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This version: February 2015

Abstract

This paper presents a game-theoretic analysis of multimarket competition with capacity investments, applied to international gas markets. It identifies a strategic advantage of "focused" pipeline gas producers (e.g., Gazprom) over "diversified" multimarket exporters of liquefied natural gas (e.g., Qatar). Based on this, the paper examines the spillover impacts of the Fukushima nuclear accident onto European gas markets, both in the short- and longer-term. It also discusses Russia's gas export strategy, especially the 2014 deals with China. More generally, the analysis shows how a less efficient oligopolist can be more profitable, and speaks to policy discussions about "security of supply" in energy markets.

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JEL classifications: D43 (oligopoly pricing), F12 (international trade with imperfect competition), L25 (firm scope), L95 (natural gas)

1 Introduction

This paper presents an analysis of competition in natural gas markets, with an emphasis on the strategic interaction between pipeline-based sellers, such as Russia/Gazprom and Norway, and exporters of liquefied natural gas (LNG), such as Qatar, Australia, and Nigeria. Following the expansion of international trade in LNG over the last 10 years, pipeline gas and LNG now increasingly compete head-to-head, notably in the European market. But they are also fundamentally different. Gas pipelines are large investments with a very high degree of asset specificity: once built, they are physically bound to a particular route, with no alternative use (Williamson, 1985; Makholm, 2012). LNG, on the other hand, is transported by tanker, giving exporters a *choice* of markets for any cargo. From a strategic perspective, a key question is how this difference affects the competitive playing field between these two types of exporters.

The global gas market lends itself to such an analysis for several reasons. First, natural gas increasingly plays an important role in energy policy—and geopolitics. The US shale gas revolution has already had large knock-on effects across energy markets and economies worldwide, and the US itself looks set to become a major LNG exporter over the coming years. The Fukushima Daiichi accident of March 2011 highlighted the ability of flexible LNG supplies to "fill the gap" in Japan's energy mix after its nuclear shutdown.[1] Concerns over energy security have re-emerged due to the political conflict between Russia and Ukraine; at the same time, Russia and China recently concluded the largest-ever natural gas deal, reportedly worth US$400 billion.[2]

Second, there can be little doubt that the interaction between these players is of a highly strategic nature. There is significant seller concentration in natural gas, and its regional fragmentation—into US, European and Asian markets, with widely varying prices—is, at least in part, driven by exporter market power (Ritz, 2014).[3] Moreover, it is striking that a commodity destined for the same end-use—in industrial production and residential heating—is supplied by two types of producers with very different technologies and organizational structures. In this way, these markets are well-suited to analysis using the toolkit of game theory.

Third, gas is underresearched in the academic literature, certainly relative to its cousins: electricity and oil. While economists have been influential in the analysis and design of electricity markets since deregulation began in the 1980s, and there is a substantial literature on the influence of OPEC on the performance of the crude oil market, there is much less on natural gas—and especially little that speaks to recent events. This paper attempts to fill some of these gaps.

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[1] Contracting arrangements have also become more flexible in LNG markets over the last decade. Traditionally, investments were backed up by long-term contracts (of around 20 years duration) between a seller and buyer. Today, trade in spot and short-term markets makes up about 30% of global LNG sales (GIIGNL, 2013). These short-term transactions were key to the market response to the Fukushima accident.

[2] Natural gas is also seen by many analysts as a pathway to achieve medium-term climate policy targets, given that it has only half the carbon intensity of coal.

[3] Average gas/LNG prices in 2013 were roughly US$16 per million metric British thermal units in Asia (Japan and South Korea), US$10/MMBtu in Europe (UK and Germany), and US$4 in the US (at Henry Hub).

The analysis examines a simplified version of the global gas market: A pipeline producer, say Russia/Gazprom, sells gas to the European market while an LNG exporter, say Qatar, sells to both European and Asian gas consumers. The model is a two-stage game of investments in production capacities followed by quantity competition. Its key feature is that the LNG exporter chooses how to deploy its capacity across the two markets. This creates a supply-side link between them, and allows for an analysis of how local "shocks" spill over from one market into another—and their implications for competitive balance and consumer welfare.

The first main result is that the "focused" producer (Gazprom) enjoys a structural competitive advantage over the "diversified" seller (Qatar) in their common market. The multimarket firm's optimal strategy equalizes marginal revenues across export markets. Recognizing this, Gazprom strategically over-expands its capacity and market share in the European market, thus depressing the local price, knowing that Qatar can still employ its capacity in Asia. This cross-market strategic effect is always present; its magnitude depends on (relative) market fundamentals. The result suggests that Gazprom's traditional focus on Europe may be a source of *strength*, rather than a weakness as is usually argued in policy discussions around "energy security" (e.g., European Commission, 2014). Moreover, Gazprom's role is similar to that of a Stackelberg leader, so this constellation *benefits* European gas buyers.[4]

What were the global impacts of the Fukushima accident? What were its repercussions for European gas markets and Gazprom? The paper examines both short-term impacts—when firms' capacity levels are fixed—and longer-term effects—when firms can re-optimize capacity in light of changes in market conditions. The long-term impacts are driven crucially by changes in the magnitude of the strategic effect. The results suggest that, in the longer term, an Asian LNG demand boom makes Qatar a *stronger* competitor in Europe. This hurts Gazprom as well as European gas consumers, as prices rise due to less aggressive competition (i.e., a weaker strategic effect). This long-run response differs from Fukushima's short-term impact: For Qatar, in the short run, raising sales to Asia means cutting those to Europe. This allows Gazprom to gain further market share in the short run—while it loses share over the longer term as LNG producers invests more heavily in capacity.

The paper presents formal conditions for these results. Simple conditions which are sufficient—but not necessary—for the long-run impacts boil down to the following: Qatar has relatively high market power in the Asian LNG market, and the demand boom enhances its ability to capture social surplus (thus mitigating its strategic weakness due to multi-market exposure). These conditions seem plausible in light of market experience before and after Fukushima. They are formally equivalent to a rate of pass-through from costs to price that is below 50% and does not rise with the demand boom. As in Weyl and Fabinger (2013), cost pass-through is a useful way to think about competitive interactions and the division of social surplus in different markets. However,

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[4]Of course, the present model should not be taken to capture all the issues that are relevant in practice; the more modest objective here is simply to point out there exists a strategic consideration which goes against the "conventional wisdom". (Gazprom assumes a role similar to that of a Stackelberg leader even though the timing of the model has simultaneous choices of capacities, and then outputs; the model does not examine issues of entry deterrence and pre-emptive investment.)

the results here are more subtle; they also depend on how pass-through might *change* with a demand boom. Some of the formal conditions are similar to those emerging in recent work on third-degree monopoly price discrimination (Cowan, 2012).

While the exposition of this paper focuses on international gas markets, its insights are more generally applicable. The analysis shows how a fundamental result from the theory of imperfect competition can be overturned. In standard oligopoly models, a more efficient firm (with lower unit cost) always has higher market share and profits. By contrast, a focused firm here can have a larger market share than a multimarket competitor despite (much) higher costs—due to the strategic effect described above.[5] In contrast to the classic repeated-game analysis of Bernheim and Whinston (1990), multimarket contact tends to *raise* market competitiveness—rather than facilitating tacit collusion.

This result has a similar flavour to the corporate-finance literature on the "diversification discount" applied to conglomerate firms by stock-market investors (Lang and Stulz, 1994; Campa and Kedia, 2002). One leading explanation is that multi-business firms are susceptible to wasteful rent-seeking by individual divisions who try to gain additional funding from corporate HQ—which has a choice of how to allocate funds across divisions (Meyer, Milgrom and Roberts, 1992). Similarly, the disadvantage of diversified firms here arises because "headquarters" has a choice of how to allocate production capacity across export markets—which can be influenced by rivals' competitive moves. The results here also suggest that the diversification discount may vary with the business cycle, and be larger during periods of market decline.

Another industry application is to airline markets. Consider the case of Frontier Airlines in the 1980s, as described by Bulow, Geneakoplos and Klemperer (1985). Frontier had diversified into new markets away from its original Denver hub. Following this, other airlines began to compete more aggressively in the Denver market. The present analysis offers an explanation: diversification gave Frontier a choice of where to deploy its airline fleet, allowing its competitors to expand by gaining a Stackelberg-type position at Denver. (This holds unless Frontier was able to extract *all* social surplus in new markets, which is highly unlikely.) More generally, the model gives a reason for why focused new entrants, especially low-cost carriers such as Southwestern, have enjoyed a strategic advantage over large incumbent airlines.

In examining how local shocks spill over to other markets, this paper relates to a growing literature on networks and "networked" markets. There has recently been a renewed interest in how production networks lead to the propagation of shocks around a system (Carvalho, 2014). An oft-cited example is the Fukushima accident, with its repercussions for global supply chains in automotives and electronics, amongst others.[6] While the modelling approaches

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[5] The model presented here builds on (and extends parts of) Shelegia (2012) who emphasized how competition between two firms in a given market can be influenced by a third firm competing in another market. This paper allows demand conditions to vary across markets and firms to be heterogeneous in terms of production and capacity costs. It also addresses different questions, while highlighting the application to international gas markets.

[6] Perhaps closest the the present paper, Bimpikis, Ehsani and Ilkilic (2014) present a model of Cournot competition in networked markets, and examine how local "shocks", such as new entry in part of the network, have implications for the entire structure of the network. They use natural gas markets as their first motivating example for their theory.

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taken in this literature are different, the underlying economic issues are closely related to those considered here.

