to be "cost-neutral for the incumbent", *i.e.* where the gas release price is adjusted to the average price paid by the incumbent under the long-term contract, is the best choice. In effect, when the gas release proportion β tends to one the producer's rent is eliminated : since the producer must share the contract surplus with the incumbent he cannot require a large payment from him, because the incumbent makes profits only on the limited volumes that are not subject to gas release. In short, such a program enables the regulator to "repatriate" the surplus generated by the long-term contract and to transfer it to new entrants and to consumers.

Such a gas release program can be implemented by creating, within the incumbent firm, a division that specializes in purchasing gas from foreign producers, and regulating the price at which this gas shall be resold on non-discriminatory terms to all suppliers. If the incumbent's supply affiliate is also allowed to buy this gas, then $\beta = \frac{n}{n+1}$, which is close to the optimum $\beta = 1$ and may appear as a fairer rule.

Clearly, $\beta = 1$ does not look like any of the gas release programs observed in practice, which usually involved at most 10% of the incumbent's sales (see Appendix). If the regulator is unwilling to set a large β, it is not possible any more to curb the producer's market power to a significant extent and the optimal choice depends on his bargaining power (α). If α is small, the *adjusted* design described above can still be the best solution, because it preserves the contract volume, and since the payment required by the producer for contract gas cannot be very large, the gas release price based on this payment will be sufficiently low to attract new entrants. However, if the producer's bargainig power is significant and the gas release proportion is small, it is better to set *ex ante* an attractive gas release price, even if it leads the incumbent to reduce the long-term contract volume, because the contract surplus is anyway essentially captured by the producer. In this case, it can be desirable to set a low gas release price, possibly such that the incumbent resells the contract gas at a loss. Finally, gas release auctions cannot be an efficient mechanism to attract new entrants because they enable the incumbent to extract all the surplus from gas release, so that entrants make no more profits than before, and therefore no new supplier will enter the market.

A limit of the present model is the assumption that new entrants will never be able to sign long-term contracts with the foreign producer. Modeling the reasons why the producer would change his mind would clearly necessitate some ad hoc assumptions. What can generally be said is that a trade-off would arise between helping new entrants through attractive conditions of release of the incumbent's long-term contract and requiring efforts from them to acquire their own long-term contracts. This trade-off is well-known in the literature on access to network infrastructure, especially in the field of telecommunications, where the problem can be posed simply in terms of investment costs. According to the "ladder of investment" argument introduced by Cave (2006), a phase of service-based competition allows entrants to gain market share and reduces their costs of investing into new infrastructure, which accelerates the switch to facility-based competition. The problem is that too favorable conditions of access to the incumbent's network could discourage new entrants from building their own infrastructure. The regulator is therefore advised to introduce "sunset clauses" or to adjust access tariffs over time so as to encourage new entrants to "climb the ladder" of infrastructure investment (see Bourreau et al., 2009, for a discussion). Even in the case where the cost of investment decreases as the customer base increases, which advocates for giving new entrants a boost until they have grown enough, the regulator should commit to a time-increasing path for access tariffs (Avenali et al., 2009). This analysis could be transposed to the natural gas market, where a significant market share might be a convincing argument to negotiate a long-term contract with a producer that is reluctant to deal with small entrants lacking credibility. In this case, gas release programs should not be too cheap and should not last forever.

References

Ausubel, Lawrence M. (2004), "An Efficient Ascending-Bid Auction for Multiple Objects," American Economic Review, 94, 5, 1452-1475.

Ausubel, Lawrence M. and Peter Cramton (2009), "Virtual Power Plant Auctions," Working Paper, University of Maryland.

Avenali, Alessandro, Giorgio Matteucci and Pierfrancesco Reverberi (2009), "Dynamic access pricing and investment in alternative infrastructures", International Journal of Industrial Organization, 28, 2, 176-190.

Bourreau, Marc, Pinar Dogan and Matthieu Manant (2009), "A Critical Review of the 'Ladder of Investment' Approach", Telecom ParisTech Working Paper No. ESS-09-06.

Brander, James and Barbara Spencer (1981), "Tariffs and the Extraction of Foreign Monopoly Rents under Potential Entry", Canadian Journal of Economics, 14, 3, 371-389.

Cavaliere, Alberto (2007), "The Liberalization of Natural Gas Markets : Regulatory Reform and Competition Failures in Italy", Oxford Institute for Energy Studies, NG 20.

Cavaliere, Alberto (2009), "The Regulation of Access to Gas Storage", A. Creti, ed., The Economics of Natural Gas Storage A European Perspective, Springer Berlin Heidelberg, 55-83.

Cave, Martin (2006), "Encouraging infrastructure competition via the ladder of investment", Telecommunications Policy, 30, 223-237.

Comisión Nacional de Energía (2005), "Spanish Regulator's annual report to the European Commission", available at http ://www.cne.es.

Commission de Régulation de l'Energie (2004), "Les expériences de Gas Release en Europe", available at http ://www.cre.fr.

Conseil de la concurrence (2007), Décision du 10 décembre 2007 relative à des pratiques mises en oeuvre par Electricité de France ('Direct Energie'), 07-D-43.

Council Directive 2004/67/EC of 26 April 2004 concerning measures to safeguard security of natural gas supply, Official Journal L 127 , 29/04/2004, P. 0092 - 0096.

DRI-WEFA (2001), "Report for the European Commission : results from opening the gas market",Volume I, European Overview, report made for the Directorate General for Transport and Energy, July 2001.

EFET (2003), "Implementation of Gas Release Programmes", position paper of the European Federation of Energy Traders, June 2003, available at http ://www.efet.org.

European Commission (2005), Decision of 21 December 2005 declaring a concentration to be compatible with the common market and the EEA agreement, Case No COMP/M.3696 - E.ON/MOL.

European Commission (2006), Green paper "A European Strategy for Sustainable, Competitive and Secure Energy", SEC(2006) 317, Brussels, 8 March 2006, COM(2006) 105 final.

European Commission (2007), DG Competition Inquiry pursuant to Article 17 of Regulation (EC) No 1/2003 into the European gas and electricity sectors (Final Report), SEC(2006) 1724, Brussels, 10 January 2007, COM(2006) 851 final.

European Commission (2008), Commission Staff Working Document accompanying the Second Strategic Energy Review, "Europe's current and future energy position Demand - resources - investments", SEC(2008) 2870, Brussels, 13 November 2008, COM(2008) 781 final.

Finon, Dominique and Catherine Locatelli (2008), "Russian and European Gas Interdependence : Can Market Forces Balance Out Geopolitics ?," Energy Policy, 36, 1, 423-442.

Jehiel, Philippe and Benny Moldovanu (2001), "Auctions with downstream interaction among buyers", The RAND Journal of Economics, 31, 4,768-791.

Nese, Gjermund and Odd Straume (2007), "Industry Concentration and Strategic Trade Policy in Successive Oligopoly", Journal of Industry, Competition and Trade, 7, 1, 31-52.

Union Professionnelle des Industries Privées du Gaz (2004), "Contribution de l'UPRIGAZ à une initiative de *gas release* en France," available at http ://www.uprigaz.com.

A Appendix

A.1 Gas release programs — the European experience

Gas release programs have been regularly implemented in Europe, either as commitments before the European Commission pursuant to a merger, or as temporary measures imposed by governments or national regulatory authorities in order to enhance competition in the market for natural gas (Commission de Régulation de l'Energie, 2004).

A.1.1 First experience : UK

Gas release programs and market share caps were first introduced by the UK government in the nineties. British Gas had initially made a voluntary commitment not to contract more than 90% of the production from new fields, but this undertaking was not very effective in releasing gas for new entrants because the volumes were mainly bought by gas-fired electricity generators. In March 1992, British gas gave an undertaking to the Office of Fair Trading to give up 60 % of the competitive market to his rivals and to release gas from its long-term contracts. A total of 58 TWh was sold under annual tranches, and was priced at WACOG (weighted average cost of gas purchased by the incumbent), plus a small proportional fee. By the end of the program in 1995, the spot market had developed, spot prices had fallen and the incumbent's market share had dropped.

A.1.2 Measures imposed by the government or national regulators

Spain :

The Spanish incumbent Gas Natural was imposed a market share cap of 70% of the downstream market by 2003. In addition, from 2001 to 2003, it had to release 25% of its imports from the Maghreb pipeline (49 TWh), which represented 9% of Spanish demand. As EFET (2003) puts it, "the program was based on the fundamental principle of keeping the incumbent neutral, as was the case in the UK" : volumes were released for three years, and the average price paid by bidders was adjusted to Gas Natural's purchasing cost. Due to stringent participation criteria, many new entrants such as foreign natural gas operators were excluded from the tender, and the successful bidders were mainly Spanish electricity companies and some natural gas producers (Comisión Nacional de Energía, 2005).

France :

Following a complaint by a foreign supplier about a network acess refusal, Gaz de France committed in 2004 to implement a gas release program in highly congested Southern France until completion of new infrastructure investments. The European Commission considered the undertaking as satisfactory and closed the case. The details of the program were negotiated by Gaz de France with the French Energy Regulator. During 3 years, Gaz de France had to sell 15 TWh annually. After a first round of bilateral transactions, the remaining volumes (in any case, not less than 6 TWh) would be auctioned. Gaz du Sud-Ouest, a subsidiary of the gas producer Total that is active in Southern France, also committed to auction 3.3 TWh in three yearly auctions from 2005 on. For both suppliers, the volumes involved correspond to 3.5% of their sales in the French downstream market.

Italy :

The decree implementing the first EU Gas directive in Italy in 2000 imposed a double market share cap on the gas incumbent SNAM : no operator was allowed to serve more than 50% of the downstream market, and the maximum share of imports was progressively brought down to 61% of total domestic consumption. This led the incumbent to sell 70 TWh annually from 2002 to 2010.[12] The measure was criticized for several reasons. First, it did not take account of gas destined for autoconsumption, which allowed Snam to minimise the amount of released gas by building gas-fired power generators. In addition, as stressed by Cavaliere (2007), import capacities remained congested and new entrants had no choice but buy gas from the incumbent, either on the domestic market (as allowed by the difference in the market share caps) or before the incumbent's imports crossed the Italian border. Though the measure allowed new entrants to increase their market shares in the domestic market, the incumbent was "able to partially compensate

[12] Contrary to the recommendations of the energy regulator, the parliament decided not to extend these rules after 2010.

the loss of sales in the Italian market with an equivalent transaction upstream", thereby keeping most of the profits.

A.1.3 Gas release programs subsequent to mergers

In the last ten years, gas release programs have increasingly been used as undertakings in mergers where competition authorities could fear the creation or reinforcement of a dominant position.

E.ON-Ruhrgas :

Government approval of the E.ON-Ruhrgas merger was conditional on Ruhrgas selling, from 2003 on, a total of 200 TWh of natural gas in six auctions, offering each 33.33 TWh under three-year contracts. The Gas Release program auction was an ascending-clock auction. The volume was divided into 33 lots, with no company allowed more than one third, and companies affiliated to E.ON or Ruhrgas were excluded. The minimum price was 95% of the average import price of Ruhrgas as stated by Germany's export control authority. The auction was rather unsuccessful, at least initially, because of the lack of transport capacity to ship the gas.

E.ON-MOL :

In connection with the acquisition by E.ON in 2006 of MOL, the largest gas company in Hungary, the European Commission required E.ON to implement a gas release program of 11 TWh per year. Gas was to be offered under a series of five annual auctions $(2006 - 2010)$ for two-year contracts in three lot sizes The program was implemented as a multiple-round ascending-clock auction. The starting price of the auction was set at 99.3% of the weighted average purchase price (WACOG) of E.ON Földgáz.

DONG-Elsam :

To address the European Commission's concerns about its merger with the electricity company Elsam, Danish Oil and Natural Gas (DONG) offered, among other undertakings, to implement six annual gas release auctions $(2006 - 2011)$, each equivalent to approximately 10% of Danish demand in 2005 (4.3 TWh/year). The gas release program, supervised by the Danish Competition Authority, took the form of a two-stage process. At the first stage, successful bidders would obtain gas in Denmark in return for volumes delivered at another northern European hub, with an auction-determined swap fee. In case some volumes would remain unsold, a second stage would be organized as a standard cash-settlement auction.

EconGas joint-venture :

EconGas was created in 2002 as a joint venture between the national oil and gas company OMV and several regional gas suppliers. Its approval was subject to the implementation of a gas release program. Natural gas was auctioned in 25 lots consisting in one-year flat supply contracts for $2.75TWh$, with a reserve price adjusted to the sourcing cost of EconGas.

In all these cases, ascending-clock auctions were used. The mechanism, proposed by Ausubel (2004), is the following.

- the auctioneer posts the ascending auction round price (Euro/MWh). Bidders are then requested to indicate the number of gas lots they are willing to acquire at this price.
- in each auction round, a participant may only reduce his original bid or leave it unchanged.
- at the end of each round, the auctioneer calculates the aggregate demand ; if it exceeds the number of lots to be auctioned off, the aggregate demand is disclosed to the bidders and the auction progresses to the next round.
- the auction ends as soon as the number of gas lots demanded falls below the number of lots to be auctioned off.
- all successful bidders pay a uniform final auction price.

