Long-Term Contracting in a Deregulated Electricity Industry: Simulation Results from a Hydro Management Model

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Abstract

The deregulation of electricity industry has introduced long-term contracting as a tool for hedging risk and strategy. A vital consideration for market participants is the relationship between behaviour in the spot market, and decisions taken in the contract market. We have developed a reservoir management model which integrates a Cournot spot market model into a Dual Dynamic Programming framework. Simulations using this model show that the market outcomes depend strongly upon the level of contracting undertaken by both competitors. We develop hypotheses for the dynamics involved, and present results from the simulation model reinforcing these.

1. Introduction

The New Zealand electricity sector currently (pre 1998 breakup) exists as a duopoly with one dominant player (ECNZ has approximately 60% of the market share). Both parties have a mix of hydro (with and without storage) and thermal generation plants.

Generators supply electricity to a spot market in the form of supply bids (much like submitting a supply curve) declaring the capacity they will make available at a range of prices. The central dispatcher constructs an industry supply curve, which has a resulting market price and quantity when combined with the demand bids.

The main focus of this paper is to investigate the interactions of this spot market with a market for long term contracts. In most deregulated industries (e.g., Norway, Britain, New Zealand, Australia) market participants are able to trade forward in electricity. The contracts are often referred to as two way contracts or contracts for differences (CfD's). A price and quantity is agreed upon at the time the contract is written, but the electricity itself is purchased off the spot market at spot market prices. The supplier and consumer then 'settle up' the difference between the price agreed upon and the price paid at a later time. Currently, many of these contract markets (including New Zealand) are not developed to the point of being a futures market, particularly because there is no standardised form of the contract.

Most models in the past have assumed that these are independent of each other, in the sense that contracting and spot decisions can be made independently. Intuitively this is unlikely to be the case. The level to which a generators output is covered by long term (1,2, 5, 10 years) forward contracts affects it's ability to game on the spot market, and empirical results from both the British and New Zealand markets have shown the higher the level of contracting in the market, the lower the mean spot price and thus generators profits. Contracts appear to shift output, prices and deadweight loss towards the competitive level.

We wish to investigate the dynamics of a deregulated, non-competitive market for electricity, with a view to modelling the spot-contract relationship that clearly exists. Section 2 reviews the work in this area to date, both in electricity and other commodities. Section 3 discusses the dynamics of an electricity market that are likely to affect contracting decisions, and Section 4 goes on to discuss some of these hypotheses using a model of a duopolistic market that has been developed previously. Section 5 draws conclusions and discusses future modelling approaches we intend taking.

2. Literature Review

Few authors have considered how oligopolists balance gaming in the spot (physical) market with trading forward in a financial market for risk hedging and/or strategic reasons. The result of the reported analyses, however, has been that a relationship between spot market behaviour and long-term contract market exists– they're not mutually exclusive. As to the nature of this relationship, models have been limited in application to a hydro electricity industry.

Allaz [1,3] applied standard financial asset markets theory to the case of oligopoly, both with [2] and without storage. The theory uses a two-stage process where a contracting decision is made under uncertainty in the first stage, and production takes place in the second, when uncertainty is resolved. He came up with an adjusted version of the familiar result that the level of contracting for a risk averse supplier of an asset is governed by both a risk-hedging element and a strategic element, based on the influence he/she may have on the spot price and/or the other suppliers contracting/spot position. Contracting decisions were not modelled as taking place in a market setting as such, just that they had certain influences on spot behaviour. The financial asset markets theory assumes that equilibrium in the contracting market is found through setting the aggregate contracting position to be zero (for every player that is short, there must be someone long). Similar analyses have been performed, with minor variations and different emphases by, and Brianza, Phlips, and Richards, [4].

Helm and Powell [7] empirically analysed the British supply industry, which is dominated by two major coal-fired generators, National Power and PowerGen. Using data from a number of years of operation of a deregulated market, they performed co-integration analysis on the pool purchase price (PPP, the equilibrium price for electricity before capacity and loss-of-load charges are added) and the demand for electricity. In their regression, they used dummy variables representing significant contracting events, which highlighted significant (in the statistical sense) changes in the relationship between pool price and demand. The significance of these variables indicated a strong effect of the level of contracting on the pool price. However the actual nature of the relationship remained a "black box".

Green [5] and Powell [9] also modelled the British market but from an analytical viewpoint. The duopolists are treated as symmetric with quadratic total costs. The equilibrium conditions are the standard Cournot equations, adjusted for contracts. Both assume the competition in the contract market is Bertrand (generators set contract prices), and observe the result that through fierce competition in the contract market, generators offer contracts at marginal cost. Competition in the spot market is limited in comparison. Green concludes from the basic model that even the most limited competition in the contract market increases spot output by 20% and reduces price/MC gap by 40%. If a more competitive situation exists in reality, gains would be even greater.