Finally, this paper takes also a different approach to the bulk of the existing literature on natural gas markets, which is dominated by a small number of large-scale numerical models.[7] These are well-suited to policy analysis via numerical simulation of scenarios in terms of gas demand, investment volumes, etc. However, their complexity means that it can be difficult to understand what is driving the numbers. The present paper instead derives analytical results from a simplified model, with an emphasis on the microeconomic intuition.[8] In related work, Growitsch, Hecking and Panke (2014) simulate a large global gas oligopoly model to explore the potential impact of a (hypothetical) blockage of LNG tankers in the Strait of Hormuz. Their analysis also emphasizes supply-side concentration and the transmission of shocks across regional markets. Newbery (2008) also uses a simple microeconomic model to argue that climate-change policy in form of an emissions trading scheme can exacerbate market power issues in natural gas.[9]

The plan for the paper is as follows. Section 2 sets up the model, and Section 3 solves for the equilibrium. Section 4 presents the result on the competitive advantage of "focused" firms. Section 5 examines the cross-market impact of a demand shift, motivated by Fukushima. Section 6 applies these insights to understand Russia's evolving gas export strategy, especially the 2014 deals with China. Section 7 concludes. (Proofs are in the Appendix.)

2 Setup of the model

Firm 1 sells to both export markets, A and B, with outputs denoted by x_1, y_1. Firm 2 can sell only into market B, with sales of y_2.

Demand conditions are as follows. For simplicity, market B has a linear inverse demand curve $p^B(y_1, y_2) = \alpha - \beta(y_1 + y_2)$. Market A has a general demand curve $p^A(x_1)$; let $\xi^A \equiv -x_1 p_{xx}^A / p_x^A$ denote its curvature coefficient. (So demand in market A is concave if $\xi^A < 0 \iff p_{xx}^A < 0$, and convex otherwise.) Direct demand is assumed to be "log-concave", $\xi^A < 1$ (Bagnoli and Bergstrom, 2005). This is a common assumption in models of imperfect competition which ensures that second-order conditions are always satisfied. Competition between firms is therefore in strategic substitutes (Bulow, Geneakoplos and Klemperer, 1985).

The game has two stages. In the first stage, firms simultaneously invest in

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[7]A representative but non-exhaustive list includes Egging, Gabriel, Holz and Zhuang (2008), Holz, von Hirschhausen and Kemfert (2008), and Chyong and Hobbs (2014).

[8]A disadvantage of the present approach is that it yields only comparative-statics results—rather than realistic-looking numbers of the global gas market as a whole. Another difference is that existing large-scale models are typically "mixed complementarity problems" solved as "open loop" equilibria, in which capacity and production decision are, in effect, made simultaneously; the analysis here instead derives a "closed loop" equilibrium in which firms' capacity decisions have a strategic impact on subsequent play.

[9]Taking a different approach, based on cooperative game theory, Hubert and Ikonnikova (2011) examine the power structure in the Russian pipeline network, focusing on the balance between Russia and transit countries such as Belarus and Ukraine. Their approach has the advantage of incorporating bargaining power of both buyers and sellers while the present paper focuses on seller power. See also Elliott (2014) for a related network model which focuses on relationship-specific investments between trading partners.

production capacities, K_1 and K_2, respectively at unit costs of capacity $r_1 > 0$ and $r_2 > 0$. Firm 1 can use its capacity in both export markets. In the second stage, firms simultaneously decide how much output to sell into markets A and B, at unit costs of production $c_1 \geq 0$ and $c_2 \geq 0$, subject to their installed production capacities. These unit costs of production can be interpreted as including shipping and other transportation costs. Choices are observable to players, and there is no discounting.

Firms maximize their respective profits and the equilibrium concept is subgame-perfect Nash equilibrium. Assume throughout that demand and cost conditions are such that both firms are active in equilibrium, selling positive amounts to their respective export markets; standing assumptions are $\alpha > r_j + c_j$ for $j = 1, 2$, $c_j < \frac{1}{2}(\alpha + c_i)$ for $j \neq i$, $p^A(0) > r_1 + c_1$ and $p^A(x_1) < 0$ at sufficiently high x_1. Also assume that both producers sell up to capacity in Stage 2.[10] Conditions on parameter values which ensure these assumptions are met are given in Lemma 1.

Application to international gas markets. Think of market A as the Asian gas market—with Japan and South Korea (JKM spot price for LNG) in mind especially—and market B as Europe. Firm 1 is an LNG exporter, such as Qatar, serving both markets.[11] Firm 2 is a pipeline seller, such as Gazprom/Russia, focused on the European market.

The model is an abstraction of the following situation.[12] Globally, gas trade is around 70% by pipeline and 30% as LNG.[13] Russia is the world's 2nd largest producer of gas, with Gazprom controlling around 75% of production and holding a legal monopoly on exports of piped gas. Of its pipeline exports, over 80% go to European markets (the remainder goes to countries of the former Soviet Union, some of which also perform a transit role).[14] Qatar is the world's largest LNG exporter with a global market share of over 30%. Its two largest LNG destinations are Europe (especially UK and Italy) and Asia (especially Japan and South Korea), with a split of around 25% and 75%. (The US is now the world's largest gas producer but has little trade exposure (beyond Canada) given its current lack of LNG export infrastructure.)

From the European viewpoint, around 80% of total gas imports are by pipeline and 20% as LNG. Around 40% of Europe's total gas consumption is met via Russian pipelines, and the majority of imports come from Russia. LNG plays a particularly important role for the UK, Italy, and Spain (for which LNG imports can exceed pipeline trade), and close to 50% of European LNG imports come from Qatar. This paper's focus on the "balance of power"

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[10] The assumption that producers are capacity-constrained considerably simplifies the analysis. In effect, it reduces the "dimensionality" of the problem from five choice variables (two capacity choices plus three output choices) to three.

[11] Other multimarket LNG exporters—serving both Europe and Asia—include Algeria (Sonatrech), Nigeria, Peru, and Trinidad & Tobago.

[12] This summary is based on data from the BP Statistical Review of World Energy 2014.

[13] The LNG value chain includes the exploration and production of natural gas, subsequent liquefaction, shipping, and its regasification at the receiving end. All parts of the chain require significant capital outlay (or charter arrangements), and maintenance expenditure plays an important role, especially for offshore infrastructure. For pipeline gas, exploration and production is followed by pipeline transportation (usually but not always onshore).

[14] Russia's exports are around 95% by pipeline; the role of its (small) LNG exports is discussed in Section 6.

between Russia and Qatar as the key suppliers is consistent with industry analysis (Stern and Rogers, 2014). By contrast, many Asian countries rely heavily on LNG imports given the lack of pipeline infrastructure (with the main exception of China); LNG makes up 100% of Japanese and South Korean gas imports, and Japan is the world's largest LNG importer, with Qatar as its top supplier.

Other modelling assumptions reflect market conditions in global gas. The setup allows LNG and pipeline producers to have different cost structures, both in terms of production and investment. It assumes that Qatar has identical production costs for the European and Asian markets; this is a reasonable assumption as the respective transport costs are indeed very similar in practice, mainly since the shipping distances are roughly equal. There is no price arbitrage between markets A and B by third-party traders; the equilibrium may thus feature price differentials resulting from international price discrimination by producers. This is in line with experience in global gas markets (see note 3). Choices in Stage 1 can be interpreted as investments in production capacity; more generally, these reflect any kind of longer-term decisions, such as maintenance expenditure or procurement/chartering of other parts of infrastructure, which occur before short-run sales. Finally, the assumption that firms sell up to capacity in Stage 2 is reasonable for the natural gas industry, in which any capacity that is operational is typically also fully used.[15]

3 Solving the model

Define firms' revenue functions across the two markets, $R_1^A(x_1) = p^A x_1$ and $R_1^B(y_1, y_2) = p^B y_1$, $R_2^B(y_1, y_2) = p^B y_2$. Also define the corresponding marginal revenues $MR_1^A(x_1) = \frac{\partial}{\partial x_1}\left(p^A x_1\right) = p^A + p_x^A x_1$ and $MR_1^B(y_1, y_2) = \frac{\partial}{\partial y_1}\left(p^B y_1\right) = p^B - \beta y_1$, $MR_2^B(y_1, y_2) = \frac{\partial}{\partial y_2}\left(p^B y_2\right) = p^B - \beta y_2$.

3.1 Stage 2: Output decisions

Consider firms' output choices in Stage 2, given the capacity investments of Stage 1. By assumption, producers are capacity-constrained, implying that firm 1's sales satisfy $x_1 + y_1 = K_1$, while $y_2 = K_2$ for firm 2. The main question at this stage, therefore, is how firm 1 splits its sales across markets.

Clearly, firm 1 maximizes its profits by equating the contribution at the margin of each market. That is, it chooses a sales strategy (x_1, y_1) that equalizes marginal revenue, net of the short-run marginal cost of production, for each market: $MR_1^A(x_1) - c_1 = MR_1^B(y_1, y_2) - c_1 \iff MR_1^A(x_1) = MR_1^B(y_1, y_2)$. Since the firms are capacity-constrained, the equilibrium condition can be rewritten in terms of capacities:

$$MR_1^A(K_1 - y_1) = MR_1^B(y_1, K_2). \tag{1}$$

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[15] The application to gas markets is stylized in other respects. This includes the absence of intertemporal considerations on resource extraction à la Hotelling (sell today, or leave in the ground and perhaps sell tomorrow), as well as gas storage. Furthermore, the capacity investments made by producers are not exactly simultaneous in practice; for example, Russian pipelines in many cases preceded the LNG investments of other players.