Ausubel and Cramton (2009) identify four advantages of dynamic ascending-clock auctions over sealed-price auctions : they offer more transparency, they facilitate the price-discovery process, they do not require the high-value bidders to reveal their true valuations, and they are better suited to a simultaneous auction of multiple products.

A.2 Proof of Proposition 3.2.

If $p_r \leq \frac{d+3b}{4}$,

$$y = \frac{d-b}{4} - \frac{\beta}{2-\beta}\frac{d+3b-4p_r}{4} \tag{3.111}$$

and the profit of entrant j can be rewritten as

$$\begin{aligned} \Pi_j &= \frac{\tau}{r}\frac{\beta}{8n(2-\beta)^2}\left(d-b-\beta(d+b-2p_r)\right)\left((4-\beta)(d+b-2p_r)-(d-b)\right) \\ &+\frac{\omega^2}{(n+2)^2}-\frac{F}{n}. \end{aligned} \tag{3.112}$$

The number of entrants increases with p_r if and only if

$$p_r \leq \frac{d+b}{2} - \frac{d-b}{\beta(4-\beta)}, \tag{3.113}$$

which is always lower than $(d+3b)/4$. Therefore, the right-hand side in this inequation is the entry-maximizing gas release price.

A.3 Proof of Proposition 3.4.

A.3.1 Case where $p_r \leq \frac{d+3b}{4}$

In this case,

$$\begin{aligned} Q &= \frac{d-b-\beta(d+b-2p_r)}{16(2-\beta)^2}\left(4(2-\beta)(d-b)\right. \\ &\left.-(3+2\alpha(2-\beta))(d-b-\beta(d+b-2p_r))\right). \end{aligned} \tag{3.114}$$

The optimal gas release price is

$$p_r = b + \frac{(1+\beta-2\alpha(1-\beta)(2-\beta))}{2\beta(3+2\alpha(2-\beta))}(d-b) \tag{3.115}$$

if $\beta \leq 2-\frac{1}{2\alpha}$, else

$$p_r = \frac{d+3b}{4}. \tag{3.116}$$

Consider the case where $\beta \geq 2-\frac{1}{2\alpha}$ (which is possible only if $\alpha \leq 1/2$). Q is an increasing function of β :

$$Q = \frac{(5-2\alpha(2-\beta))(d-b)^2}{64}, \tag{3.117}$$

so that the optimal choice is $\beta = 1$, and the corresponding value of Q is

$$Q = \frac{(5-2\alpha)(d-b)^2}{64}. \tag{3.118}$$

Now consider the case where $\beta \leq 2 - \frac{1}{2\alpha}$ (which is possible only if $\alpha \geq 1/4$). Q is an increasing function of β :

$$Q = \frac{(d-b)^2}{4(3+2\alpha(2-\beta))}, \tag{3.119}$$

so that the optimal choice is $\beta = \min\left(2 - \frac{1}{2\alpha}, 1\right)$. Accordingly, if $\alpha \leq 1/2$, the optimal choice is $\beta = 2 - \frac{1}{2\alpha}$ and $p_r = \frac{d+3b}{4}$, so that

$$Q = \frac{(d-b)^2}{16}, \tag{3.120}$$

whereas if $\alpha \geq 1/2$, the optimal choice is $\beta = 1$ and $p_r = b + \frac{d-b}{3+2\alpha}$, in which case

$$Q = \frac{(d-b)^2}{4(3+2\alpha)}. \tag{3.121}$$

Finally, since $\frac{(5-2\alpha)(d-b)^2}{64} \geq \frac{(d-b)^2}{16}$ when $\alpha \leq 1/2$, the optimal choice in the case where $p_r \leq \frac{d+3b}{4}$ can be summarized as follows :

- If $\alpha \leq \frac{1}{2}$, the optimum is $p_r = \frac{d+3b}{4}$ and $\beta = 1$.
- If $\alpha \geq \frac{1}{2}$, the optimum is $p_r = b + \frac{d-b}{3+2\alpha}$ and $\beta = 1$.

A.3.2 Case where $\frac{d+3b}{4} < p_r \leq \frac{3d+5b}{8} - \frac{\beta}{2(4-\beta)}\frac{d-b}{4}$

The entrants participate and $y = \frac{d-b}{4}$. The corresponding value of Q is

$$Q = \frac{d-b}{64}\left((5-4\alpha)(d-b) + 2\alpha\beta(3d+5b-8p_r)\right). \tag{3.122}$$

Q is a decreasing function of p_r and an increasing function of β (since on the relevant interval $3d + 5b - 8p_r > 0$), therefore the optimal choice is

$$p_r = \frac{d + 3b}{4} \tag{3.123}$$

$$\beta = 1 \tag{3.124}$$

In this case,

$$Q = \frac{(5 - 2\alpha)(d - b)^2}{64}. \tag{3.125}$$

A.3.3 Case where $p_r > \frac{3d+5b}{8} - \frac{\beta}{2(4-\beta)} \frac{d-b}{4}$

The entrants do not participate, $y = \frac{d-b}{4}$, and the corresponding value of Q is

$$Q = \frac{(5 - 4\alpha)(d - b)^2}{64}, \tag{3.126}$$

Choosing p_r in this interval is clearly not optimal.

Comparing the expressions in (3.119), (3.120) and (3.125) yields proposition (3.3).

Chapitre 4

Real asset valuation based on spot prices : can we forget about market fundamentals ?

1 Introduction

Commodity contracts can involve some flexibility with respect to both the timing and the amount of commodity delivered, especially in the electricity and natural gas markets. Such contracts allow their holders to repeatedly receive variable volumes, subject to daily, monthly and/or annual constraints, at a predetermined price, thereby incorporating options known as swing or take-or-pay options (see Thompson, 1995, for a description). The pricing of these options constitutes an active domain of research (see for example Barrera-Esteve et al., 2006 ; Jaillet et al., 2004 ; Carmona-Ludkovski, 2008). While these valuation techniques were primarily designed for the pricing of financial assets, their use has been extended to the valuation of real assets —such as production plants, pipelines or storage sites— that allow their owners to obtain energy on short notice under some operational and capacity constraints.

The value of a real asset is computed as the stream of profits that can be obtained from this asset through arbitrage in a liquid spot market. While the recent literature has

This chapter is based on joint work with Corinne Chaton.

developed increasingly sophisticated methods to model the spot price process[1] and to incorporate operational constraints (*e.g.* lead times, maximum injection or withdrawal rates and capacity constraints), it never questions two basic premises : all the relevant market information is assumed to be included in the spot price, and all the players are assumed to take this price as given. However, these assumptions are very strong, and they are likely to be violated when operators have market power, which is the case in a number of commodity markets. Our paper questions the validity of the conventional real asset valuation methods when both the spot market and the downstream market are imperfectly competitive.

First consider competition in the spot market. The assumption that traders do not take the impact of their own transactions on the market price into account can be questioned in industries where few traders make large transactions. In effect, market liquidity is an issue in a number of commodity spot markets, especially in the market for natural gas.[2] Many energy markets are dominated by large suppliers, and most financial traders in spot markets are large trading companies or divisions of major banks.[3] It is reasonable to assume that these traders are aware that their transactions affect the spot price : for instance, they will avoid flooding the market if they anticipate that the resulting price decrease will lower their profits. Martinez-de-Albeniz and Vendrell Simon (2008) show that a trader who takes into account the price impact of his transactions into account can refrain from arbitrage in some cases where the price spread exceeds the transaction costs, and prefers to sell less, but at a better price. Felix, Woll and Weber (2009) specifically consider the impact of limited liquidity on gas storage valuation ; to model

[1] The stochastic process governing the commodity price plays a crucial role in the pricing of related products. Models of commodity spot prices commonly use mean-reverting processes (Gibson and Schwartz, 1990 ; Schwartz, 1997). Models dealing with energy commodities tend to incorporate price seasonality (Manoliu and Tompaidis, 1998) and occasional price spikes (Deng, 2000).

[2] A market is said to be liquid when trades of any size can be transacted at any moment without causing a significant movement in price. Industry players characterize market liquidity using several indicators such as the number of players active in the market, the total volume traded, the number of trades, the churn ratio (ratio of traded volume to volume delivered physically), or the bid-ask spread. The UK spot market is the most liquid natural gas market in Europe, with roughly 70 players and a high churn ratio. Conversely, the total spot trade in the most active hubs in continental Europe (Zeebrugge in Belgium, TTF in the Netherlands) is roughly a third of that on the UK hub, while gas demand in this region is much larger (see the ECORYS report by Rademaekers, Slingenberg and Morsy, 2008, based on Heren data).

[3] On the APX Gas UK exchange, the five largest traders accounted for around half of traded volume in 2008 (Ofgem, 2009).

the impact of traded volumes on the spot price, they introduce an illiquidity parameter that determines the bid-ask spread, but the lack of liquidity is not explicitly related to strategic interactions between firms with market power.

In the case of commodities, the spot market only exists because there is a downstream market and a final demand for the commodity. Our model features two types of players : pure traders, who use their physical assets[4] for arbitrage transactions on the spot market, and suppliers, whose core business consists in purchasing a commodity and reselling it to downstream customers (of course, they have the ability to make arbitrage transactions as well). The model considers the issue of real asset valuation under imperfect competition and is applied to the valuation of natural gas storage capacities.[5] Is the value of a real asset identical for the two types of players ? In other words, is the trading value, based on the sole spot price, the right value for a firm with supply activities ? In principle, at least in a competitive context with liquid markets, the spot price process should simply reflect the fundamentals of supply and demand ; therefore it should include all the information that is relevant to any type of player. Secomandi (2009) proves that under perfect competition, the value of pipeline capacity is the same for a pure trader and a shipper. However, if there is market power in the downstream market, selling on spot or downstream ceases to be indifferent : a firm that has the ability to sell downstream (*e.g.,* because it has the necessary authorizations, access to the network, or a large customer base) could make more profit than a pure trader with the same real asset.

To our knowledge, the only paper that compares the value of a real asset for different types of agents in an oligopolistic setting is Sioshansi (2009). Building on the analysis developed in Sioshansi et al. (2009), which describes the impact of large-scale electricity storage on electricity prices, and thus on generators' profits and consumer surplus, Sioshansi (2009) examines the incentives for three different agent types (producers, merchant storage operators and consumers) to use storage. Under perfect competition these

[4]Financial traders and the buying and selling of forward contracts or futures could also be introduced without changing the results, as long as the no-uncertainty assumption is maintained and there is free entry in the financial market. The number of physical traders, however, is bounded due to the scarcity of storage.

[5]The model could be extended to the valuation of other real conversion assets : while storage capacity can be interpreted as converting natural gas today into natural gas at a later date, "pipeline capacity can be interpreted as an asset that can convert natural gas at one location into natural gas at a different location" (Secomandi, 2009). Finally, the analysis could be applied to real assets that convert one commodity into another, *e.g.*, converting coal, fuel or natural gas into electricity.

incentives are identical, but in an oligopolistic setting they are lowest for producers and highest for consumers. In some respects, his model is similar to ours : all storage operators are aware that an increased use of storage will reduce its arbitrage value, and the model compares the use of storage by operators playing different roles in the market. In Sioshansi's model, however, demand is completely inelastic and consumers pay the real-time spot price (there are no intermediaries between producers and consumers, which is common in the market for electricity but much less so for natural gas). Conversely, demand in our model is only inelastic in the short run, because consumers buy from suppliers under two-period contracts that guarantee them a fixed price over the two periods. In the longer run, demand becomes elastic because suppliers compete for contracts with downstream customers, who choose the lowest price. Another significant difference is that our model allows for the simultaneous use of storage by traders and suppliers, and more importantly, it takes the initial allocation of storage capacities into account. As we will prove, the results are drastically changed by whether this initial allocation is symmetric or characterized by a dominant operator.

The remainder of this paper is organized as follows. A stylized model of the natural gas market with no uncertainty is proposed in section 2 with two types of strategic players : pure traders and suppliers with downstream customers. Section 3 compares three methods for the pricing of storage capacity. First, myopic valuation corresponds to the usual technique with a price-taking assumption. The second method computes the actual trading value of the asset, taking the impact of transactions on the spot price into account. The third method computes the value of additional storage capacity for a supplier who uses it to supply his downstream customers. The analysis sheds light on the biases generated by traditional pricing techniques : while ignoring the price response to one's transactions leads to an overestimation of the asset's value, ignoring downstream profit opportunities leads to an underestimation. Globally, the value obtained under price-taking assumptions proves to be downward biased, except for dominant suppliers with large initial capacities : in an imperfectly competitive market, traditional methods tend to induce under-investment. Finally, section 4 analyzes a situation where suppliers active in different downstream markets source their gas from the same spot market. The value of storage for a supplier proves to be affected by the demand profile of other suppliers, even though they are not his competitors. Again, traditional methods tend to underestimate the real value of storage, except in the particular case where a supplier's demand is flat and the demand of other suppliers is seasonal.

2 The model

The model considers the valuation of seasonal storage capacities under imperfect competition.[6] To enhance the clarity of the analysis, we do not consider uncertainty (in the case of seasonal storage, demand for the next season is not precisely known in advance, but it can be reasonably anticipated). The model is divided into two periods, a low-demand period, followed by a high-demand period, which can be interpreted as a summer season followed by a winter season.[7] The discount rate between the periods is r. For any variable y relating to the first period, y' relates to the second period.

2.1 Assumptions

Producers sell gas in a spot market[8] to suppliers, who resell it in a downstream market. Pure traders can also buy or sell on spot, but they have no access to the downstream market.[9]

To simplify, there is a single, non-strategic producer with a production cost function

$$C(q) = \frac{1}{2}q^2 + bq. \tag{4.1}$$

He produces q in the first period and q' in the second period. The spot price is p (p' in

[6] Storage facilities such as depleted fields or aquifers are mainly used for seasonal storage. These specific facilities are ill-suited for short-term arbitrage because of their low withdrawal rates. This is why we rule out arbitrage operations that take place within a single season.

[7] Since natural gas is largely used for heating, gas consumption is strongly influenced by weather and subject to a significant seasonal swing. In Northwestern Europe, approximately two-thirds of the gas is consumed during the winter (October–March).

[8] Natural gas trading relies on three main channels : bilateral contracts, exchanges and OTC markets. An exchange is a marketplace where standardized products (commodities, derivatives or other financial instruments) are traded. Exchanges usually provide a day-ahead market, also called a spot market, and allow for trading in future (standardized) contracts. Over-the-counter (OTC) trades account for the majority of traded gas volumes, especially for forward contracts. OTC trades are neither standardized nor anonymous, and they are usually facilitated by brokers. In this paper, the 'spot market' relates more generally to the market where all short-term trades take place.

[9] Approximately one-third of the actors in Zeebrugge, the largest European gas hub, are physical or financial traders with no downstream customers.

the second period). The inverse spot supply function can easily be computed : $p = b + q$ and $p' = b + q'$ in the first and the second periods, respectively.

The other firms active in the spot market are strategic players : m traders (indexed by i, $i = i_1, .., i_m$) and n suppliers (indexed by j, $j = j_1, .., j_n$) are competing in quantities. Trader i and supplier j are spot buyers if their spot positions s_i, s_j (s'_i, s'_j in the second period) are positive numbers. Suppliers sell gas to final consumers in the downstream market.

Demand for natural gas is not completely inelastic, but in practice consumer prices tend to be fixed for some period of time so that they do not respond to demand variations in the short term. In the longer term, however, contract prices can be modified. We assume that suppliers compete in quantities for two-period contracts with final consumers. Consumer demand is seasonal : a consumer signing a contract for quantity z at a price p_z per unit will consume a fraction $(1 - x)$ of this volume in the first period, and a fraction x in the second period, where $\frac{1}{2} \leq x \leq 1$. A high value of x denotes a strongly seasonal demand, while x close to $\frac{1}{2}$ denotes a flat demand profile. The demand for gas by final consumers is elastic, it is modelled as a linear function : $z = d - p_z$.

Suppliers and traders have access to limited storage capacities. The use of storage between the two periods costs c per unit injected. In the first period, trader i ($i = i_1, .., i_m$) injects $w_i \leq K_i$ and supplier j ($j = j_1, .., j_n$) injects $w_j \leq K_j$ into storage. By assumption, all inventories have to be emptied by the end of the second period.[10] Therefore, in the second period, these quantities are withdrawn and sold either on spot, or in the downstream market.

The timing can be summarized as follows.

– First period

  The producer sells q at price p in the spot market. Trader i buys w_i and injects it into inventory. Suppliers compete for contracts with downstream customers. Sup-

[10] Clearly, this is a strong assumption because it means that injecting w_j amounts to a commitment to sell this quantity in the next period. But actually, in a seasonal setting, keeping volumes in stock from one year to another is uneconomical and is rarely practiced. Of course, stating that at equilibrium there should be no unsold inventory at the end of the gas year is not equivalent to introducing such a constraint, but in practice, the contracts of many storage operators (*e.g.*, E-ON Ruhrgas, RWE Energy, NAM, Dong Storage, and Edison Stoccaggio) do stipulate that no volume should be left in stock at the end of the gas year, as detailed in their respective websites. Stoccaggio) do stipulate that no volumes be left in stock at the end of the gas year, as detailed in their respective websites.

plier j commits to sell z_j at price p_z over the two periods; he buys s_j on spot, sells $(1-x)z_j$ to his customers, and saves the remaining quantity w_j as inventory for the next period.

– Second period

The producer sells q' at price p' in the spot market. Trader i withdraws w_i from his stocks and sells it on spot. Supplier j has to sell xz_j to his downstream customers : he withdraws w_j from his stocks and adjusts his spot position, so that $s'_j = xz_j - w_j$ (positive if he is a spot buyer).

To simplify the notation, the following convention is used : for any variable y, $y_{-i} = \sum_{\substack{k\in\{i_1,..,i_m\}\\ k\neq i}} y_k$ and $y_{-j} = \sum_{\substack{k\in\{j_1,..,j_n\}\\ k\neq j}} y_k$. Indices shall be dropped whenever the resulting notation is not ambiguous, *e.g.*, Σw_i represents $\sum_i w_i$. The game is solved backwards.

2.2 Second period

The second-period spot price results from the equilibrium between demand and supply :

$$p' = b - \Sigma w_i - \Sigma w_j + x\Sigma z_j. \tag{4.2}$$

There is no strategic choice to make. The traders simply sell the quantities stored in the previous period, and the suppliers adjust their spot market position depending on their inventories and downstream sales. Note that some suppliers —but not all of them— can be spot sellers in the second period if they have built up large inventories, exceeding the volume needed to supply their customers.

All stocks have the same effect of decreasing the second-period spot price either by increasing spot supply in the case of traders or suppliers who are spot sellers, or by decreasing spot demand in the case of suppliers who are spot buyers.

2.3 First period

In the first period, competition takes place simultaneously in the downstream market and in the spot market. All traders and suppliers are necessarily spot buyers. Trader i injects into storage a volume that cannot exceed his maximum capacity ($w_i \leq K_i$). Supplier j, who commits to sell z_j to his customers over the two periods, simultaneously buys on spot s_j, sells $(1-x)z_j$ downstream, and injects the remaining quantity $w_j = s_j - (1-x)z_j$ into storage ($w_j \leq K_j$). The first-period spot market equilibrium is

$$p = b + \sum_i w_i + \sum_j w_j + (1-x)\sum_j z_j. \tag{4.3}$$

We introduce the following definitions.[11] Let

$$\alpha \equiv (1+r)\frac{\partial}{\partial z_j}\left(\frac{p'}{1+r} - p - c\right), \tag{4.4}$$

$$\beta \equiv -(1+r)\frac{\partial}{\partial z_j}\left(p_z - (1-x)p - x\frac{p'}{1+r}\right). \tag{4.5}$$

α is the marginal increase in arbitrage profits (multiplied by $(1+r)$) when a supplier's downstream sales increase by one unit, which amplifies the price spread. Symmetrically, α is also equal to the marginal increase in supply profits (multiplied by $(1+r)$) when inventories increase by one unit, which smoothes spot prices, thereby lowering suppliers' purchasing costs :

$$\alpha = (1+r)\frac{\partial}{\partial w_j}\left(p_z - (1-x)p - x\frac{p'}{1+r}\right). \tag{4.6}$$

β is the marginal decrease in supply profits (in absolute value, multiplied by $(1+r)$) when a supplier's downstream sales increase by one unit : when the demand profile is not flat, more sales mean increasing the purchasing price even more in the period where it is already higher. Computing the values of α and β, we see that α is large when demand in the second period is high relative to the first period, and β is large when the swing (difference in demand) between the two periods is large, with a higher demand in either period :

$$\alpha = x - (1+r)(1-x), \tag{4.7}$$

$$\beta = 2(1+r)(1-x+x^2) - rx^2. \tag{4.8}$$

[11] Note that α and β are well-defined because in both equations, the right-hand side is the same for all j.

β is always positive, and $\alpha > 0$ if $x > \frac{1}{2} + \frac{r(1-x)}{2}$. In the rest of the analysis, we assume that r and x are such that $\alpha > 0$.

2.3.1 Downstream sales

A supplier's activity can be decomposed into trading on the one hand, and supply to downstream customers on the other :

$$\Pi_j = \left(\frac{p'}{1+r} - p - c\right) w_j + \left(p_z - (1-x)p - x\frac{p'}{1+r}\right) z_j. \quad (4.9)$$

Competing in quantities with the other suppliers, supplier j chooses his total downstream sales z_j to maximize his intertemporal profit, taking his rivals' sales and all inventories as given. The marginal impact of additional downstream sales on his profit is

$$\frac{\partial \Pi_j}{\partial z_j} = \left(p_z - (1-x)p - x\frac{p'}{1+r}\right) + \frac{1}{1+r}(\alpha w_j - \beta z_j). \quad (4.10)$$

When combining the first-order conditions of all suppliers, the sales of supplier j prove to increase with the inventories of traders and own inventories only

$$z_j = \frac{1}{(n+1)\beta}((1+r)d - (1+r(1-x))b) + \frac{\alpha}{(n+1)\beta}\Sigma w_i + \frac{\alpha}{\beta} w_j. \quad (4.11)$$

All inventories have a positive direct effect on the sales of supplier j because they reduce the spot price spread, thereby reducing his sourcing costs. However, rival suppliers holding inventories tend to compete more aggressively, which counters this positive effect, so that the net effect of their stocks is zero (they can only have an indirect effect through the impact on unconstrained traders' stocks). In contrast, own inventories have an additional positive effect : these units are purchased at a lower price. Therefore, holding more inventories allows a supplier to increase his downstream sales.

Total sales in the downstream market can be expressed as

$$\Sigma z_j = \frac{1}{\beta}\frac{n}{n+1}((1+r)d - (1+r-rx)b) + \frac{\alpha}{\beta}\frac{n}{n+1}\Sigma w_i + \frac{\alpha}{\beta}\Sigma w_j. \quad (4.12)$$

These sales increase more with the stocks of suppliers than with the stocks of traders.

This is because each supplier's sales increase more with his own inventories than with traders' stocks, while they are not directly affected by the stocks of rival suppliers.

2.3.2 Inventory choice by a trader

Trader i chooses his stocks w_i $(0 \leq w_i \leq K_i)$, taking into account the impact of his transactions on the spot prices : one additional unit of inventories causes the first-period spot price to increase and the second-period spot price to decrease (arbitrage transactions reduce the price spread). He solves $\max_{w_i \leq K_i} \Pi_i$, where

$$\Pi_i = \left(\frac{p'}{1+r} - p - c\right) w_i. \tag{4.13}$$

The marginal effect of one additional unit of inventories, if the trader is not capacity-constrained, is

$$\begin{aligned}\frac{\partial \Pi_i}{\partial w_i} &= \left(\frac{p'}{1+r} - p - c\right) - \left(\frac{\partial p}{\partial w_i} + \frac{1}{1+r}\frac{-\partial p'}{\partial w_i}\right) w_i & (4.14)\\ &= \left(\frac{p'}{1+r} - p - c\right) - \frac{2+r}{1+r} w_i. & (4.15)\end{aligned}$$

The best response of trader i to other players' stocks and to suppliers' sales is

$$w_i = \frac{1}{2(2+r)}\left(\alpha \Sigma z_j - rb - (1+r)c\right) - \frac{1}{2}(\Sigma w_j + w_{-i}) \tag{4.16}$$

if the right-hand side is positive and lower than K_i, else $w_i = 0$ or $w_i = K_i$. The equilibrium profit of a trader only depends on the amount w of his inventories ; it shall be denoted as $T(w)$.

2.3.3 Inventory choice by a supplier

Supplier j chooses his stock level to maximize his intertemporal profit given by (4.9), under the constraints $0 \leq w_j \leq K_j$. Note that, given the expressions for p and p', the derivative of $\left(\frac{p'}{1+r} - p - c\right)$ with respect to w_j is equal to its derivative with respect to trader i's stocks w_i, so that

$$\frac{\partial}{\partial w_j}\left[\left(\frac{p'}{1+r}-p-c\right)w_j\right]=T'(w_j). \tag{4.17}$$

Accordingly, the impact of one additional unit of inventories on the profit of a supplier can be expressed as

$$\frac{\partial \Pi_j}{\partial w_j}=T'(w_j)+\frac{\alpha}{1+r}z_j. \tag{4.18}$$

– **The first term** is equal to the effect of one additional unit of inventories on the profit of a pure trader holding w_j in stock. This term combines two elements : the substitution effect of buying and storing one unit more in the first period instead of buying it in the second period ; and the impact of these transactions on the spot prices, and thus indirectly on the costs of purchasing and the revenues from selling the entire volume w_j.
– **The second term** is the global decrease in purchasing costs due to the price-smoothing effect of inventories, which makes downstream sales more profitable.

For a supplier, storage is not only an arbitrage tool, it also increases purchases in the low-demand period and lowers them in the high-demand period, which globally reduces purchasing costs, and therefore yields additional profits. This allows us to state the following Lemma.

Lemma 4.1. *Suppliers with non-binding storage capacities always carry more inventories than traders.*

Proof 4.1. *Let w_j be the equilibrium stock of supplier j, with $w_j < K_j : \partial\Pi_j/\partial w_j \leq 0$. Therefore, from (4.18), $T'(w_j) \leq -\frac{\alpha}{1+r}z_j$, which is negative. For any trader i with positive inventories, $T'(w_i) \geq 0$. Therefore, $T'(w_j) \leq T'(w_i)$, and because the function T' is strictly decreasing, $w_j \geq w_i$.*

analyzing equations (4.18) and (4.15) leads us to a second result.