Note that firm 1's choice of output to market B thus depends on the capacity installed by its rival, firm 2. This plays a crucial role, and is examined more closely, in what follows.

By contrast, for firm 2, $y_2 = K_2$, irrespective of firm 1's actions. The key difference is that, having made their investments, firm 1 has an alternative use for its capacity while firm 2 does not.

To summarize, given capacities $\mathbf{K} = (K_1, K_2)$, firms' output choices are $x_1(\mathbf{K})$, $y_1(\mathbf{K})$, and $y_2(\mathbf{K}) = K_2$.

3.2 Stage 1: Capacity decisions

Anticipating these output decisions, consider firms' decisions to invest in capacity at Stage 1. Firm 1 chooses its investment so as to maximize its joint profits across both export markets:

$$\max_{K_1} \left\{ R_1^A(x_1(\mathbf{K})) + R_1^B(y_1(\mathbf{K}), y_2(\mathbf{K})) - r_1 K_1 - c_1[x_1(\mathbf{K}) + y_1(\mathbf{K})] \right\},$$

which makes explicit the indirect dependency of its revenues and production costs on both firms' capacity choices. The first-order condition is:

$$0 = MR_1^A \frac{\partial x_1}{\partial K_1} + MR_1^B \frac{\partial y_1}{\partial K_1} - r_1 - c_1 \left(\frac{\partial x_1}{\partial K_1} + \frac{\partial y_1}{\partial K_1} \right). \tag{2}$$

This condition can be simplified. First, since the firm is capacity-constrained, $\partial x_1/\partial K_1 + \partial y_1/\partial K_1 = 1$; in other words, total sales across both markets rise one-for-one with capacity. Second, from (1), the firm equates marginal revenue across markets, $MR_1^A = MR_1^B$. This shows that the multi-market firm invests in capacity such that

$$MR_1^A = MR_1^B = r_1 + c_1, \tag{3}$$

where the right-hand side is its combined unit cost of capacity and production, i.e., its long-run marginal cost.

So the outcome in market A is the monopoly price given marginal cost $r_1 + c_1$. Denoting the associated monopoly output by x_m, it follows that $x_1 = x_m$, and so $y_1 = K_1 - x_m$.

Firm 2 chooses its capacity investment to:

$$\max_{K_2} \left\{ R_2^B(y_1(\mathbf{K}), y_2(\mathbf{K})) - r_2 K_2 - c_2 y_2(\mathbf{K}) \right\}$$

The first-order condition is:

$$0 = MR_2^B \frac{\partial y_2}{\partial K_2} + \frac{\partial R_2^B}{\partial y_1} \frac{\partial y_1}{\partial K_2} - r_2 - c_2 \frac{\partial y_2}{\partial K_2}. \tag{4}$$

Analogously to the previous firm, $\partial y_2/\partial K_2 = 1$, due to the binding capacity constraint. Note also $\partial R_2^B/\partial y_1 = -\beta y_2$ given the linear demand structure of market B. Define the "strategic effect" connecting markets $\lambda \equiv (-\partial y_1/\partial K_2)$. Thus simplifying the first-order condition gives:

$$MR_2^B + \beta \lambda y_2 = r_2 + c_2. \tag{5}$$

3.3 The strategic effect connecting markets, cost pass-through, and market power

Firm 2 recognizes that its capacity choice affects the product-market behaviour of firm 1 in their common market B. Totally differentiating the equal-marginal-revenues condition from (1) shows that the strategic effect satisfies:

$$\lambda \equiv \left(-\frac{\partial y_1}{\partial K_2} \right) = \frac{\frac{\partial MR_1^A}{\partial K_2} - \frac{\partial MR_1^B}{\partial K_2}}{\frac{\partial MR_1^A}{\partial y_1} - \frac{\partial MR_1^B}{\partial y_1}} = \left[\frac{\beta}{2\beta + \left(-p_x^A \right) \left(2 - \xi^A \right)} \right] \in (0, \tfrac{1}{2}), \quad (6)$$

and observe that $\left(-p_x^A \right) \left(2 - \xi^A \right)$ is the absolute value of the slope of the marginal revenue curve of firm 1 in market A, $\left| \frac{\partial}{\partial x_1} MR_1^A \right|$.[16] This effect raises the marginal return to firm 2 of installing an additional unit of capacity and so, in equilibrium, $MR_2^B < r_2 + c_2$.

The λ term captures how strongly firm 2 can induce firm 1 to cut back output in market B. This effect is always present unless, in the limiting cases, either $\beta \to 0$ or $\left(-p_x^A \right) \left(2 - \xi^A \right) \to \infty$. The case with $\beta \to 0$ corresponds to market B becoming very large (relative to market A). In such situations, firm 1 finds this market very attractive, and therefore only reluctantly redirects output away from it, and so λ is small. The case with $\left(-p_x^A \right)$ very large corresponds to consumers in market A being very price-insensitive; a small reduction in price only induces little additional demand. Finally, $\left(2 - \xi^A \right)$ very large, that is, $\xi^A \to -\infty$, corresponds to very concave demand in market A—in the limit, the demand curve becomes rectangular (so all consumers have almost the same willingness-to-pay).

The degree of monopoly power that firm 1 has in market A is key to understanding the strategic effect. An *index of monopoly power* equals the inverse of the rate of cost pass-through, $1/\rho^A = (2 - \xi^A)$, where the pass-through coefficient $\rho^A \equiv dp^A/dMC$ measures by how much the equilibrium price responds to a change in marginal cost (Bulow and Pfleiderer, 1983). The assumption of log-concave demand $\xi^A < 1$ means that pass-through lies below 100%. For a monopolist, the inverse rate of pass-through is equal to the ratio of firm profits to consumer surplus (Weyl and Fabinger, 2013).[17]

In the limit, as pass-through tends to zero, the monopolist extracts all the available gains from the trade in market A; thus, there is no distortion below the first-best level of output. In this situation, there is no scope for firm 2 to strategically influence its decision-making, as it will not deviate from its preferred level of output, and so $\lambda = 0$. Intuitively, with such pronounced market power, firm 1 will be very careful to divert additional units to market

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[16] The final equality uses that $\partial MR_1^A/\partial K_2 = 0$ (firm 2's actions have no direct impact on revenues in market A), $\partial MR_1^B/\partial K_2 = \partial MR_1^B/\partial y_2$, $\partial MR_1^A/\partial y_1 = -\partial MR_1^A/\partial x_1$, as well as the definition of demand curvature $\xi^A \equiv -x_1 p_{xx}^A/p_x^A$. To understand the expression, note that a small increase $dK_2 > 0$ lowers 1's marginal revenue in market B by $dMR_1^B = (\partial MR_1^B/\partial y_2)(dK_2) = -\beta(dK_2) < 0$. By how much does y_1 need to adjust to restore optimality? Cutting y_1 both raises MR_1^B and lowers MR_1^A; specifically, $dMR_1^B = -2\beta(dy_1) > 0$ and $dMR_1^A = \left(-p_x^A \right) \left(2 - \xi^A \right) (dy_1) < 0$, thus leading to the expression for λ.

[17] The rate of pass-through has no necessary relationship with the conventional price elasticity of demand. Recall that a monopolist facing a linear demand curve extracts 50% of the potential social surplus (with 25% left each as consumer surplus and deadweight loss), *regardless* of the particular equilibrium value of the price elasticity of demand.

A—and depress price there. By contrast, an almost perfectly competitive seller with little market power would be almost indifferent to selling more to market *A*, and can thus be more easily manipulated in its decision-making.

3.4 Summary of the equilibrium

Firm 1's output in market A is at the monopoly level, $x_1 = x_m$. By assumption firm 2 sells up to capacity, $y_2 = K_2$, and firm 1 uses all of its capacity across markets, $K_1 = x_m + y_1$. So only two unknowns are left: y_1 and K_2.

The following result gives the equilibrium values $(\widehat{\mathbf{K}}, \widehat{x}_1, \widehat{y}_1, \widehat{y}_2)$, together with a parameter condition which ensures that the equilibrium, for both firms, (i) is an interior solution with strictly positive outputs to each market, and (ii) involves production up to installed capacity.

Lemma 1. *Suppose the following condition on parameter values holds:*

$$(r_1 + c_1) \in \left([2(r_2 + c_2) - \alpha], \min\left\{ \tfrac{1}{3} [\alpha + 2(r_2 + c_2)], [2(3r_2 + c_2) - \alpha] \right\} \right).$$

The equilibrium in firms' capacity investments and production volumes is given by:

$$\widehat{x}_1 = x_m$$
$$\widehat{y}_1 = \frac{[(2-\lambda)(\alpha - r_1 - c_1) - (\alpha - r_2 - c_2)]}{\beta(3 - 2\lambda)}$$
$$\widehat{K}_1 = \widehat{x}_1 + \widehat{y}_1$$
$$\widehat{K}_2 = \widehat{y}_2 = \frac{[2(\alpha - r_2 - c_2) - (\alpha - r_1 - c_1)]}{\beta(3 - 2\lambda)}$$

where x_m solves $MR_1^A(x_m) = r_1 + c_1$, and the equilibrium value of the strategic effect satisfies

$$\lambda = \left[\frac{\beta}{2\beta + (-p_x^A)(2 - \xi^A)} \right]_{x_1 = \widehat{x}_1}.$$

Equilibrium prices follow as $\widehat{p}^A = p^A(\widehat{x}_1)$ and $\widehat{p}^B = \alpha - \beta(\widehat{y}_1 + \widehat{y}_2)$.