Lemma 4.2. *If no supplier is constrained by his storage capacity, then there can be no traders.*

Proof 4.2. *See Appendix.*

The best response of supplier j to the stocks of other suppliers and traders is

$$w_j = \frac{1}{2(2+r)}\left(\alpha(z_j + 2z_{-j}) - rb - (1+r)c\right) - \frac{1}{2}(\Sigma w_i + w_{-j}) \tag{4.19}$$

if the right-hand side is positive and lower than K_j, else $w_j = 0$ or $w_j = K_j$.

We introduce the following notation :

$$\begin{aligned} D &= (1+r)d - (1+r-rx)b, & (4.20) \\ C &= rb + (1+r)c. & (4.21) \end{aligned}$$

If no supplier is constrained, there are no traders and suppliers' stocks are

$$\Sigma w_j = \frac{n}{n+1}\frac{\alpha D - \beta C}{(1+r)(3+r)}. \tag{4.22}$$

In this case, the spot price differential is :

$$\frac{p\prime}{1+r} - p - c = -\frac{rb + (1+r)c}{(n+1)(1+r)}. \tag{4.23}$$

When the downstream market is perfectly competitive (n tends to infinity), the price spread is completely smoothed by storage. When it is imperfectly competitive, an individual supplier does not take into account the fact that increasing his own stocks reduces the value of storage for the other suppliers, so that at equilibrium, suppliers carry "too much" inventory and the price spread is negative.

If at least one supplier is constrained, the equilibrium in the general case where some suppliers and some traders can be capacity-constrained is detailed in the Appendix.

Let $\Sigma w \equiv \Sigma w_i + \Sigma w_j$ denote the total inventories carried at equilibrium. The social welfare, *i.e.,* the sum of the surplus of consumers and the profits of the traders, the suppliers and the producer, can be expressed as

$$\begin{aligned} SW &= p_z\Sigma z_j + \frac{1}{2}(\Sigma z_j)^2 - c\Sigma w - (b + \frac{1}{2}((1-x)\Sigma z_j + \Sigma w))((1-x)\Sigma z_j + \Sigma w) \\ &\quad - \frac{1}{1+r}(b + \frac{1}{2}(x\Sigma z_j - \Sigma w))(x\Sigma z_j - \Sigma w). & (4.24) \end{aligned}$$

How should storage capacities be allocated to maximize social welfare ? Obviously, if some operators do not use their entire storage capacity, it is preferable to reallocate them to other operators that lack capacity. What if all operators are constrained ? The expression in (4.24) increases with Σw and with Σz_j. From (4.60), Σw increases more with Σw_j than with Σw_i when there are some unconstrained traders, and otherwise the effect is identical. Downstream sales increase more with Σw_j than with Σw_i (see (4.12)). As a consequence, when allocating scarce storage capacities, it is always better to give priority to capacity-constrained suppliers, because this will lead to a larger increase in their downstream sales, which benefits consumers. Conversely, when no supplier is constrained, as stated by Lemma 1, there is no need to allocate capacities to traders because they would not use them.

Proposition 4.1. *Giving storage capacities to pure traders is never welfare-improving. If some suppliers are capacity-constrained, it would be preferable to reallocate these capacities to them ; if no supplier needs additional capacity, then traders cannot make any profit in the market.*

Therefore, when storage is scarce, clear priority should be given to operators with downstream customers. Some countries already apply such a policy. In France, available storage capacities are allocated to suppliers according to storage rights based on their current customer portfolio[12] ; if storage capacities are scarce, operators that supply gas to domestic customers or customers under non-interruptible contracts have a priority over, *e.g.*, pure traders.[13] Note, however, that under our assumptions, the distribution of capacities between constrained suppliers plays no role : both total inventories and total downstream sales depend on the number of constrained operators and on total constraining capacities, but not on the way that the capacity is allocated among the operators. As long as no storage capacities remain idle, a reallocation of capacities among suppliers has no impact on social welfare. This is not necessarily true in the case of suppliers with different demand profiles, as will be discussed in section 4.

[12] Article 5, Loi n° 2003-8 du 3 janvier 2003 relative aux marchés du gaz et de l'électricité et au service public de l'énergie.

[13] Article 3, Décret n° 2006-1034 du 21 août 2006 relatif à l'accès aux stockages souterrains de gaz naturel.

3 Storage valuation with market power

This section is devoted to investments in new storage capacity. The analysis focuses on the case where all suppliers and traders are capacity-constrained. If this were not the case, it could be profitable for an operator with excess capacity to lend it to a capacity-constrained operator, unless withholding available capacity proved to be even more profitable. Since such foreclosure strategies are not the focus of this paper, we shall assume that all operators are capacity-constrained : $w_i = K_i$ for all i and $w_j = K_j$ for all j. This section compares three methods for the valuation of storage capacity :

– the myopic valuation, $\widetilde{V} \equiv \frac{p'}{1+r} - p - c$,

– the trading valuation $V_i \equiv \frac{\partial \Pi_i}{\partial K_i}$,

– the supplier valuation $V_j \equiv \frac{\partial \Pi_j}{\partial K_j}$.

We analyze the bias generated by the use of the "traditional" methods that simply compute the arbitrage profits of a price-taking trader when the storage facility is to be used by a trader with market power, or by a supplier. The myopic valuation is identical for all operators because it is solely based on the spot price spread and does not take the specific characteristics of each operator into account. This value can be easily computed using the expressions for the spot prices in (4.2) and (4.3), and total downstream sales are given by (4.12) :

$$\widetilde{V} = \frac{n\alpha D - (n+1)\beta C - \alpha^2 \Sigma K_i}{(1+r)(n+1)\beta} - \frac{3+r}{\beta}(\Sigma K_i + \Sigma K_j). \tag{4.25}$$

3.1 Use of traditional techniques by a trader

The value of one additional unit of capacity for a constrained trader i is easily obtained by reformulating equation (4.14) :

$$V_i \equiv \frac{\partial \Pi_i}{\partial K_i} = \left(\frac{p'}{1+r} - p - c\right) - \left(\frac{\partial p}{\partial K_i} + \frac{1}{1+r}\frac{-\partial p'}{\partial K_i}\right) K_i. \tag{4.26}$$

Note, however, that the derivative of a variable (such as p or p') with respect to storage capacity K_i is not equal to its derivative with respect to inventories w_i : when a trader chooses w_i, he takes all other inventories (as well as suppliers' sales) as given, whereas the choice of K_i is made anticipating its impact on all stocks and sales.

The bias induced by the use of the myopic valuation in the case of a trader with market power is

$$\widetilde{V} - V_i = \left(\frac{\partial p}{\partial K_i} + \frac{1}{1+r} \frac{-\partial p'}{\partial K_i} \right) K_i. \tag{4.27}$$

The effect of a marginal increase in the capacity of trader i on the spot prices can be expressed as

$$\frac{\partial p}{\partial K_i} = 1 + \frac{n}{n+1} \frac{(1-x)\alpha}{\beta}, \tag{4.28}$$

$$\frac{\partial p'}{\partial K_i} = -1 + \frac{n}{n+1} \frac{x\alpha}{\beta}. \tag{4.29}$$

Note that $\partial p/\partial K_i > 0$ and $\partial p'/\partial K_i < 0$: the trader's first-period purchases push the spot price upwards, while his second-period sales push it downwards. As a result, the price spread, and therefore the trader's profit, is lower than if the prices were unaffected by his transactions : $\widetilde{V} - V_i$ is necessarily positive. Strikingly, the number of traders m has no impact on the bias, indicating that the degree of competition in the spot market does not matter. Only the size of the trader's initial capacity determines whether his transactions will have a significant effect on spot prices. A small trader (*i.e.* with a small initial capacity) can reasonably behave as if he were a price taker. Conversely, a large trader will make a larger error.

What about the impact of imperfect competition in the downstream market ? A higher K_i means a lower price spread, and thus lower overall purchasing costs for suppliers ; in return, all suppliers increase their downstream sales, which reinforces spot demand especially in the second period, thereby limiting the decrease in the price spread. This countervailing effect becomes weaker when the downstream market moves away from perfect competition, because a decrease in purchasing costs will not lead suppliers to significantly increase their sales. Accordingly, the bias is larger when the number of suppliers is small :

$$\widetilde{V} - V_i = \left(\frac{2+r}{1+r} - \frac{n}{n+1} \frac{\alpha^2}{(1+r)\beta} \right) K_i. \tag{4.30}$$

The results are summarized in the following Proposition.

Proposition 4.2. *A trader with market power who ignores the impact of his transactions on spot prices always* overestimates *the value of additional storage capacity. This bias is* *reinforced by imperfect competition in the downstream market.*

3.2 Use of traditional techniques by a supplier

Without loss of generality, consider the case of supplier j_1. His profit is the sum of his trading profit and his supply profit :

$$\Pi_{j_1} = \left(\frac{p'}{1+r} - p - c\right) K_{j_1} + \left(p_z - (1-x)p - x\frac{p'}{1+r}\right) z_{j_1}. \tag{4.31}$$

The value of additional storage capacities for him is

$$V_{j_1} \equiv \frac{\partial \Pi_{j_1}}{\partial K_{j_1}} = \frac{\alpha D - \beta C}{(1+r)\beta} - \frac{3+r}{\beta}(\Sigma K_i + \Sigma K_j + K_{j_1}).$$

We will now compare this value with the myopic valuation. $\widetilde{V}$ is equal to the expression in brackets in the first term in equation (4.31). The second term in brackets is the profit per unit supplied to downstream customers. It is not affected by an increase in the storage capacity. In effect, if K_{j_1} becomes larger, downstream sales z_{j_1} increase and the resulting decrease in p_z is exactly compensated for by the increase in the cost of spot purchases :

$$p_z - (1-x)p - x\frac{p'}{1+r} = \frac{D + \alpha \Sigma K_i}{(n+1)(1+r)}. \tag{4.32}$$

As a result, the value of one additional unit of capacity for supplier j_1 can be expressed as

$$V_{j_1} = \left(\frac{p'}{1+r} - p - c\right) - B1_{j_1} - B2_{j_1} \tag{4.32}$$

where

$$B1_{j_1} = \left(\frac{\partial p}{\partial K_{j_1}} - \frac{1}{1+r}\frac{\partial p'}{\partial K_{j_1}}\right) K_{j_1}, \tag{4.33}$$

$$B2_{j_1} = -\left(p_z - (1-x)p - x\frac{p'}{1+r}\right)\frac{\partial z_{j_1}}{\partial K_{j_1}}. \tag{4.34}$$

The error made by a supplier with market power who uses the myopic value $\widetilde{V}$ instead of the supplier value V_{j_1} that takes into account his profits on the downstream market is

$$B_{j_1} \equiv \widetilde{V} - V_{j_1} = B1_{j_1} + B2_{j_1}. \tag{4.34}$$

3.2.1 First bias : volume effect

The first bias $B1_{j_1}$ is due to the fact that the use of additional storage capacities by a supplier will reduce the price spread. The intuition here is the same as in the case of a pure trader. However, the stocks of suppliers have a larger upward impact on the spot price than the stocks of traders in the first period, but a smaller downward impact in the second period : since suppliers' stocks stimulate downstream sales more than traders' stocks do, they push total spot purchases upwards. Globally, the impact on the price spread is smaller when stocks are held by suppliers :

$$B1_{j_1} = \frac{3+r}{\beta} K_{j_1}. \tag{4.34}$$

3.2.2 Second bias : downstream market power effect

The second bias is due to the positive effect of additional storage capacities on the downstream sales of supplier j_1. Since holding inventories allows him to buy more in the first period and less in the second period, where the spot price is higher, a higher K_{j_1} means lower sourcing costs, which leads him to compete more aggressively for downstream customers and increase his profits. This bias is clearly negative :

$$B2_{j_1} = -\frac{\alpha}{\beta} \frac{D + \alpha \Sigma K_i}{(n+1)(1+r)}. \tag{4.34}$$

3.2.3 Global bias

The global bias is $B_{j_1} \equiv B1_{j_1} + B2_{j_1}$:

$$B_{j_1} = \frac{3+r}{\beta} K_{j_1} - \frac{\alpha}{\beta} \frac{D + \alpha \Sigma K_i}{(n+1)(1+r)}. \tag{4.34}$$

$B1_{j_1}$ is proportional to the supplier's initial storage capacity, since arbitrage profits on all units in stock are affected by the reduction in the price spread. Conversely, $B2_{j_1}$ does not depend on the initial capacity of supplier j_1, but it is larger in absolute terms when the downstream market is concentrated (small n). Accordingly, the sign of the global bias depends both on the degree of competition in the downstream market and on the initial allocation of storage capacities :

$$B < 0 \Leftrightarrow (n+1)K_{j_1} < \frac{\alpha D + \alpha^2 \Sigma K_i}{(1+r)(3+r)}. \tag{4.34}$$

The bias is more likely to be negative when the downstream market is concentrated and the initial capacity of supplier j_1 is small. Does this mean that j_1 will invest less than what is optimal for him ?