The parameter condition in terms of firm 1's long-run marginal cost, $r_1 + c_1$, is sufficient for the equilibrium to obtain as described in Lemma 1. It is stated in a way that is *independent* of the value of the strategic effect $\lambda \in (0, \tfrac{1}{2})$. Importantly, therefore, this condition does not depend on the details of the equilibrium in market A; it varies only with the firms' marginal costs and the state of demand in market B. Later on, this will facilitate the analysis of the cross-market impacts of changes in A on B.[18]

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[18] To see that this leaves room for manoeuvre in terms of parameter values, consider the special case where both firms have an identical cost structure with $c_1 = c_2 = c$ and $r_1 = r_2 = r$. The three individual conditions then collapse into two, and become $r \in \left(\tfrac{1}{5}(\alpha - c), (\alpha - c) \right)$. In this setting, $r + c < \alpha$ is always satisfied since there would otherwise be no gains from trade in market B. Intuitively, the requirement that $r > \tfrac{1}{5}(\alpha - c)$ ensures that the unit cost of capacity is sufficiently high such the firms' do not install too much capacity—and thus end up using all of it. To see another example, let $\alpha = 1$ with zero production costs $c_j = 0$ for $j = 1, 2$. Then the condition becomes $r_1 \in \left(2r_2 - 1, \min\left\{ \tfrac{1}{3}(2r_2 + 1), 6r_2 - 1 \right\} \right)$, and it is easy to check that there is a substantial set of values for r_1, r_2 which satisfies this. For instance, if $r_2 = \tfrac{1}{4}$, then any $r_1 \in (0, \tfrac{1}{2})$ works.

4 Competitive advantage of "focused" pipeline gas over multimarket LNG exporters

The first key result is that a firm which is focused on a single export market enjoys a competitive advantage in that market. The reason is the presence of the strategic effect: firm 2 has an incentive to overexpand capacity and sales to market B, knowing that firm 1 has an alternative use for its capacity in market A. This effect operates in an asymmetric fashion since firm 2 has no such "outside option".

A natural measure of competitive advantage is the relative market share of the two firms in their common export market B (using Lemma 1):

$$\frac{\widehat{y}_1}{\widehat{y}_2} = \frac{[(2-\lambda)(\alpha - r_1 - c_1) - (\alpha - r_2 - c_2)]}{[2(\alpha - r_2 - c_2) - (\alpha - r_1 - c_1)]}, \tag{7}$$

where the firm with a higher market share is said to have a competitive advantage. Note that the standard Cournot-Nash equilibrium is nested as a special case where the strategic effect from multi-market contact is zero, $\lambda = 0$. This leads to the following result:

Proposition 1. *For market B, in equilibrium:*

(a) Firm 2's market share and profits rise with the strategic effect λ, while the price and firm 1's profits fall;

(b) Firm 2's market share and profits are higher than under Cournot-Nash competition, while the price and firm 1's profits are lower;

(c) Firm 2 has a competitive advantage over firm 1 despite a cost disadvantage whenever $(r_2 + c_2) \in ((r_1 + c_1), \frac{1}{3}[\lambda\alpha + (3-\lambda)(r_1 + c_1)])$.

Multi-market interaction can overturn a fundamental result from oligopoly theory: that high market share goes hand in hand with low marginal cost (i.e., firms' market shares and efficiency levels are co-monotonic). This applies in all common (single-market) oligopoly models, including Cournot (quantity) and Bertrand (price) competition, as well as spatial competition models such as Hotelling, and the supply-function equilibrium (SFE) models often used to analyze electricity markets (see Vives 2000 for a useful overview).[19]

In the present model, by contrast, firm 2 can have a larger share of the market even if it has a significantly higher marginal cost. To illustrate, let the demand parameter $\alpha = 30$, firm 2's marginal cost $r_2 = 5$ and $c_2 = 5$, so $(r_2 + c_2) = 10$, and the equilibrium value of the strategic effect $\lambda = \frac{1}{3}$. (Note that it is possible to obtain any $\lambda \in (0, \frac{1}{2})$ by appropriate choice of β.) Then, whenever firm 1's long-run marginal cost $(r_1 + c_1) \in (7\frac{1}{2}, 10)$, firm 2 retains a higher share of market B. So its cost can be over 30% higher than that of the multi-market firm. (The parameter condition of Lemma 1 is satisfied for these values.) If the firms have identical costs, $r_1 + c_1 = r_2 + c_2$, firm 2 enjoys a competitive advantage with a market share of almost 67%, as $\lambda \to \frac{1}{2}$, and profits in market B that are twice as high as its rival's.

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[19]Proposition 1 generalizes to asymmetric cost structures a result due to Shelegia (2012) who showed that a multi-market competitor may have a smaller market share than an otherwise identical single-market firm with the same cost structure.

Strategic considerations enable firm 2 to take on a quasi-Stackelberg leader role. It recognizes that "overinstalling" capacity in stage 1 induces its multi-market competitor to cede market share in stage 2. This aggressive move benefits consumers in market B, just as in the usual Stackelberg setting. The difference is that firms here make choices simultaneously rather than sequentially, so the strategic advantage is due to an asymmetry in organizational structure rather than an asynchronous timing of moves.

Applied to competition in international gas markets, the result suggests that Gazprom enjoys *two* sources of competitive advantage over Qatar in the European market. First, it is likely true that it has lower costs (including both production and transportation costs), leading to a standard efficiency-based advantage. Second, and thus magnifying the cost argument, it enjoys the strategic advantage identified here.

In contrast to many energy policy discussions, this analysis highlights that Gazprom's dependency on the European market may be a source of *strength*—rather than a weakness, as is usually claimed. Moreover, European gas customers actually *benefit* from Gazprom having a large market share.

This also shows a limitation to the common practice of using Herfindahl concentration indices to measure "security of supply" in energy markets (e.g., European Commission, 2014). Here, assuming that Gazprom has (weakly) lower costs, $r_2+c_2 \leq r_1+c_1$ (and hence a larger market share, $\widehat{y_2} > \widehat{y_1}$), a higher value of the strategic effect *raises* the Herfindahl index ($= (\widehat{y_1}^2+\widehat{y_2}^2)/(\widehat{y_1}+\widehat{y_2})^2$). But this makes European gas buyers better off—with greater consumption at a lower price. Sometimes a higher Herfindahl index may be *good* for supply security.

5   Global effects of the Fukushima nuclear accident

The Fukushima Daiichi accident of March 2011 led to a large-scale shutdown of Japanese nuclear reactors. This sharply raised the demand for substitute energy sources, with LNG imports rising by around 25% while prices increased by over 50%.[20] While these "local" effects of Fukushima seem fairly straightforward, what are its "global" repercussions—in particular, what are the knock-on effects for the European market?

Consider the impact of an upward shift in demand conditions in market A, both on the equilibrium in market A itself as well as spillovers onto market B. Formally, write demand in market A as $p^A(x_1, \theta)$, where θ is a shift parameter, and assume $p_\theta^A > 0$ (everywhere, for simplicity), so a higher θ raises consumers' willingness-to-pay (WTP). Note that a demand shock can both change the shape of the demand curve and lead to a movement along it.

5.1   Local effects on the domestic market

Before turning to the main question at hand, it is important to establish the impact of "stronger demand" in market A on market A itself. However

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[20] Total LNG imports to Japan were 70.9 million metric tons in 2010, rising to 88.1mt in 2012 (GIIGNL, 2013), while the average import price in 2010 was US$10.91 and US$16.75 by 2012 (BP Statistical Review of World Energy 2014). The share of nuclear energy in Japan's power generation mix fell from 30% to zero, while that of LNG imports rose from 30% to almost half. (The remainder of the gap was filled by coal and oil.)

intuitive, it is not always true that a demand shift that raises consumers' WTP also raises price and output.

The following result characterizes the set of conditions under which the "expected" local effects prevail. Let $\eta_\theta^A \equiv d\log p_\theta^A / d\log x_1$ denote the elasticity of the higher WTP with respect to market output.

Lemma 2. *(a) In market A, in equilibrium, a demand shift from θ' to θ'' raises output $\widehat{x}_1(\theta'') > \widehat{x}_1(\theta')$ if and only if*

$$\int_{\theta'}^{\theta''} \left(\frac{p_\theta^A (1 + \eta_\theta^A)}{(-p_x^A)(2 - \xi^A)} \right)_{x_1 = \widehat{x}_1} d\theta > 0,$$

and raises price $\widehat{p}_1^A(\theta'') > \widehat{p}_1^A(\theta')$ if and only if

$$\int_{\theta'}^{\theta''} \left(\frac{p_\theta^A \left[(1 - \xi^A) - \eta_\theta^A \right]}{(2 - \xi^A)} \right)_{x_1 = \widehat{x}_1} d\theta \leq 0.$$

(b) A sufficient condition for output to rise is $\eta_\theta^A > -1$ for all $\theta \in [\theta', \theta'']$, and a sufficient condition for the price to rise is $\eta_\theta^A < (1 - \rho^A)/\rho^A$ for all $\theta \in [\theta', \theta'']$.

In sum, both of the expected local effects go through as long as the elasticity η_θ^A is not too large either way. In other words, the jump in WTP is not allowed to vary too much across consumers. These conditions are necessary and sufficient in the case of a small (i.e., infinitesimal) shift in demand, and sufficient with a large (i.e., discrete) demand shift. They are always met, for example, if demand takes the form $p^A = \theta + f(x_1)$ so that WTP is raised uniformly (so $\eta_\theta^A \equiv 0$), and more likely to be satisfied the *lower* the rate of cost pass-through ρ^A. For the equilibrium quantity to rise, the demand shift must not only raise WTP, $p_\theta^A > 0$, but also raise marginal revenue, $\eta_\theta^A > -1 \Longleftrightarrow \frac{\partial}{\partial \theta} MR_1^A > 0$.