By assumption, j_1 only considers investing if the myopic valuation is positive, which means (see (4.25)) that

$$\Sigma K_j < \frac{n\alpha D - (n+1)\beta C - \alpha^2 \Sigma K_i}{(n+1)(1+r)(3+r)} - \Sigma K_i. \tag{4.34}$$

If this is not the case, he will not invest, and obviously his investment will be lower than or equal to the optimum. Now suppose that inequality (3.2.3) is satisfied. If the capacity of supplier j_1 is equal to or lower than the average capacity of suppliers, this inequality implies that

$$nK_{j_1} < \frac{n\alpha D - (n+1)\beta C - \alpha^2 \Sigma K_i}{(n+1)(1+r)(3+r)} - \Sigma K_i, \tag{4.34}$$

which in turn implies that the global bias is negative (inequality (3.2.3)) : supplier j_1 underestimates the value of additional investments. Finally, we can state the following Proposition.

Proposition 4.3. *A supplier with market power who uses the myopic valuation method, thereby ignoring both the impact of his transactions on the spot price and the downstream profits to be expected from larger stocks,* underestimates *the value of additional storage capacity, as long as his initial capacity is not higher than the average capacity of suppliers.*

In fact, if the initial capacity allocation is (at least roughly) symmetric, the bias is negative for all suppliers. In this case, traditional methods based on arbitrage pricing systematically underestimate the profits from new storage capacity and lead to under-investment. This is all the more true as the downstream market is concentrated (small n).

The only situation where the myopic valuation can lead to over-investment with respect to the profit-maximising level is when $\tilde{V} > 0$ and $B_{j_1} > 0$, which holds if and only if

$$\Sigma K_j < \frac{n\alpha D - (n+1)\beta C - \alpha^2 \Sigma K_i}{(n+1)(1+r)(3+r)} - \Sigma K_i < \frac{n\alpha D + n\alpha^2 \Sigma K_i}{(n+1)(1+r)(3+r)} < nK_{j_1}. \quad (4.34)$$

This is only possible when the initial capacity allocation is highly asymmetric, with most available capacities allocated to j_1. When one dominant supplier owns a large proportion of the available capacity, the use of traditional valuation methods can lead him to overestimate the value of additional storage capacity. However, the other suppliers will underestimate it.

In addition to underinvestment, another side-effect of the use of the myopic valuation is to inhibit the growth of small suppliers in the downstream market. In effect, if all suppliers would use the actual valuation, suppliers with less initial capacity would be more induced to invest, which would progressively re-equilibrate the allocation of storage capacities. Instead, the use of the same myopic valuation $\tilde{V}$ by all suppliers irrespective of their initial capacities tends to maintain the initial storage capacity positions of the suppliers, and hence, to freeze their downstream market shares.

4 Storage valuation and demand characteristics

Suppliers buying in the same spot market can be active in different downstream markets. Gas markets in Europe are organized on a regional basis around a small number of hubs, and the suppliers who meet there are not necessarily competing in the same geographical markets.[14] In addition, even in a single country, suppliers can serve different customer segments : incumbents tend to serve most residential customers, while new entrants specialize in supply to the business or manufacturing sectors. These customer segments can have very different demand profiles : typically, residential demand exhibits a strong seasonal swing as more gas is used in the winter for heating, whereas industrial demand is rather flat throughout the year.

In this section, we prove that when a supplier interacts in the spot market with firms

[14] A gas hub is the point of entry into a natural gas transmission network. Hubs draw supply from a variety of sources and enable suppliers to market gas to their customers. A gas hub can be a physical location, usually a pipeline network node, or a virtual trading point (like the National Balancing Point (NBP) in Great Britain) where gas products are financially traded but not physically delivered. For a description of European gas hubs, see the Ecorys report (2008).

active in other downstream markets, his valuation of storage is affected both by his own demand profile and by the demand profile of the other operators.

Consider two suppliers, A and B, each active in a different downstream market. They face demands characterized by

$$p_A = d - z_A, \tag{4.35}$$

$$p_B = d - z_B, \tag{4.36}$$

where p_j and z_j (for $j = A, B$) are the price and the total quantity sold on market j, *i.e.* the market where supplier j is active. As in the previous section, supplier j commits to sell to his customers at price p_j a total quantity z_j, of which a proportion $1 - x_j$ (with $0 \leq x_j \leq 1$) is to be sold in a first period and a proportion x_j in a second period. We assume that d is the same in both markets, to focus on the impact of seasonality (x_A and x_B can differ).

To simplify, we suppose that suppliers A and B are the only operators active in the spot market. As in the previous section, a price-taking producer whose production cost function is given by (4.1) is assumed to sell gas in the spot market. The spot prices in the first and second periods are, respectively,

$$p = b + w_A + w_B + (1 - x_A)z_A + (1 - x_B)z_B, \tag{4.37}$$

$$p' = b - w_A - w_B + x_A z_A + x_B z_B. \tag{4.38}$$

Suppliers have access to storage : supplier j can store $w_j \leq K_j$ between the two periods. To simplify, both the storage cost and the interest rate are set to zero. The timing is similar to the previous section. In the first period, suppliers simultaneously choose their spot market positions, downstream sales and inventories. In the second period, they deplete their inventories and adjust their spot market positions to obtain the volumes needed to supply their downstream customers.

As previously, we introduce the following notation : for $j = A, B$, let

$$\begin{aligned} \alpha_j &\equiv \frac{\partial(p' - p)}{\partial z_j} && (4.39) \\ &= 2x_j - 1 && (4.40) \end{aligned}$$

denote the marginal impact of sales in the downstream market j on the spot price spread ; α_j is positive if demand in market j is higher in the second period than in the first period. Let

$$\begin{aligned} \beta_j &\equiv -\frac{\partial(p_j - (1 - x_j)p - x_j p')}{\partial z_j} && (4.41) \\ &= 2(1 - x_j + x_j^2) && (4.42) \end{aligned}$$

denote, in absolute terms, the impact of additional downstream sales in market j on the profit per unit sold in this market ; β_j is large if the seasonal profile of demand in market j is strongly marked (demand can be higher in either period), because in this case an increase in z_j tends to increase the spot price especially in the period where supplier j's spot demand is already high, which increases the average cost per unit purchased. Note that β_j is always strictly positive. Finally, let

$$\begin{aligned} \gamma_{AB} &\equiv -\frac{\partial(p_A - (1 - x_A)p - x_A p')}{\partial z_B} && (4.43) \\ &= x_A x_B + (1 - x_A)(1 - x_B) && (4.44) \end{aligned}$$

denote, in absolute terms, the impact of additional sales by supplier B in his downstream market on the profit per unit sold by supplier A in his own downstream market ; γ_{AB} is higher when the demand profile is similar in both markets (x_A and x_B are close to each other), because in this case a higher z_B tends to increase the spot price, especially in the period where A's spot purchases are higher, which adversely affects the supply profits of A. Note that $\gamma_{AB} = \gamma_{BA}$.

4.1 Equilibrium with no capacity constraints

The profit of supplier j is

$$\Pi_j = (p_j - (1-x_j)p - x_j p')z_j + (p'-p)w_j. \tag{4.44}$$

In the second period, there is no strategic choice to make, and supplier j simply buys $x_j z_j - w_j$ on spot, so as to sell $x_j z_j$ to his downstream customers. Now consider the choice of downstream sales and inventories by supplier A in the first period. He is a monopolist in his downstream market, but he interacts with the other supplier in the spot market. As in the previous section, we assume that suppliers are aware of the impact of their transactions on the spot prices. The derivatives of supplier A's profit with respect to his own sales and inventories are

$$\frac{\partial \Pi_A}{\partial z_A} = (d - z_A - (1-x_A)p - x_A p') + \alpha_A w_A - \beta_A z_A, \tag{4.45}$$
$$\frac{\partial \Pi_A}{\partial w_A} = (p'-p) + \alpha_A z_A - 2w_A. \tag{4.46}$$

The first-order condition with respect to z_A is

$$z_A = \frac{1}{2\beta_A}\left(d - b - \gamma_{AB} z_B + \alpha_A(2w_A + w_B)\right). \tag{4.46}$$

As expected, the sales of supplier A decrease when the other supplier's sales increase, because higher spot purchases by B increase the sourcing costs of supplier A. Given z_B, the sales of supplier A increase with all inventories — because all inventories reduce the price spread — but they increase more with his own inventories, which are bought at a cheaper price and carried over to the high-demand period, thereby lowering his total purchasing costs.

The first-order condition with respect to w_A is

$$w_A = \frac{1}{4}(2\alpha_A z_A + \alpha_B z_B - 2w_B). \tag{4.46}$$

If both $\alpha_A > 0$ and $\alpha_B > 0$, the stocks of the two suppliers are

$$w_A = \frac{\alpha_A(d-b)}{7}, \tag{4.47}$$
$$w_B = \frac{\alpha_B(d-b)}{7}. \tag{4.48}$$

The inventories smooth the spot price differential ($p' = p$), and therefore downstream sales are identical ($z_A = z_B = 2(d-b)/7$).

If only $\alpha_A > 0$ but $\alpha_B \leq 0$ (supplier B's demand profile is opposed to that of supplier A), the equilibrium inventories and sales are

$$w_A = \frac{3}{2(9\beta_B+4)}\left(\alpha_A\beta_B + \frac{\alpha_A+5\alpha_B}{6}\right)(d-b), \tag{4.49}$$
$$w_B = 0, \tag{4.50}$$
$$z_A = \frac{(1+6\beta_B)}{2(9\beta_B+4)}(d-b), \tag{4.51}$$
$$z_B = \frac{5}{9\beta_B+4}(d-b), \tag{4.52}$$

if and only if

$$\alpha_A\beta_B + \frac{\alpha_A+5\alpha_B}{6} > 0. \tag{4.52}$$

In this case, A holds inventories, but they are reduced due to the lower spot demand by B in the period where A's demand is high. Otherwise, if α_A is not large enough to compensate for the negative α_B, supplier A is not induced to carry inventories at all, even though his own demand profile increases over the two periods. To summarize, A holds inventories if and only if

$$\alpha_A > 0 \text{ and} \tag{4.53}$$
$$\max\left(\alpha_B, \alpha_A\beta_B + \frac{\alpha_A+5\alpha_B}{6}\right) > 0 \tag{4.54}$$

4.2 Equilibrium with capacity constraints

First assume, without loss of generality, that only supplier B is constrained : $w_B = K_B$. Combining the first-order conditions of both suppliers' programmes with respect to

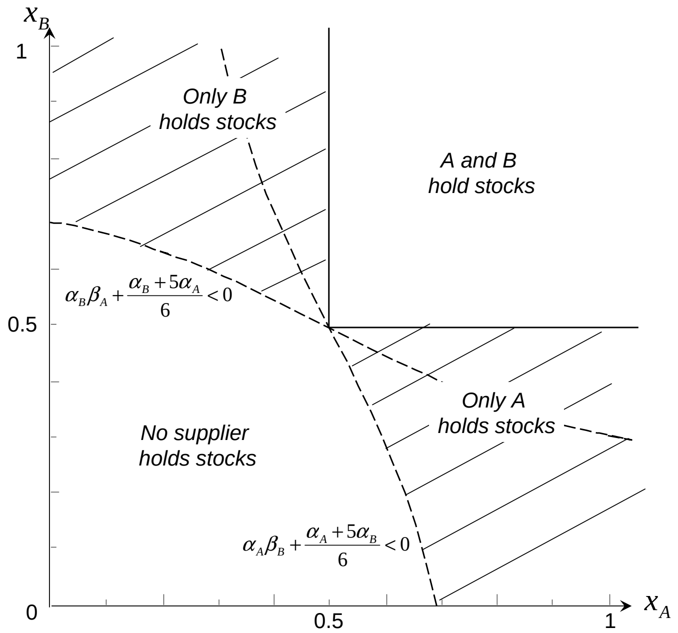

FIG. 4.1: Storage behaviour as a function of both suppliers' demand profiles (case with no capacity constraints).

sales and inventories yields the optimal inventory choice of A :

$$w_A = \frac{3}{2(9\beta_B + 4)} \left(\left(\alpha_A\beta_B + \frac{\alpha_A + 5\alpha_B}{6} \right) (d - b) - (\frac{16}{3} + \gamma_{AB})K_B \right) \tag{4.54}$$

if the right-hand side is lower than K_A (else $w_A = K_A$) and positive (else $w_A = 0$). Contrary to the unconstrained case, if B's demand is much higher in the second period and B's storage capacity is low, A will carry inventories even if his own demand is lower in the second period ($\alpha_A \leq 0$). In other words, supplier A carries inventories for supplier B, whose storage capacity is insufficient.

We shall focus on the case where both suppliers are capacity-constrained and they consider expanding their storage capacity. Given that supplier B is capacity-constrained, supplier A is constrained if and only if his capacity does not allow him to play his best response :

$$K_A < \frac{3}{2(9\beta_B + 4)} \left(\left(\alpha_A\beta_B + \frac{\alpha_A + 5\alpha_B}{6} \right) (d - b) - (\frac{16}{3} + \gamma_{AB})K_B \right), \tag{4.54}$$

and the condition for supplier B is obtained by symmetry.

Combining the first-order conditions of each supplier's programme with respect to his own sales yields

$$z_A = \frac{1}{4\beta_A\beta_B - \gamma_{AB}^2}((2\beta_B - \gamma_{AB})(d-b) + (4\beta_B\alpha_A - \gamma_{AB}\alpha_B)K_A + 2(\beta_B\alpha_A - \alpha_B\gamma_{AB})K_B), \tag{4.54}$$

$$z_B = \frac{1}{4\beta_B\beta_A - \gamma_{AB}^2}((2\beta_A - \gamma_{AB})(d-b) + (4\beta_A\alpha_B - \gamma_{AB}\alpha_A)K_B + 2(\beta_A\alpha_B - \alpha_A\gamma_{AB})K_A). \tag{4.54}$$

As expected, a supplier's sales increase with his own storage capacity. The effect of the other supplier's storage capacity is ambiguous. Consider the effect of K_A on z_B.

– A first, direct effect is related to the reduction of the price spread due to additional stocks : this effect is positive if $\alpha_B > 0$ ($x_B > \frac{1}{2}$).
– As can be seen from equation (4.1), K_A also has an indirect effect on z_B through its impact on z_A : the increase in supplier A's downstream sales is all the larger as the cost savings from additional stocks are significant, *i.e.*, x_A is large. In turn, a larger z_A will push spot prices upwards, which will negatively affect B, all the more so as the demand profiles are correlated (that is, A's additional demand tends to raise the spot price especially in the period where B purchases larger quantities on spot). The latter effect is proportional to γ_{AB}.

The global effect of K_A on the sales of supplier B is proportional to $\beta_A\alpha_B - \alpha_A\gamma_{AB}$, which can be computed explicitly :

$$\beta_A\alpha_B - \alpha_A\gamma_{AB} = 3(x_B - \frac{1}{2}) - (x_A - \frac{1}{2}). \tag{4.54}$$

This effect is positive if demand in market B is much higher in the second period than in the first, and/or if demand in market A is rather flat or higher in the first period. The impact of K_A on total sales can be positive or negative :

$$\frac{\partial(z_A + z_B)}{\partial K_A} = \frac{3}{4\beta_A\beta_B - \gamma_{AB}^2}\left(\alpha_A\beta_B + \frac{\alpha_A + 5\alpha_B}{6}\right). \tag{4.54}$$

The denominator is strictly positive, but $\alpha_A + 5\alpha_B$ can be sufficiently negative for the right-hand side to be negative. This leads us to state the following counterintuitive result.

Proposition 4.4. *Total sales of suppliers in the various downstream markets can decrease when a supplier expands his storage capacity, if the other supplier's demand profile is strongly "countercyclical".*

4.3 Storage valuation

4.3.1 Myopic storage valuation

A supplier who does not take the impact of his transactions on the spot prices into account will calculate the value of one additional unit of storage capacity as follows :

$$\widetilde{V} \equiv p' - p \tag{4.55}$$

$$= -2(K_A + K_B) + \alpha_A z_A + \alpha_B z_B. \tag{4.56}$$

Reinjecting the equilibrium sales from (4.54) and (4.54) yields

$$\begin{aligned}\widetilde{V} = & \frac{1}{2(4\beta_A\beta_B - \gamma_{AB}^2)}\left((\alpha_A + \alpha_B)(\alpha_A\alpha_B + 5)(d - b)\right. \\ & \left. -2(\gamma_{AB} + 6\beta_B + 8)K_A - 2(\gamma_{AB} + 6\beta_A + 8)K_B\right).\end{aligned} \tag{4.56}$$

The denominator is positive. When K_A and K_B are sufficiently small, the myopic valuation is positive whenever $\alpha_A + \alpha_B > 0$ (if the demand profiles are opposed, the inequality holds if the demand swing is larger in the market where demand is higher in the second period).

4.3.2 Actual storage valuation

When computing the additional profits from a marginal increase in storage capacity, a supplier has to take into account its consequences on the spot prices, whether they are direct or indirect (through a change in the other supplier's behaviour). Let $V_A \equiv \partial\Pi_A/\partial K_A$ denote the value of additional storage capacities for supplier A.

$$V_A = (p' - p) + \frac{\partial(p' - p)}{\partial K_A}K_A + \frac{\partial\left((p_A - (1 - x_A)p - x_A p')z_A\right)}{\partial K_A}. \tag{4.56}$$

Let us analyze the difference between this valuation and the myopic valuation $\widetilde{V} \equiv p' - p$. The global bias $\widetilde{V} - V_A$ can be decomposed into a first bias, related to cost savings from spot arbitrage, and a second bias, related to downstream profits :

$$\widetilde{V} - V_A = -\frac{\partial(p'-p)}{\partial K_A} K_A - \frac{\partial\left((p_A - (1-x_A)p - x_A p')z_A\right)}{\partial K_A}. \tag{4.56}$$

Volume effect

The price spread $p' - p$ is not constant with respect to K_A. As is clear from equation (4.56), additional storage capacities have a direct, negative impact on the price spread, and also have an indirect impact through their impact on equilibrium sales, whose sign is ambiguous according to Lemma 4.4. Globally, the impact of a higher K_A on the price spread is always negative, so that the first bias is positive :

$$-\frac{\partial(p'-p)}{\partial K_A} = \frac{\gamma_{AB} + 6\beta_B + 8}{4\beta_A\beta_B - \gamma_{AB}^2}. \tag{4.56}$$

Due to this volume effect, which reduces the savings actually achieved through the use of inventories, the myopic valuation tends to overstate the value of storage.

Downstream market power effect

A and B are not pure traders ; they also supply downstream customers, which leads to a second bias, because downstream profits are affected by a change in K_A :

$$\begin{aligned} &-\frac{\partial\left((p_A - (1-x_A)p - x_A p')z_A\right)}{\partial K_A} = \\ &-(p_A - (1-x_A)p - x_A p')\frac{\partial z_A}{\partial K_A} - \frac{\partial(p_A - (1-x_A)p - x_A p')}{\partial K_A} z_A. \end{aligned} \tag{4.56}$$

On the one hand, a supplier's sales increase with additional storage capacities if storage is justified by his own downstream demand : from (4.54), $\partial z_A/\partial K_A = 4\beta_B\alpha_A - \gamma_{AB}\alpha_B$, and because $4\beta_B$ is large compared to γ_{AB}, $\partial z_A/\partial K_A$ will generally be positive when $\alpha_A > 0$, and the first term in (4.56) will be negative.

On the other hand, the profit per unit sold in the downstream market (second term) can decline, especially if the increase in storage capacity raises purchasing costs, which means that the second term could be positive. Whether this will be the case depends on the demand profiles of both suppliers :

$$\begin{aligned}\frac{\partial(p_A-(1-x_A)p-x_Ap')}{\partial K_A} &= \alpha_A-\beta_A\frac{\partial z_A}{\partial K_A}-\gamma_{AB}\frac{\partial z_B}{\partial K_A} && (4.57)\\ &= \frac{\gamma_{AB}(\alpha_A-3\alpha_B)}{2(4\beta_A\beta_B-\gamma_{AB}^2)}. && (4.58)\end{aligned}$$

This expression is negative if and only if $\alpha_A < 3\alpha_B$, or equivalently, $x_A-\frac{1}{2} < 3(x_B-\frac{1}{2})$: we thus retrieve the condition that characterized the cross-effect of supplier A's storage capacity on the other supplier's sales. If the demand swing is sufficiently large in market B, the price-smoothing effect of additional stocks held by A will lead supplier B to increase his sales, and hence his spot purchases, which in turn will increase the purchasing costs for supplier A. In this case, an increase in K_A will decrease the profit per unit sold in market A.

To summarize, the first bias is positive, and the second bias is the sum of a negative term and a term that can be positive or negative : the sign of the total bias is generally ambiguous. This total bias can be expressed as a function of suppliers' sales :

$$\begin{aligned}\widetilde{V}-V_A &= \frac{-1}{4\beta_A\beta_B-\gamma_{AB}^2}\big((\frac{3\alpha_A-\alpha_B}{2}+3\alpha_A\beta_B)(d-b-\gamma_{AB}z_B+\alpha_AK_B)\\ &\quad +2(4+(9-4\beta_A)\beta_B+\gamma_{AB}^2)K_A\big)+\alpha_Az_A. && (4.58)\end{aligned}$$

Reinjecting the values of z_A and z_B yields

$$\widetilde{V}-V_A=\frac{1}{(4\beta_A\beta_B-\gamma_{AB}^2)^2}(\lambda_0(d-b)+\lambda_AK_A+\lambda_BK_B), \qquad (4.58)$$

where

$$\begin{aligned}\lambda_0 &= \frac{1}{4}(2\beta_B-\gamma_{AB})\left(-3\alpha_A(2\beta_A-1)(2\beta_B+1)-13\alpha_A+6\alpha_B\right) && (4.59)\\ \lambda_A &= (4\beta_A\beta_B-\gamma_{AB}^2)(12\beta_B-\gamma_{AB})+2\beta_B(3\alpha_B-\alpha_A)^2 && (4.60)\\ \lambda_B &= (4\beta_A\beta_B-\gamma_{AB}^2)(-4-6\beta_A+9\beta_B-\gamma_{AB})\\ &\quad -\frac{1}{2}\alpha_B(3\alpha_B-\alpha_A)(\gamma_{AB}^2+8\beta_A\beta_B)-\beta_B(3\alpha_B-\alpha_A)^2. && (4.60)\end{aligned}$$

$\lambda_A > 0$, but the sign of λ_B is ambiguous : it is generally negative, except for some cases where both x_A and x_B are close to 1/2. The sign of λ_0 is also ambiguous.

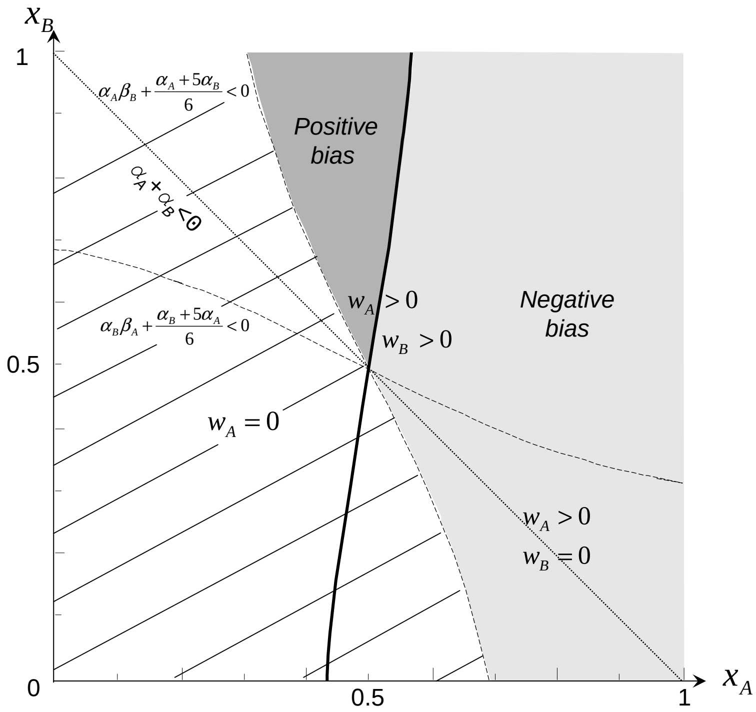

FIG. 4.2: Sign of the bias induced by the use of the myopic valuation by supplier A, when K_A and K_B are close to zero.

In the case where supplier A envisages investing in additional storage capacities, does the myopic valuation lead him to invest too much or too little ? We focus on the situation where supplier A already carries inventories (otherwise, additional investment is not an issue).[15]

To gain more insight into the role played by the demand profiles of both suppliers, consider the case where K_A and K_B are close to zero. In this case, the condition that guarantees that A holds positive stocks, also guarantees that he is capacity-constrained. Accordingly (see (4.1)), we assume that

$$\alpha_A\beta_B + \frac{\alpha_A + 5\alpha_B}{6} > 0,$$

[15]When inequality (4.1) is not satisfied, A carries no inventories at all ; however, it is possible that $\alpha_A + \alpha_B > 0$, so that myopic valuation is positive. In this case, the myopic valuation will overestimate the real value of storage for supplier A. However, it is not realistic to suppose that a supplier will invest if presently he uses no inventories at all.

which excludes the dashed area in Figure 4.2.

These conditions do not guarantee that the myopic valuation would lead the supplier to invest too little (negative bias). For small values of K_A and K_B (including the cases where B does not hold inventories), the sign of the bias is the sign of λ_0, which is negative if and only if

$$3\alpha_A(2\beta_A - 1)(2\beta_B + 1) > -13\alpha_A + 6\alpha_B, \tag{4.60}$$

where the left-hand side is strictly positive, and the right-hand side is negative unless α_B is much higher than α_A. Therefore, for most values of x_A and x_B, the bias will be negative.

However, the bias can be positive when α_A is close to zero (x_A close to 1/2) and α_B is very large (dark gray area in Figure 4.2). In such a situation, the strong demand swing in market B leads both suppliers to carry inventories, but despite a positive spot price spread, the fundamentals of demand in market A do not justify an increase in supplier A's stocks : this increase would make his purchases globally more expensive (as it would push supplier B's spot purchases upwards, as explained before), whereas it would hardly allow for any additional sales in market A. If supplier A based his investment decision on the sole price spread he would be induced to invest ; but an investment would not in fact be profitable for him. In this case, the myopic valuation overestimates the true value of additional capacities (positive bias).