The response of the Japanese energy sector to Fukushima gives an opportunity to calibrate (unobserved) demand parameters. This event no doubt qualified as a large shift in Japan's LNG import demand. Furthermore, the observed market response suggests that its impact on buyers' WTP satisfies the conditions of Lemma 2, in terms of η_θ^A and ξ^A (equivalently, ρ^A).

5.2 Global spillover effects to other markets

Now turn to the main question: How does a demand shock in market A spill over to market B? The answer will depend on the timeframe under consideration. The analysis begins with the short-run response, in which firms' global capacity levels are fixed. Then it examines the longer-term response, in which firms can optimally adjust their capacity levels.

5.2.1 Short-term responses with fixed capacities

In the short run, both firms' capacities are fixed at the levels that were optimal with respect to the "initial" state of demand in market A. So firms can only re-optimize their output choices in light of new market conditions.

For simplicity, suppose that the new short-run "equilibrium" features interior solutions, that is, both firms continue serve each of their markets. This is consistent with gas industry experience following Fukushima. Also assume, as is standard, that firms engage in Nash behaviour.

Proposition 2. *Suppose that $\eta_\theta^A > -1$ for all $\theta \in [\theta', \theta'']$. In the short run, with fixed capacities, a demand shift from θ' to θ'' in market A increases firm 2's market share and the price in market B.*

The reason for the result is as follows. The demand boom in market A makes it relatively more attractive to firm 1 (see Lemma 2) thus inducing it redirect capacity from B to A (since it was already selling up to capacity before). For firm 2, there is no direct change in its demand conditions, as it serves only market B; its position changes only in that firm 1 sells less to market B. This, as such, induces it to increase its own sales—but this is impossible given its (already binding) capacity constraint. So total sales to market B decline, and the local price and firm 2's market share rise. Since overall demand conditions have improved, the firms still do best by selling up to capacity—although the spread across export markets has shifted.

Applied to international gas markets following the Fukushima accident, these results suggests that *both* Asian and European prices rise—at least in the short run. This is due to their connection via the global export capacities of LNG producers, who, in turn, cede market share in Europe to pipeline gas. An implication is that Fukushima made European gas buyers worse off.

5.2.2 Longer-term responses with optimal capacities

In the longer term, firms will be able to adjust their capacity levels in such a way that they are optimal given the new global market fundamentals. What, then, is the long-run impact on market B of the demand boom in market A?

Formally, compare the equilibrium of the two-stage game, with capacity investments followed by quantity choices, at the initial demand level θ' with that following the demand shift θ'', under the maintained assumption that firms always produce up to their respective capacities.[21]

From the previous discussion with optimal capacities (see Lemma 1), the *only* cross-market effect comes via possible changes in the magnitude of the strategic effect. Writing $\lambda(\theta) \equiv -\beta / \left[2\beta + \left(-p_x^A(\theta)\right)\left(2 - \xi^A(\theta)\right)\right]$, the key issue is how changes in θ affect the term $\left(-p_x^A\right)\left(2 - \xi^A\right)$, that is, determining the sign of $\frac{d}{d\theta}\left[\left(-p_x^A\right)\left(2 - \xi^A\right)\right] = \frac{d}{d\theta}\left[-\text{slope of marginal revenue curve } A\right]$.

The case with linear demand serves as a useful benchmark. If demand in market A is everywhere linear (i.e., its curvature $\xi^A = 0$ for all x_1), then $\left(-p_x^A\right)\left(2 - \xi^A\right) = -2p_x^A$ is just a constant. (Note that then also $\eta_\theta^A = 0$.) In this case, the demand shift is "strategically neutral", i.e., $\lambda'(\theta) = 0$ for all θ. As a result, the equilibrium in market B is unchanged in the long run when firms optimally adjust capacity (and market A is affected as per Lemma 2).

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[21] The analysis does not consider a fully dynamic model in which there is a time-dependence of the capital stock. The technique employed here can be justified on various grounds. For example, it corresponds to a setting in which capacity depreciates after each period, so firm 1 first invests given low demand, and then must make a new investment given high demand. Alternatively, the setup fits the interpretation of capacity as maintenance expenditure, which is required period by period. Solving a fully dynamic version of the model looks hard.

More generally, however, the demand shock will not be "strategically neutral" for market B. The following result gives a general condition to sign the effect, and a set of simple conditions which are sufficient for the demand shock to *weaken* the cross-market connection.

Proposition 3. *(a) A demand shift from θ' to θ'' in market A weakens the strategic effect $\lambda(\theta'') \leq \lambda(\theta')$ if and only if:*

$$\int_{\theta'}^{\theta''} \left(\frac{\beta[\frac{p_\theta^A}{x_1} \left(\xi^A + 2\eta_\theta^A \right) + \left(-p_x^A \right) \frac{d}{d\theta} \xi^A]}{[2\beta + \left(-p_x^A \right) \left(2 - \xi^A \right)]^2} \right)_{x_1 = \widehat{x}_1} d\theta \leq 0.$$

(b) Sufficient conditions for $\lambda \left(\theta'' \right) < \lambda \left(\theta' \right)$ are that, for all $\theta \in [\theta', \theta'']$, cost pass-through is sufficiently low, $\rho^A < \frac{1}{2} \left(1 + \eta_\theta^A \right)^{-1}$, and non-increasing, $d\rho^A/d\theta \leq 0$.

The former condition is certainly met if $\rho^A < \frac{1}{2}$ (if and only if demand is concave, $\xi^A < 0$) and the impact of the demand increase on consumers' willingness-to-pay satisfies $\eta_\theta^A \leq 0$ (if and only if $p_{x\theta}^A \leq 0$).

Combining Propositions 1(a) and 3 leads directly to:

Proposition 4. *In the long run, with optimal capacities, a demand shift from θ' to θ'' in market A increases the price but decreases firm 2's market share in market B, under the conditions of Proposition 3.*

Under these conditions, the demand boom in market A means that firm 1 becomes less strategically vulnerable to aggressive overexpansion by its focused competitor in their common market B. Because competition in market B becomes less aggressive, consumers there lose out.

Loosely put, the conditions of Proposition 3 are met when firm 1 already has relatively high market power—equivalently, "low" pass-through—in market A, and this market power tends to be further strengthened by the demand boom. Very simple sufficient conditions are that its rate of pass-through is less than 50%—and that this rate does not rise following the shift in demand conditions. This is sufficient combined with a non-negative cross-partial on the impact of the demand shift on consumers' WTP, $p_{x\theta}^A \leq 0$. To understand this, think of it as $\frac{\partial}{\partial x_1} \left(p_\theta^A \right) \leq 0$: WTP increases for all consumers but tends to rise more strongly for consumers who have a higher WTP in the first place (i.e., those with lower "q" on the demand curve). Again, this is consistent with the idea that the demand shift raises firm 1's ability to capture surplus in market A.[22]

The conditions identified seem relatively plausible for the case of Asian LNG imports, especially by Japan. To begin with, it is commonly assumed in the analysis of natural gas markets that demand curves are concave (e.g., Doane, McAfee, Nayyar and Williams, 2008). The argument, applied to LNG, goes as follows: At very high prices, buyers will prefer to access substitute sources of energy, such as those linked to oil or coal prices. It follows that,

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[22] The condition from Proposition 3(b) $\rho^A < \frac{1}{2} \left(1 + \eta_\theta^A \right)^{-1} \iff \eta_\theta^A < -\xi^A/2$, for all $\theta \in [\theta', \theta'']$, implies that price rises in market A, $\widehat{p}_1^A(\theta'') > \widehat{p}_1^A(\theta')$ (using Lemma 2, since $\eta_\theta^A < -\xi^A/2 \implies \eta_\theta^A < 1 - \xi^A$ as $\xi^A < 1$).

at high prices, the demand curve for LNG imports is almost flat. Conversely, the amount of LNG imports is constrained by the existence and availability of regasification terminals (which are needed to allow consumption). In practice, therefore, the existing regasification capacity places a cap on the feasible import quantity. In other words, the "effective" demand curve for LNG is essentially vertical in the vicinity of the cap. Taken together, this suggests a concave overall shape of the LNG import demand curve.

The presence of such a concave demand curve means that LNG exporters enjoy significant pricing power, which again seems consistent with recent market experience in Asian LNG. In the present model, if consumers' maximum WTP satisfies $p^A(0) \geq \alpha$ and Gazprom's long-run marginal cost is no greater than that of Qatari LNG, $r_2 + c_2 \leq r_1 + c_1$, then concave demand in market A with $\xi^A < 0$ implies that the equilibrium price in market A ("Asia") is indeed higher than in market B ("Europe"), $\widehat{p}^A > \widehat{p}^B$. (Since then demand conditions are more tilted towards the seller in market A, and, of course, there is an additional seller in market B.)

Proposition 4 therefore suggests that, in the longer term, Qatar benefits *twice* from the demand shift due Fukushima. First, there is the obvious direct gain in the Asian market due to higher LNG imports at a higher price (Lemma 2). Second, and less obviously, the demand shift in Asia makes Qatar a stronger competitor in the European market—precisely because it facilitates capturing value in Asia.[23]

Another perspective on these results is as follows. The key is how the demand shift θ affects the marginal revenue curve of the monopolist in market A. This determines both the "local" impact on market A, as well as, via the strategic effect, the spillover effect onto market B. The conditions of Lemma 2 ensure that higher θ raises the monopolist's marginal revenue. The conditions of Proposition 3 ensure that higher θ steepens the *slope* of the monopolist's marginal revenue curve. This makes her less prone to redirecting sales away from market A due to a weakened strategic effect.

To close this discussion, it is worth stressing two points. Firstly, the conditions identified in Proposition 3(b)—in short, low and non-increasing pass-through—are only *grossly* sufficient for a weakened strategic effect, and hence the result of Proposition 4. The conclusions also go through as long as these conditions hold for a sufficiently large portion of the interval $[\theta', \theta'']$ but not everywhere—so demand could be *convex* in some places. Proposition 3(a) makes this statement precise. Secondly, it is also true that there are counterexamples. In such cases, the demand shift strengthens the strategic effect, and the result of Proposition 4 would flip. The discussion here suggests that these counterexamples are less likely in the case of the global gas market.

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[23] As an example, suppose that the demand curve in market A takes the form $p^A(x_1, \theta) = \alpha - \beta(x_1)^{\theta}$, where initially $\theta' = 1$ and following the demand shift $\theta'' = \infty$. In other words, initial demand is linear and then becomes rectangular in the limit, enabling the monopolist to extract the entire social surplus. It is easy to check that the implied strategic effect $\lambda(\theta') = \frac{1}{4}$ while $\lambda(\theta'') = 0$. Assuming that the firms have identical costs, relative market shares in market B initially satisfy $\widehat{y}_1/\widehat{y}_2 = \frac{7}{8}$, so the focused firm has market share of around 54% and makes a higher profit. Following the demand shift, market shares and hence profits are split evenly. (Strictly speaking, this example violates the technical assumption $p_{\theta}^A > 0$, since $p_{\theta}^A = 0$ at $x_1 = 0$ but it illustrates the economic forces at work.)

5.2.3 Comparing short- and long-term responses

Propositions 2 and 4 identify similarities and differences between the short-run and long-run multimarket effects of the demand shock.

The key prediction is that short- and long-run responses differ in terms of the competitive playing field in the firms' common market B. In the short term, by Proposition 2, firm 1 cedes market share as it redirects capacity to market A. However, in the longer term, this is reversed: Under the conditions of Proposition 4, firm 1 invests in additional capacity to the extent that it gains share in market B. Fukushima thus benefits Russian gas exports to Europe in the short run but harms them in the longer run.

The main similarity is that European gas consumers lose out both in the short- and long-run. However, the reasons for these two conclusions differ. In the short term, European buyers lose because they are further "outcompeted" by Asian buyers who have an even higher WTP. In the long term, by contrast, they lose because the competitive intensity in their home market declines. Asian buyers still have a higher WTP than before, but this additional demand is now entirely satisfied by newly installed LNG export capacity.

5.2.4 Some empirical evidence

The model yields predictions on cross-market spillovers that are potentially empirically testable. An important constraint is the limited availability of data on the natural gas industry. In particular, even basic information on production volumes and trade is often only available at an annual frequency. This makes difficult any econometric analysis around particular market events.

The limited evidence that is available is broadly consistent with the above results. The Fukushima accident happened on 11 March 2011. No other large market events appear to have occurred around those days; Fukushima can be assumed to have dominated the "news". Table 1 shows the Platts JKM (Japan Korea Marker) LNG price and the European gas price NBP (the UK's National Balancing Point) around the days of the Fukushima accident. Consistent with Lemma 2, the Asian LNG price rose sharply, by over 20%, over four trading days following Fukushima. However, the European gas price also rose by almost 13%. This is in line with the short-term prediction from Proposition 2— from which Gazprom stood to gain. LNG imports to Europe peaked in the spring of 2011 and pipeline imports, especially from Russia, subsequently rose (Stern and Rogers, 2014).

Table 1: Asian LNG prices (JKM) and European gas prices (NBP) around the Fukushima accident (11 March 2011) in US$/MMbtu (Source: Platts)

	10 Mar	11 Mar	14 Mar	15 Mar	16 Mar	% change
JKM	9.40	9.90	11.00	10.95	11.35	+20.7%
NBP	9.30	9.60	10.20	10.50	10.50	+12.9%

Testing the longer-term predictions—the "continuation" of a higher European gas price, greater LNG capacity investment, and Gazprom ultimately *losing* market share (Proposition 4)—is more difficult. First, while 11 of 53

nuclear reactors shut down on the day of the accident, Japanese policymakers closed virtually the entire nuclear fleet over the following 12 months, so the "event" *itself* was drawn out. Second, many other factors vary over such a period time. Third, the observed market response should reflect a *transition* from short-run impacts to the longer term; all else equal, this is predicted to be a rise in Gazprom's market share, followed by a decline to a level below that of the *status quo ante.*

Investment in LNG infrastructure has indeed risen strongly since 2011 (GIIGNL, 2013), and Gazprom is widely seen to have come under pressure in Europe (Stern and Rogers, 2014). But the extent to which these developments have indeed been *driven* by Fukushima is yet to be tested empirically. Future research may be able to pursue these issues econometrically.

6   Observations on Russian gas export strategy

In May 2014, Russia and China reached agreement on the largest contract in the history of the natural gas industry.[24] The "Power of Siberia" deal involves pipeline gas deliveries worth US$400 billion over a 30 year period commencing in 2018. The price is said to be close to European levels, and thus well below recent Asian LNG import prices. China may also extend US$25 billion of financing to support the development of Eastern Siberian gasfields and pipeline construction.

This eastward diversification of Russian gas exports may appear puzzling in light of the preceding game-theoretic analysis. In particular, it seems to turn Russia into a multi-market exporter and thus expose her to the same strategic vulnerability of LNG exporters. On closer inspection, however, it turns out that this conclusion does not follow.

The key observation is that gas sales via pipeline cannot be redirected between different end markets in the same way as LNG tankers can. In effect, the existing western-bound and the new eastern-bound pipeline are different capacities, specific to different gas fields, with no scope for redirection into each other's markets. Therefore, the strategic weakness of multi-market exposure identified above does not apply.

Two other components of Russian gas export strategy warrant related comment. First, Russia has over the last decade been building a presence in LNG, though it remains small at around 5% of total gas exports. This LNG comes exclusively from the Sakhalin-2 project, which has been running since 2009, with Gazprom partnered with Royal Dutch Shell, Mitsui and Mitsubishi.[25] Again, these LNG exports do not come from the same fields that sell pipeline gas to Europe; in effect, they represent different capacity investments. To date, the project has been selling almost exclusively to Japan and South Korea, in part because transport costs to Europe or Latin America are high. Yet, in principle, Gazprom-led LNG exports may become strategically vulnerable.

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[24] The factual background here is based on press reports, especially "Gazprom's China Gas Price Said to be Near German Level" (*Bloomberg*, 2 June 2014) and "Putin Snubs Europe with Siberian Gas Deal that Bolsters China Ties" (*Financial Times*, 10 November 2014).

[25] There is also the Yamal LNG project in the Russian Arctic, which involves Novatek, Total, and CNPC, and which some observers expect to double Russia's share of the global LNG market over the coming years.

More generally, this paper demonstrates that diversification of a traditionally pipeline-based exporter into LNG (from the same gas fields) can come at a strategic cost. So it can be rational for a pipeline seller to reject a seemingly profitable diversification opportunity into LNG so as to protect its existing business.

Second, and particularly interesting, is the November 2014 announcement that China and Russia have agreed on a further major gas deal.[26] This "Altai" deal is fundamentally different from that of May 2014—it involves pipeline gas from Western Siberia which has so far gone to European consumers. Some analysts expect Russia to thus become the new "swing producer" between European and Asian markets. So this deal *does* appear to be "flexible" diversification in that it leads to a choice of which export market to deliver gas from a given Siberian field. The present analysis suggests that, from a strategic viewpoint, this deal should be significantly less attractive to Russia because it risks undermining Gazprom's position in the European market.

7   Concluding remarks

This paper has presented some new results on classic questions on multimarket competition between firms, with an application to the international gas industry. Instead of rehearsing the arguments made above, this section discusses some further issues and avenues for future research.

First, this paper has focused, quite narrowly, on a *strategic* advantage enjoyed by a firm which serves fewer markets than its rivals. In practice, uncertainty over demand and costs (and rival behaviour) can play a significant role in driving decisions.[27] There may be trade-offs between committing to particular investments and retaining flexibility to adjust decisions further down the road. Perhaps multimarket firms are better equipped to deal with, and benefit from, such uncertainty.

Second, the analysis assumed that firms are profit-maximizers. This is a canonical assumption which seems appropriate for a range of markets. But it is perhaps less clear to what extent it applies when some actors are state-controlled entities. It turns out that the results are not overly sensitive to this. If players instead maximize *utility* functions, the multimarket firm equalizes marginal utility across markets. As long as competition remains in strategic substitutes, the basic insights from the analysis continue to apply; it is more important that players maximize than what exactly is being maximized.

Third, there is ample scope for more careful empirical work on natural gas markets. The present paper has derived a number of results that are empirically testable. One is the competitive advantage of focused pipeline sellers over LNG exporters in common markets. Another is the "predicted" impact of the Fukushima accident; some preliminary evidence was discussed above but there is clearly room to do more. It would also be valuable to have empirical evidence on cost pass-through in natural gas markets.

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[26] See Henderson (2014) for another perspective on the recent gas deals between Russia and China.