More generally, the bias is more likely to be positive when K_A is large (remember that $\lambda_A > 0$) : as in the previous section, the volume effect prevails for a supplier with a large capacity, and the myopic valuation tends to overstate the true value of a capacity expansion.

Conversely, for a wide range of values of x_A and x_B, when x_B is not too large compared to x_A, the bias will be negative (light gray area in Figure 4.2), which means that using the myopic valuation will lead supplier A to underestimate the true value of a capacity increase, and thus to under-invest.

Proposition 4.5. *When suppliers buying in the same spot market are active in different downstream markets where they enjoy market power, the value of additional storage capacities for each of them is not equal to the traditional valuation based on spot price* *arbitrage. The sign of the bias is ambiguous.*

The bias is negative (the myopic valuation underestimates the true value) when the demand profile is strongly increasing in both markets, or when it is increasing in the investing supplier's market and is relatively flat in the other supplier's market.

The bias can be positive when demand in the investing supplier's market is flat but has a strong seasonal swing in the other market.

To conclude, it is possible for the myopic valuation to overestimate the true value of additional storage capacities in some particular cases, *i.e.*, where the demand profile of the investing supplier is rather flat and demand in the other market has a very strong seasonal profile. More often, the bias will be negative, and it will increase as the supplier's own demand exhibits a strong seasonal swing. In these cases, the myopic valuation will tend to underestimate the true value of storage and will induce under-investment in new storage capacity.

5 Conclusion

Most techniques developed for the valuation of real assets (such as storage capacities) related to commodities exchanged on a spot market are based on the modelling of spot prices and the computation of arbitrage profits. These methods consider that all the relevant information is included in these prices ; they ignore not only the determinants of supply and final demand for the good, but also the structure of the market, and in particular, the existence of market power. Even assuming a perfect modelling of spot prices, can real assets be valued correctly if market fundamentals are ignored ?

This paper has determined, in a simple setting, the error made by using a passive trading valuation that ignores the market power of storage users, whether they are pure traders or suppliers with downstream customers. Overlooking the volume effect of transactions on the price spread leads to overestimating the stream of trading profits from capacity additions. In addition, the right method for a pure trader is not necessarily well suited for a supplier. Indeed, it will be adequate only if both the upstream and downstream markets are competitive. Otherwise, ignoring downstream profit opportunities leads a supplier to underestimate the real value of storage capacity. Finally, in the case where suppliers active on the same spot market have customers with different demand profiles, the traditional valuation will usually be biased downwards, unless the demand profile of the investing supplier is flat while the demand of other suppliers exhibits a strong seasonal swing.

This systematic bias leads to real-world concern. In the European natural gas market, suppliers have increasingly had to rely on more rigid imports from external producers due to the decline of indigenous production from flexible fields in Northwestern Europe. Höffler and Kübler (2007) estimated that an increase from 25 % to 72 % of working gas volume will be necessary to mitigate the loss of supply flexibility related to this decline. Zwitserloot and Radloff (2009) emphasized the need for appropriate policy measures fostering investment in underground storage facilities to provide sufficient storage capacity for the European gas market. The present paper indicates that an unfavorable regulatory environment may not be the only reason that firms are reluctant to invest, in spite of the conspicuous need for additional storage. Suppliers' perceptions of the gains to be expected from new investments might be distorted due to the use of inappropriate valuation methods.

Why would a supplier use the myopic valuation approach to value his storage capacities if it is biased ? Presumably, this reflects a lack of necessary information to compute the correct valuation. The traditional techniques only require an accurate forecast of spot prices. While this might be difficult in general, in a relatively stable market, a model based on past realisations of prices and encompassing some elements related to external shocks (*e.g.*, weather or prices of other commodities) can yield fairly good predictions of future spot prices. Much more information is required to take market fundamentals into account, including detailed data about the market structure, about the supplier's own and other suppliers' final demand and about the storage capacities and costs of all market players. This information is difficult to collect and is sometimes not publicly available. As a consequence, the choice of traditional techniques can be explained by an insufficient knowledge of demand and of the functioning of the market. As all market players become more experienced and this sort of information proves to be relevant for making the right choices, new valuation techniques could be developed that more explicitly take market fundamentals into account.

References

Barrera-Esteve, Christophe, Florent Bergeret, Emmanuel Gobet, and al. (2006), "Numerical methods for the pricing of Swing options : a stochastic approach", Methodology and Computing in Applied Probability, 8, 4, 517-540.

Carmona, René and Michael Ludkovski (2008), "Pricing Asset Scheduling Flexibility using Optimal Switching", Applied Mathematical Finance, 15, 5-6, 405-447.

Décret n° 2006-1034 du 21 août 2006 relatif à l'accès aux stockages souterrains de gaz naturel, JO n° 0194, 23 August 2006.

Deng, Shi-Jie (2000), "Stochastic Models of Energy Commodity Prices and Their Applications : Mean-reversion with Jumps and Spikes", University of California Energy Institute Working Paper No. 73.

Felix, Bastian, Oliver Woll and Christoph Weber (2009), "Gas storage valuation under limited market liquidity : an application in Germany", EWL Working Paper n° 5, Chair for Management Sciences and Energy Economics, University of Duisburg-Essen.

Gibson, Rajna and Eduardo S. Schwartz (1990), "Stochastic convenience yield and the pricing of oil contingent claims", The Journal of Finance, 45, 3, 959-976.

Höffler, Felix and Madjid Kübler (2007), "Demand for storage of natural gas in northwestern Europe : Trends 2005-30", Energy Policy, 35, 10, 5206-5219.

Jaillet, Patrick, Ehud I. Ronn and Stathis Tompaidis (2004), "Valuation of Commodity-Based Swing Options", Management Science, 50, 909-921.

Loi n° 2003-8 du 3 janvier 2003 relative aux marchés du gaz et de l'électricité et au service public de l'énergie, JO n° 3, 4 January 2003.

Martinez-de-Albéniz, Victor and Josep Maria Vendrell Simon (2008), "A capacitated commodity trading model with market power", Working Paper no 728, IESE Business School-University of Navarra.

Manoliu, Mihaela and Stathis Tompaidis (2002), "Energy futures prices : term structure models with Kalman filter estimation", Applied Mathematical Finance, 9, 21-43.

Office of Gas and Energy Markets (2009), "Liquidity in the GB wholesale energy markets", Ofgem Discussion Paper 62/09.

Rademaekers, Koen, Allister Slingenberg and Salim Morsy (2008), "Review and analysis of EU wholesale energy markets", ECORYS Nederland BV report for the European Commission DG TREN.

Schwartz, Eduardo S. (1997), "The Stochastic Behavior of Commodity Prices : Implications for Valuation and Hedging", The Journal of Finance, 52, 923-973.

Secomandi, Nicola (2009), "On the Pricing of Natural Gas Pipeline Capacity", Manufacturing and Service Operations Management, Articles in Advance.

Sioshansi, Ramteen (2009), "Welfare impacts of electricity storage and the implication of ownership structure", mimeo, Ohio State University.

Sioshansi, Ramteen, Paul Denholm, Thomas Jenkin and Jurgen Weiss (2009), "Estimating the value of electricity storage in PJM : Arbitrage and some welfare effects", Energy Economics, 31, 2, 269-277.

Thompson, Andrew C. (1995), "Valuation of path-dependent contingent claims with multiple exercise decisions over time : the case of Take or Pay", Journal of Financial and Quantitative Analysis, 30, 271-293.

Zwitserloot, Reinier and Anke Radloff (2009), "Strategic Use of Gas Storage Facilities", Handbook Utility Management, A. Bausch and B. Schwenker (eds.), Springer-Verlag Berlin Heidelberg.

A Appendix

A.1 Proof of Lemma 4.2

From Lemma 4.1, if at least one supplier carries no inventory, then neither do the traders. Now suppose that all suppliers carry positive inventories and that their storage capacities are not binding. From (4.18), for all j, $T'(w_j) + \frac{1}{1+r}\alpha z_j = 0$. Summing up over all suppliers and rearranging yields

$$-n(rb + (1+r)c) - (2+r)(n\sum w_i + (n+1)\sum w_j) + (n+1)\alpha\sum z_j = 0. \tag{4.60}$$

Now suppose that m traders are active in the market with positive stocks : $T'(w_i) \geq 0$ for all i. Summing up over all traders and rearranging yields

$$-m(rb + (1+r)c) - (2+r)((m+1)\sum w_i + m\sum w_j) + m\alpha\sum z_j \geq 0. \tag{4.60}$$

Multiplying equation (A.1) by m and equation (A.1) by $(n+1)$ and then subtracting yields

$$m(rb + (1+r)c) + (2+r)(m+n+1)\sum w_i \leq 0. \tag{4.60}$$

This is impossible ; therefore no trader can be active in the market.

A.2 Equilibrium inventories in the case where not all firms are capacity-constrained

Let m_u and n_u denote the number of unconstrained traders and suppliers, and ΣK_{ic} and ΣK_{jc} denote the aggregate stocks of capacity-constrained traders and suppliers, respectively. Combining equations (4.11), (4.16) and (4.19) yields the equilibrium aggregate stocks :

$$\begin{aligned}\Sigma w_i \quad = \quad & \Sigma K_{ic} + \frac{m_u}{\Delta}\left((n-n_u)\alpha D - (n+1)\beta C - (n+1)(1+r)(3+r)\Sigma K_{jc}\right. \\ & \left. -((n+1)(1+r)(3+r) + (n_u+1)\alpha^2)\Sigma K_{ic}\right), \end{aligned} \tag{4.60}$$

$$\begin{aligned}\Sigma w_j &= \Sigma K_{jc} + \frac{n_u}{\Delta}\Big((m_u+n+1)\frac{(2+r)\beta}{(1+r)(3+r)}(\alpha D-\beta C)+m_u\beta C \\ &\quad -(n+1)(2+r)\beta\Sigma K_{ic} - ((n+1)(2+r)\beta + m_u\alpha^2)\Sigma K_{jc}\Big)\,, \qquad (4.60)\end{aligned}$$

where

$$\Delta = m_u(n-n_u)(1+r)(3+r) + (m_u+n+1)(n_u+1)(2+r)\beta. \qquad (4.60)$$

The inventories of one individual unconstrained firm are easily computed : $w_i = (\Sigma w_i - \Sigma K_{ic})/m_u$ and $w_j = (\Sigma w_j - \Sigma K_{jc})/n_u$. Let $\Sigma w \equiv \Sigma w_i + \Sigma w_j$ denote the total inventories carried at equilibriu. Total inventories are

$$\begin{aligned}\Sigma w &= \frac{1}{\Delta}\Big(\frac{\Delta-(m_u+n+1)(2+r)\beta}{(1+r)(3+r)}(\alpha D-\beta C)-m_u\beta C \\ &\quad +(n+1)(2+r)\beta(\Sigma K_{ic}+\Sigma K_{jc}) + m_u\alpha^2\Sigma K_{jc}\Big)\,. \qquad (4.60)\end{aligned}$$

Conclusion Générale

Cette thèse s'appuie sur des modèles théoriques d'économie industrielle pour analyser les problèmes liés à la libéralisation du marché du gaz naturel en Europe. Si ces modèles sont trop simplifiés pour permettre des simulations à partir de données réelles, ils permettent néanmoins de comprendre des mécanismes qui sont à l'œuvre dans les relations entre les acteurs stratégiques de ce marché loin d'être en concurrence pure et parfaite, et de révéler des résultats qui vont parfois à l'encontre des intuitions basiques.

Le premier chapitre a analysé le lien entre durée des contrats et incitations à l'investissement en capacités, dans une relation bilatérale où le vendeur ne peut écouler son produit que dans les limites de la capacité initialement installée par l'acheteur. On considère souvent que les contrats à long terme permettent de stimuler l'investissement, puisque l'investisseur se voit garantir un prix raisonnable sur une longue durée et n'a donc pas à craindre d'être exproprié de tout le surplus créé grâce à son investissement. L'analyse développée dans ce chapitre montre que dans le cas d'investissements en capacités, si l'acheteur préfère effectivement une protection plus longue, il n'est pas pour autant incité à investir plus, au contraire. La raison est la suivante. Dans le cas de contrats avec une tarification linéaire, le vendeur ne dispose que d'un seul instrument, le prix unitaire valable durant le contrat, pour inciter l'acheteur à investir (ce qui requiert un prix faible) et pour extraire le surplus de l'acheteur pendant la durée du contrat (ce qui requiert un prix élevé). Quand le contrat est long, le vendeur n'est pas prêt à sacrifier ses profits en attendant l'expiration du contrat, et il fixe un prix de contrat relativement élevé, qui donnera de moins bonnes incitations à l'investissement. Dans ce contexte, l'acheteur et le vendeur ont des intérêts opposés : le premier souhaiterait le contrat le plus long possible, et le second préfèrerait un contrat le plus court possible. La durée des contrats observés en pratique ne serait donc pas le résultat d'une optimisation, mais plutôt un compromis entre des parties aux intérêts divergents.