[27] Though the above analysis would be robust to uncertainty in form of additive *iid* shocks to demand or costs.

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Appendix

Proof of Lemma 1

Begin by deriving the equilibrium values $(\widehat{\mathbf{K}}, \widehat{x}_1, \widehat{y}_1, \widehat{y}_2)$, and then determine conditions which ensure that the equilibrium is indeed valid. From the above discussion, the two remaining unknowns (y_1, K_2) are pinned down by two equilibrium conditions. The first follows from firm 1 equalizing marginal revenues across markets, $MR_1^A(K_1 - y_1) - MR_1^B(y_1, K_2) = 0$, by (1). Using the linearity of demand in market B, and recalling from (3) that, by profit-maximization in market A, $MR_1^A = r_1 + c_1$, and some rearranging gives:

$$y_1 = \frac{(\alpha - r_1 - c_1 - \beta K_2)}{2\beta} \tag{8}$$

The second follows from profit-maximization by firm 2 at Stage 1, recognizing the strategic effect of its capacity choice, $MR_2^B + \beta \lambda y_2 = r_2 + c_2$, from (5):

$$K_2 = \frac{(\alpha - r_2 - c_2 - \beta y_1)}{\beta (2 - \lambda)} \tag{9}$$

Solving these two equations simultaneously yields:

$$y_1 = \frac{(\alpha - r_1 - c_1)}{2\beta} - \frac{(\alpha - r_2 - c_2 - \beta y_1)}{2\beta (2 - \lambda)} \tag{10}$$

$$\Longrightarrow \widehat{y}_1 = \frac{[(2 - \lambda)(\alpha - r_1 - c_1) - (\alpha - r_2 - c_2)]}{\beta(3 - 2\lambda)} \tag{11}$$

$$K_2 = \frac{[(\alpha - r_2 - c_2) - [(2 - \lambda)(\alpha - r_1 - c_1) - (\alpha - r_2 - c_2)]/(3 - 2\lambda)]}{\beta (2 - \lambda)} \tag{12}$$

$$\Longrightarrow \widehat{K}_2 = \frac{[2(\alpha - r_2 - c_2) - (\alpha - r_1 - c_1)]}{\beta(3 - 2\lambda)} \tag{13}$$

The equilibrium value of the strategic effect λ is defined (implicitly) by (6), evaluated at the equilibrium output in market A. The remaining equilibrium choices follow immediately from $\widehat{K}_1 = \widehat{x}_1 + \widehat{y}_1$ and $\widehat{y}_2 = \widehat{K}_2$.

Confirming this as a valid solution requires two more steps. First, finding conditions for this to be an interior equilibrium in which both firms sell strictly positive amounts to market B. Second, verifying that both firms indeed find it optimal to fully use their installed capacity. These conditions are now derived so as to hold for any possible value of the strategic effect $\lambda \in (0, \frac{1}{2})$.

Step 1: For firm 1, note that $\widehat{y}_1$ is strictly decreasing in the strategic effect λ. It follows that, for any value of λ, firm 1's output to market B satisfies $\widehat{y}_1 > \left[\frac{3}{2}(\alpha - r_1 - c_1) - (\alpha - r_2 - c_2)\right]/2\beta$, so that:

$$\tfrac{3}{2}(\alpha - r_1 - c_1) > (\alpha - r_2 - c_2) \Longrightarrow \widehat{y}_1 > 0. \tag{14}$$

This condition can be rearranged as $(r_1 + c_1) < \frac{1}{3}[\alpha + 2(r_2 + c_2)]$. For firm 2, by inspection, a necessary and sufficient condition for positive output is:

$$2(\alpha - r_2 - c_2) > (\alpha - r_1 - c_1) \Longleftrightarrow \widehat{y}_2 > 0. \tag{15}$$

This condition can also be written as $(r_1 + c_1) > [2(r_2 + c_2) - \alpha]$.

Step 2: Firm 1 will fully utilize all of its installed capacity as long as this is profit-maximizing, i.e., where the marginal revenue generated from sales exceeds the associated costs. Recalling that firm 1 chooses capacity such that $MR_1^A = MR_1^B = r_1 + c_1$, it follows that $MR_1^A = MR_1^B > c_1$ (since, by assumption, $r_1 > 0$). Thus $\widehat{x}_1 + \widehat{y}_1 = \widehat{K}_1$ is indeed optimal.

For firm 2, it similarly must be verified that $MR_2^B(\widehat{y}_1, \widehat{y}_2) > c_2$, with its marginal revenue evaluated at the equilibrium outputs to market B. Noting that $MR_2^B(\widehat{y}_1, \widehat{y}_2) = \alpha - \beta\widehat{y}_1 - 2\beta\widehat{y}_2$, and using the expressions for outputs from above shows that:

$$(\alpha - c_2) > \frac{3(\alpha - r_2 - c_2) - \lambda(\alpha - r_1 - c_1)}{(3 - 2\lambda)} \iff MR_2^B(\widehat{y}_1, \widehat{y}_2) > c_2. \quad (16)$$

This condition can be rearranged as $\lambda(\alpha - 2c_2 + r_1 + c_1) < 3r_2$, which is more difficult to satisfy for higher values of the strategic effect λ (since $\alpha - 2c_2 + c_1 > 0$ is assumed). Thus letting $\lambda = \frac{1}{2}$, and some further manipulation shows that

$$(r_1 + c_1) < [2(3r_2 + c_2) - \alpha] \implies MR_2^B(\widehat{y}_1, \widehat{y}_2) > c_2, \quad (17)$$

regardless of the value of λ. Thus $\widehat{y}_2 = \widehat{K}_2$ is indeed optimal. The three parameter conditions obtained can be combined into a single condition:

$$(r_1 + c_1) \in \left([2(r_2 + c_2) - \alpha], \min\left\{\tfrac{1}{3}[\alpha + 2(r_2 + c_2)], [2(3r_2 + c_2) - \alpha]\right\}\right),$$

thus completing the proof.

Proof of Proposition 1

For part (a), inspection of the expression for relative market shares $\widehat{y}_1/\widehat{y}_2$ from (7) shows that it is decreasing in λ, from which it follows that firm 2's market share rises with λ. Firm 2's equilibrium profits are $R_2^B(\widehat{y}_1, \widehat{y}_2) - (r_2 + c_2)\widehat{y}_2 = \beta(1 - \lambda)(\widehat{y}_2)^2$, since $MR_2^B + \beta\lambda y_2 = \widehat{p}^B - \beta(1 - \lambda)\widehat{y}_2 = r_2 + c_2$ by (5), and are easily checked to rise with $\lambda \in (0, \frac{1}{2})$. Using Lemma 1, equilibrium outputs by both firms in market B satisfy

$$\widehat{y}_1 + \widehat{y}_2 = \frac{[(1 + \lambda)(\alpha - r_1 - c_1) + (\alpha - r_2 - c_2)]}{\beta(3 - 2\lambda)}. \quad (18)$$

Total output rises with λ, so the price $\widehat{p}^B$ falls with λ as claimed. Firm 1's equilibrium profits from market B are $R_1^B(\widehat{y}_1, \widehat{y}_2) - (r_1 + c_1)\widehat{y}_1 = \beta(\widehat{y}_1)^2$, since $MR_1^B = \widehat{p}^B - \beta\widehat{y}_1 = r_1 + c_1$ by (3), and decline with λ since $\widehat{y}_1$ falls with λ. For part (b), the comparison with the Cournot-Nash equilibrium, i.e., where $\lambda = 0$, follows immediately from (a). For part (c), note that $\widehat{y}_1/\widehat{y}_2 < 1 \iff [(r_2 + c_2) - (r_1 + c_1)] < (\lambda/3)(\alpha - r_1 - c_1)$, which clearly can hold even when $r_1 + c_1 < r_2 + c_2$.

Proof of Lemma 2

Proof. The equilibrium in market A is defined by firm 1's first-order condition $MR_1^A(\widehat{x}_1) = r_1 + c_1$ from (3). For part (a), differentiation gives the impact of a small demand increase on output:

$$\frac{d\widehat{x}_1}{d\theta} = \left.\frac{p_\theta^A + x_1 p_{x\theta}^A}{-(2p_x^A + x_1 p_{xx}^A)}\right|_{x_1 = \widehat{x}_1} = \left.\frac{p_\theta^A(1 + \eta_\theta^A)}{(-p_x^A)(2 - \xi^A)}\right|_{x_1 = \widehat{x}_1}, \quad (19)$$

using the definitions of η_θ^A and ξ^A. The denominator is strictly positive by the maintained assumption that demand is log-concave, $\xi^B < 1$. The change in output due to a demand shift from θ' to θ'' is given by $[\widehat{x}_1(\theta'') - \widehat{x}_1(\theta')] = \int_{\theta'}^{\theta''} \left[\frac{d\widehat{x}_1}{d\theta}(\theta)\right] d\theta$, leading to the first result. Using (19), the impact of a small demand increase on the equilibrium price is:

$$\frac{d\widehat{p}_1^A}{d\theta} = p_\theta^A + p_x^A \frac{d\widehat{x}_1}{d\theta} = p_\theta^A - \frac{p_\theta^A + x_1 p_{x\theta}^A}{(2 - \xi^A)} = \frac{p_\theta^A \left[(1 - \xi^A) - \eta_\theta^A\right]}{(2 - \xi^A)}, \qquad (20)$$

again with all terms evaluated at $x_1 = \widehat{x}_1(\theta)$. The result again follows from $\left[\widehat{p}_1^A(\theta'') - \widehat{p}_1^B(\theta')\right] = \int_{\theta'}^{\theta''} \left[\frac{d\widehat{p}_1^A}{d\theta}(\theta)\right] d\theta$. For part (b), on the output side, the sufficient condition $\eta_\theta^A > 1$ for all $\theta \in [\theta', \theta''] \Longrightarrow \widehat{x}_1(\theta'') > \widehat{x}_1(\theta')$ is immediate. On the price side, the sufficient condition $\eta_\theta^A < (1 - \rho^A)/\rho^A$ for all $\theta \in [\theta', \theta'']$ follows since $\xi^A = 2 - 1/\rho^A$.

Proof of Proposition 2

The initial equilibrium is $\widehat{x}_1(\theta') + \widehat{y}_1(\theta') = \widehat{K}_1$ and $\widehat{y}_2(\theta') = \widehat{K}_2$ by Lemma 1.

Begin with the optimal strategy for firm 2 following the demand shift to θ''. It maximizes short-run profits $\max_{y_2} \left\{R_2^B(y_1, y_2) - c_2 y_2\right\}$ subject to the capacity constraint $y_2 \leq \widehat{K}_2$. Its marginal profit from an additional unit of output thus equals $MR_2^B(y_1, y_2) - c_2$, which does not depend directly on θ''.

Previously under θ', its marginal profit was $MR_2^B + \beta\lambda y_2 - (r_2 + c_2)$. In the initial equilibrium, this was equal to $MR_2^B(\widehat{y}_1, \widehat{K}_2) + \beta\widehat{K}_2 \left.\lambda\right|_{x_1 = \widehat{x}_1(\theta')} - (r_2 + c_2) = 0$, by its first-order condition from (5). Recall that firm 2's capacity constraint was binding, which required $MR_2^B(\widehat{y}_1, \widehat{K}_2) - c_2 > 0 \iff [\beta\widehat{K}_2 \left.\lambda\right|_{x_1 = \widehat{x}_1(\theta')} - r_2] < 0$ (see the proof of Lemma 1).

Thus comparing marginal profits, $MR_2^B(y_1, y_2) - c_2 \geq MR_2^B(\widehat{y}_1, \widehat{K}_2) - c_2 + [\beta\widehat{K}_2 \left.\lambda\right|_{x_1 = \widehat{x}_1(\theta')} - r_2]$ holds if $y_1 \leq \widehat{y}_1(\theta')$ (since $y_2 \leq \widehat{K}_2$ by its capacity constraint). In other words, it is certainly optimal for firm 2 to again sell up to capacity at θ'' whenever firm 1's output is no greater than it was at θ'.

Now consider firm 1. By Lemma 2, $\eta_\theta^A > -1$ for all $\theta \in [\theta', \theta'']$ is equivalent to $\frac{\partial}{\partial\theta} MR_1^A(x_1; \theta) > 0$ for all $\theta \in [\theta', \theta'']$. So the shift from θ' to θ'' raises $MR_1^A(x_1; \theta)$ (given x_1) but again has no direct effect on $MR_1^B(y_1, y_2)$.

The assumption of an interior solution implies that, taking its rival's y_2 as given, firm 1 maximizes its short-term profits by equalizing marginal revenue across markets, $MR_1^A(x_1; \theta'') = MR_1^B(y_1, y_2)$. Previously under θ', its optimal strategy was $MR_1^A(x_1; \theta') = MR_1^B(y_1, y_2)$. Since $\frac{\partial}{\partial\theta} MR_1^A(x_1; \theta) > 0$, it follows that, for any given y_2, firm 1's optimal x_1 is now higher than before, while its optimal y_1 is now lower (because of its capacity constraint).

The short-run "equilibrium" thus has $\widetilde{x}_1(\theta'') > \widehat{x}_1(\theta')$ and $\widetilde{y}_1(\theta'') < \widehat{y}_1(\theta')$, with $\widetilde{x}_1(\theta'') + \widetilde{y}_1(\theta'') = \widehat{K}_1$, for firm 1, and $\widetilde{y}_2(\theta'') = \widehat{y}_2(\theta') = \widehat{K}_2$ for firm 2.

Finally, confirm that it is also optimal for firm 1 to fully use its installed capacities. Firm 1's marginal revenues in this allocation $MR_1^A(\widetilde{x}_1(\theta''); \theta'') = MR_1^B(\widetilde{y}_1(\theta''), \widehat{K}_2) > MR_1^A(\widehat{x}_1(\theta'); \theta') = MR_1^B(\widehat{y}_1(\theta'), \widehat{K}_2)$ are both higher than before, so it is again optimal to fully use capacity.

From these results, it is immediate that firm 2's share of market B has risen, and that the price has also increased, $\widetilde{p}^B(\theta'') = p^B(\widetilde{y}_1(\theta'') + \widetilde{y}_2(\theta'')) > \widehat{p}^B(\theta')$ (from Lemma 1), thus completing the proof.

Proof of Proposition 3

For part (a), write $\left[\lambda\left(\theta''\right) - \lambda\left(\theta'\right)\right] = \int_{\theta'}^{\theta''}\left[\lambda'(\theta)\right]d\theta$, where differentiation of $\lambda(\theta) = \beta/[2\beta + \left(-p_x^A\left(\theta\right)\right)\left(2 - \xi^A\left(\theta\right)\right)]$ gives

$$\lambda'(\theta) = \frac{\beta\frac{d}{d\theta}\left[\left(-p_x^A\left(\theta\right)\right)\left(2 - \xi^A\left(\theta\right)\right)\right]}{\left[2\beta + \left(-p_x^A\left(\theta\right)\right)\left(2 - \xi^A\left(\theta\right)\right)\right]^2}. \tag{21}$$

Consider the components of $\frac{d}{d\theta}\left[\left(-p_x^A\left(\theta\right)\right)\left(2 - \xi^A\left(\theta\right)\right)\right]$ in turn:

$$
\begin{aligned}
\frac{d}{d\theta}\left(-p_x^A\left(\theta\right)\right) &= \left(-p_{x\theta}^A\right) + \left(-p_{xx}^A\right)\frac{dx_1}{d\theta} \\
&= \left(-p_{x\theta}^A\right) + \left(-p_{xx}^A\right)\frac{\left(p_\theta^A + x_1 p_{x\theta}^A\right)}{\left(-p_x^A\right)\left(2 - \xi^A\right)} \\
&= \left(-p_{x\theta}^A\right) - \frac{\xi^A\left(p_\theta^A + x_1 p_{x\theta}^A\right)}{\left(2 - \xi^A\right)x_1} \quad \text{since } \xi^A \equiv -p_{xx}^A x_1/p_x^A \\
&= -\frac{1}{\left(2 - \xi^A\right)}\left[\xi^A\frac{p_\theta^A}{x_1} + 2p_{x\theta}^A\right] \\
&= -\frac{1}{\left(2 - \xi^A\right)}\frac{p_\theta^A}{x_1}\left(\xi^A + 2\eta_\theta^A\right) \quad \text{since } \eta_\theta^A \equiv p_{x\theta}^A x_1/p_\theta^A. \tag{22}
\end{aligned}
$$

Next, observe that

$$\frac{d}{d\theta}\left[\left(2 - \xi^A\left(\theta\right)\right)\right] = -\frac{d}{d\theta}\xi^A\left(\theta\right). \tag{23}$$

Combining these results,

$$\frac{d}{d\theta}\left[\left(-p_x^A\left(\theta\right)\right)\left(2 - \xi^A\left(\theta\right)\right)\right] = -\frac{p_\theta^A}{x_1}\left(\xi^A + 2\eta_\theta^A\right) - \left(-p_x^A\right)\frac{d}{d\theta}\xi^A\left(\theta\right), \tag{24}$$

and therefore

$$\lambda'(\theta) = -\left(\frac{\beta\left[\frac{p_\theta^A}{x_1}\left(\xi^A\left(\theta\right) + 2\eta_\theta^A\left(\theta\right)\right) + \left(-p_x^A\right)\frac{d}{d\theta}\xi^A\left(\theta\right)\right]}{\left[2\beta + \left(-p_x^A\left(\theta\right)\right)\left(2 - \xi^A\left(\theta\right)\right)\right]^2}\right) \tag{25}$$

which yields the necessary and sufficient condition for $\lambda\left(\theta''\right) = \lambda\left(\theta'\right) + \int_{\theta'}^{\theta''}\left[\lambda'\left(\theta\right)\right] \leq \lambda\left(\theta'\right)$. For part (b), the sufficient conditions in terms of cost pass-through, recall that $\xi^A = 2 - 1/\rho^A$, so $\xi^A + 2\eta_\theta^A = 2(1 + \eta_\theta^A) - 1/\rho^A$ and $\frac{d}{d\theta}\xi^A\left(\theta\right) = -\frac{d}{d\theta}\left(1/\rho^A\right)$. Then it is clear that jointly sufficient for $\lambda\left(\theta''\right) < \lambda\left(\theta'\right)$ are $\rho^A < \frac{1}{2}\left(1 + \eta_\theta^A\right)^{-1}$ together with $\frac{d}{d\theta}\left(1/\rho^A\right) \geq 0 \iff d\rho^A/d\theta \leq 0$, for all $\theta \in [\theta', \theta'']$. Finally, $\rho^A < \frac{1}{2} \iff \xi^A < 0$ and $\eta_\theta^A \leq 0 \iff p_{x\theta}^A \leq 0$ jointly imply $\rho^A < \frac{1}{2}\left(1 + \eta_\theta^A\right)^{-1}$.

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