Le deuxième chapitre s'est intéressé aux possibilités d'utilisation stratégique du stockage saisonnier. La littérature sur le sujet voit dans le stockage un moyen de préempter la demande future au détriment des concurrents : chaque fournisseur voudrait ainsi être le seul, ou le premier, à accéder au stockage. Pourtant, l'analyse présentée dans ce chapitre montre que tel n'est pas nécessairement le cas lorsque la structure verticale du marché est prise en compte. En effet, le stockage joue aussi un rôle dans les relations avec le producteur auprès duquel les fournisseurs s'approvisionnent. En l'absence de stockage, le producteur pourrait ajuster son prix à chaque période en fonction de la demande des consommateurs finals, mais l'existence du stockage permet aux fournisseurs de contrer ce pouvoir de marché puisqu'ils peuvent acheter quand le prix est bas et stocker plutôt que de subir les fluctuations des prix amont. Le stockage donne donc aux fournisseurs un avantage stratégique vis-à-vis du producteur. On montre cependant que si les fournisseurs s'approvisionnent sur un marché de gros à un prix commun fixé par le producteur, les stocks des uns exercent une externalité sur les profits des autres puisque tous sont affectés par les variations des prix de gros. Il est ainsi possible, lorsque les capacités de stockage sont relativement abondantes, qu'un fournisseur préfère laisser stocker son concurrent et bénéficier de la baisse future du prix de gros due à ces stocks, ce qui est d'autant plus profitable que, n'ayant pas ou peu stocké, il achètera des quantités importantes à ce prix. Néanmoins, si la capacité totale est suffisamment faible, un fournisseur préférera toujours réserver le plus de capacités possible pour stocker lui-même, sans en laisser à son rival. Cette analyse confirme donc les craintes des autorités de concurrence et de régulation sur de possibles abus sur le marché du stockage, sur un marché européen où les capacités semblent globalement limitées. En revanche, la rétention injustifiée de capacités ne semble pas être un risque réel : les capacités réservées par l'opérateur détenant le stockage sont toujours utilisées intégralement.

Le troisième chapitre s'est penché sur la problématique de l'accès à la ressource gazière par les nouveaux entrants ne disposant pas, comme l'opérateur historique, de contrats à long terme avec les gros producteurs extracommunautaires. Cette problématique est au croisement de l'objectif de libéralisation du marché aval et des préoccupations liées à la sécurité d'approvisionnement. Pour remplir le premier, on souhaiterait donner aux nouveaux entrants un accès à ces contrats à des conditions attractives, mais pour faire face aux secondes, il convient de ne pas supprimer les incitations de l'opérateur historique à importer des volumes suffisants, et si possible, à des conditions raisonnables. La conception d'un programme de cession de gaz semble donc relever de la quadrature du cercle. Ce chapitre a comparé différents modèles de programmes de cession de gaz et analyse leurs limites. Il apparaît que promouvoir l'entrée de nouveaux acteurs et maintenir des volumes suffisants de contrats à long terme à un prix attractif ne sont pas des objectifs incompatibles. Le choix optimal pourrait consister à laisser l'opérateur historique continuer à négocier seul les contrats avec son partenaire, mais à l'obliger à revendre les volumes acquis à tous les fournisseurs intéressés, à un prix égal à son coût moyen d'approvisionnement. Cette solution, qui a l'avantage de ne pas affecter le volume des contrats, serait la plus efficace à la fois pour attirer de nouveaux entrants et pour réduire la rente du producteur étranger, qui serait transférée vers l'aval. Un choix aussi radical peut cependant être difficilement applicable. Les programmes de "gas release" mis en place jusqu'ici étaient beaucoup moins ambitieux. Si le régulateur ne peut exiger que la cession d'une faible proportion du contrat, il peut être préférable de fixer un prix de cession inférieur au coût d'approvisionnement de l'opérateur historique, en particulier si le producteur a un pouvoir de négociation important qui lui permet d'exiger un prix élevé et de récupérer la plus grande partie du surplus lié au contrat à long terme. D'une part, ce prix de cession attractif compensera la faiblesse des volumes cédés. D'autre part, comme le producteur doit partager avec l'opérateur historique le surplus lié au contrat et que ce surplus est réduit puisque les quantités vendues en "gas release" sont vendues à perte, il devra se contenter d'une rente plus faible.

Le dernier chapitre a évoqué la question de la valorisation d'actifs réels tels que des actifs de stockage par des méthodes basées sur des opérations d'arbitrage sur les marchés de gros. Ces méthodes sont indifféremment employées par des purs arbitragistes qui se servent effectivement du stockage pour ce type d'opérations, et des fournisseurs qui l'utilisent pour faire face aux fluctuations saisonnières de la demande de leurs clients. L'analyse montre que de telles méthodes, en supposant que tous les acteurs prennent les prix comme donnés, négligent l'impact des transactions sur les prix, impact qui est en fait pris en compte par les opérateurs qui effectuent ces transactions. Elles conduisent ainsi à surévaluer les profits qui peuvent être générés par des installations de stockage servant à l'arbitrage sur les marchés de gros. A l'inverse, ces méthodes ignorent les fondamentaux de la demande sur le marché aval, alors que des données comme le nombre d'acteurs présents, leur capacité de stockage et l'évolution de la demande doivent être prises en compte pour une valorisation correcte du stockage dès lors que le marché aval n'est pas en concurrence parfaite. Cet oubli conduite généralement à sous-estimer la valeur d'un investissement dans une nouvelle installation de stockage. De plus, le fait que des nouveaux entrants donnent au stockage la même valeur que des opérateurs importants disposant déjà de capacités significatives, et pour qui des capacités additionnelles sont de peu de prix, risque d'entraver le rééquilibrage naturel auquel devrait conduire une valorisation correcte tenant compte de la situation de chaque opérateur. L'usage de ces méthodes ignorant les fondamentaux du marché, s'il est généralisé, risque ainsi à la fois de conduire à un sous-investissement global dans le stockage et de geler les positions acquises par les opérateurs dominants.

Tout modèle stylisé d'un marché aussi complexe que celui du gaz naturel présente nécessairement des limites. Chacun des chapitres de cette thèse a nécessairement dû, pour pouvoir présenter des résultats analytiques, se restreindre à une vision partielle du marché. Ainsi, les modèles du premier et du troisième chapitre supposent qu'il n'existe qu'un seul producteur auprès duquel le ou les acheteurs peuvent négocier des contrats à long terme, alors qu'en pratique, ils peuvent dans une certaine mesure mettre en concurrence les différents grands producteurs ; c'est moins vrai, cependant, lorsque les capacités de production et de transit ne permettent pas une augmentation des volumes échangés et que tout nouveau contrat implique un investissement spécifique lourd. A l'inverse, le deuxième chapitre ne modélise pas la possibilité, pour les fournisseurs, de s'approvisionner par contrats à long terme et non pas seulement sur un marché spot, une alternative qui est ouverte (au moins à l'opérateur historique) dans le troisième chapitre. Le deuxième chapitre représente une industrie où les relations aussi bien en amont, avec le producteur, qu'en aval, avec les consommateurs, sont extrêmement flexibles. Une modélisation alternative comme celle du chapitre 4, où les fournisseurs s'engagent auprès de leurs clients par des contrats annuels, pourrait être envisagée. Plus généralement, la modélisation du pouvoir de marché à la fois en amont et en aval, qui est une spécificité du marché du gaz naturel européen, pose des difficultés particulières. Une représentation par un oligopole successif, comme dans le deuxième chapitre, implique que les fournisseurs prennent comme donné le prix qui est fixé par le producteur au niveau où il le souhaite. Cette modélisation a l'avantage de permettre d'obtenir des résultats analytiques qui peuvent se prêter à des simulations numériques (Boots, Rijkers et Hobbs, 2004). Cependant, elles ne correspond pas nécessairement à la réalité des relations entre producteurs et fournisseurs (Smeers, 2008). D'autres modélisations sont possibles, où, par exemple, le producteur décide d'une quantité et les fournisseurs annoncent le prix qu'ils sont prêts à payer pour cette quantité (Gabzewicz et al., 2007). C'est en quelque sorte l'inverse qui se produit dans le modèle du premier chapitre, où l'acheteur détermine à l'avance le volume maximal qu'il pourra acheter, et le producteur garde la maîtrise du prix. Ce chapitre souligne combien la nature des instruments de tarification a un effet crucial sur l'équilibre obtenu en termes de prix, de quantités et d'investissement. Enfin, des modélisations de type coopératif comme celle proposée dans le troisième chapitre ont été adoptées par certains auteurs (Hubert et Ikonnikova, 2004). Comme le souligne Smeers (2008), si les économistes modélisateurs choisissent souvent de ne représenter le pouvoir de marché qu'à l'amont de la chaîne afin de pouvoir obtenir des résultats analytiques explicites (Egging et Gabriel, 2006), la Commission Européenne semble avoir adapté sa vision du marché du gaz naturel à ses possibilités réelles d'action en déclarant que le marché amont n'est probablement pas concentré et que c'est le pouvoir de marché sur l'aval de la chaîne qui est problématique (European Commission, 2007) ; son analyse est différente pour l'électricité, produite essentiellement en Europe par des opérateurs dont la Commission souligne le pouvoir de marché. Pourtant, comme le montrent les modèles présentés dans cette thèse, une meilleure connaissance des fondamentaux du marché du gaz naturel et une meilleure compréhension des comportements stratégiques de ses acteurs sont essentielles pour concevoir des politiques énergétiques et des politiques de concurrence efficaces.

Références

Boots, Maroeska G., Fieke A.M. Rijkers and Benjamin F. Hobbs (2004), "Trading in the Downstream European Gas Market : A Successive Oligopoly Approach", Energy Journal, 25, 3, 73-102.

European Commission (2007), DG Competition Inquiry pursuant to Article 17 of Regulation (EC) No 1/2003 into the European gas and electricity sectors (Final Report), SEC(2006) 1724, Brussels, 10 January 2007, COM(2006) 851 final.

Egging, Rudolf G. and Steven A. Gabriel (2006) : Examining Market Power in the European Natural Gas Market. Energy Policy, 34, 17, 2762-2778.

Gabszewicz, Jean, Didier Laussel, Tanguy van Ypersele, and Skerdilajda Zanaj (2007), "Market games and successive oligopolies", CORE Discussion Paper 2007/10, Université catholique de Louvain.

Hubert, Franz and Svetlana Ikonnikova (2003), "Strategic Investment and Bargaining Power in Supply Chains : A Shapley Value Analysis of the Eurasian Gas Market", mimeo, Humboldt Universität. Berlin.

Smeers, Yves (2008), "Gas Models and Three Difficult Objectives", CESSA Working Paper Nr. 13.

Vu : le Président

M.

Vu : les suffragants

M.M.

Vu et permis d'imprimer :

Le Vice-Président du Conseil Scientifique Chargé de la Recherche de l'Université Paris-Dauphine.

Stratégies d'engagement et pouvoir de marché : une application au marché du gaz naturel

Cette thèse est consacrée à l'analyse des stratégies d'engagement en concurrence imparfaite, avec une application au marché européen du gaz naturel. Les deux premiers chapitres s'intéressent aux aspects dynamiques des stratégies d'engagement comme la préemption, les contrats à long terme ou l'expropriation. Le premier chapitre traite des investissements en capacités dans une relation bilatérale où l'acheteur est soumis à un risque d'expropriation. Bien qu'un degré minimal d'engagement soit indispensable pour assurer l'investissement, un engagement trop long du vendeur peut conduire à un niveau d'investissement plus faible. Le deuxième chapitre analyse l'utilisation stratégique du stockage dans un double oligopole, et montre que si le stockage peut être utilisé dans le but de préempter la demande future, les firmes peuvent néanmoins avoir intérêt à s'engager à ne pas utiliser une telle stratégie. Les deux chapitres suivants traitent des situations où les acteurs présentent des asymétries dans l'accès au marché. Le troisième chapitre propose une analyse positive et normative des programmes de cession de gaz visant à renforcer la concurrence sur le marché aval de la fourniture du gaz, en donnant aux nouveaux entrants un accès aux contrats à long terme de l'opérateur historique avec des producteurs étrangers. Enfin, le quatrième chapitre montre que l'utilisation, par des entreprises du secteur de l'énergie, de méthodes de valorisation des actifs fondées sur des opérations d'arbitrage sur les marchés de gros risque de ne pas conduire aux choix d'investissement optimaux. Ce chapitre souligne combien il est important de prendre en compte les fondamentaux du marché pour prendre des décisions optimales en concurrence imparfaite.
Mots-clés : économie industrielle, gaz naturel, stockage, contrats à long terme, investissements.

Commitment strategies and market power in the natural gas market

This thesis is devoted to the analysis of commitment strategies in oligopolistic markets, with a particular focus on the European natural gas market. The first two chapters analyze dynamic aspects of commitment strategies such as preemption, long-term contracts and holdup. The first chapter focuses on capacity investments in a bilateral relationship where the buyer-investor faces the threat of holdup. While some commitment is necessary to ensure investment, a too long commitment by the seller can lead to a lower investment level. The second chapter analyzes the strategic use of storage in a successive oligopoly and shows that while demand preemption through storage can be profitable, firms can however choose to commit not to use such a strategy. The next two chapters consider situations where access to the market is asymmetric. The third chapter provides a positive and normative analysis of gas release programs that aim at fostering competition in the downstream gas market by granting new entrants access to the incumbent's long-term contracts with foreign producers. Finally, the fourth chapter analyzes how real asset valuation methods based on spot market arbitrage can lead to suboptimal investment choices. It underlines why taking market fundamentals into account can be crucial to make efficient decisions under imperfect competition.
Key words : industrial organization, natural gas, storage, long-term contracts, investments.