Green goes on to introduce a more competitive model than Cournot – that of linear supply functions similar to that of Klemperer and Meyer's analysis [8] and as a pre-runner to his 1996 analysis [6]. The example shows that when the pool is more competitive, the generators face less incentive to use the contract market to increase their output. Greens multi period model has the important result that the contract market may have much less of an effect on keeping pool prices down, implying a greater need for a regulator. Since generators know that they can influence future contract prices by artificially supporting high pool prices, they will do so, even if they sacrifice some present profits in the process.

Scott [10] modelled a duopolistsic market in the context of a hydro reservoir management model. The spot market was modelled as a Cournot duopoly with a fixed volume of long term contracts. Although the model took account of the incentives from these contracts there was no market for the trading of the contracts themselves. However the simulation model was run for a wide variety of contract levels and demand elasticities to observe the impact on system outputs such as price, generation, storage and profit. The results show that the level of contracting has a significant impact on these outputs. Here we aim to examine some of the relationships found in this earlier work, and to explore some ideas for modelling the complex relationship between the spot and contract markets.

3. Basic dynamics of a market for contracts

In order to build a model of the relationship between the contract and spot markets, the major driving factors of the supply of and demand for contracts need to be identified and discussed.

3.1 Demand for contracts (consumers of electricity)

Demand is likely to be driven by expectations of spot price, and variance of spot price over the relevant interval, ie, variance over a week may not be concerning to a risk-averse electricity consumer, but variance over a year, and from year to year would be. The same is true for the mean spot price – a spot price that is trending upwards over a year is more concerning than a high mean within a week. If consumers are aware that generators are likely to use their market power to game up prices, they will be motivated to use contracts to reduce the amount of output a generator has available to him for 'second order' effects. If there were a small number of consumers, (in limit a monopsonist) there could exist a gaming or strategic element too.

3.2 Supply of contracts (electricity generators)

We will examine two different issues which are likely to strongly influence a generators contracting decision: risk hedging and strategy.

Risk hedging is the most common incentive for suppliers of a good or asset to go short in a forward contract – it is based on the underlying assumption that the supplier is exposed to uncontrollable fluctuations in the spot price, and so signing more and more contracts (which, having a fixed price, have zero variance) we will eventually reduce our exposed risk to nil. However, generators in a non-competitive environment have another tool at their disposal to reduce profit variance: to control the spot price. Market power allows a generator to control the spot price, possibly maintaining it at a high level. In addition, a hydro generator with input (inflow) risk can absorb fluctuations by reducing his/her output in anticipation of low inflows. Contracts could actually be counter-productive in this situation – contracts reduce the market power that allows a generator to control the market. Hence we can draw the conclusion that the greater share of the market a generator has, the less risk-hedging will be an influence in contract decision-making.

As Allaz has already pointed out, there is likely to be a *strategic* element to contracting. We can postulate that our contracting position will have an effect on our competitors contracting position and spot market strategy, and vice versa. Contracting could be viewed as a pre-commitment to a particular set of spot market strategies, and as long as contract position is observable in the market, this is valuable information to the generators. For example, if my competitor is highly contracted, he is likely to be supplying a large amount of energy to the market, which will in turn have an effect on spot market behaviour. If he is lowly contracted, he is likely to game prices according to his market power. Both of these effects will depend on the relative cost structures of the firms and how they influence market equilibrium. Knowledge pertaining to the nature of these relationships will help a generator answer the questions:

1. How highly do I want my competitor to be contracted? From a variance minimisation and/or profit maximisation point of view?

2. Can I influence his choice of contracting position through the contract or spot markets?

There may also be another strategic element to contracting which is beneficial to a generator. If connections exist between the spot and contract markets, generators may also be able to drive contract prices up without increasing their own risk. Market destabilisation by a generator may increase demand for contracts as consumers see higher variance in the market, yet as long as it is controlled, it is not a risky policy for the generator.

If we assume that a generator will wish to have a low level of contracts, how much will he charge to enter into one if there is demand for more? A price for a contract will have to compensate (in a profit maximisation) for loss in market power and spot profits, and take into account any loss or benefit in influence over the competitor. Hence we can generate a supply curve for contracts which assimilates the above effects.

4. Simulation results

The graphs are summary results from twenty years of weekly simulation time from our reservoir management model (Scott [10]). They are from a hypothetical system with two firms. Firm One has one hydro station with capacity of 3000 MW and storage of 500 GWh. Annual inflows average about 250 GWh per week, so on average the hydro station can run at around 50% capacity. Firm Two has four thermal stations at marginal costs of one, three, seven and nine cents per kWh, each with a capacity of 750 MW. The demand is represented by constant elasticity demand curves, ranging from a reference of 3000 MW in summer to 5000 MW in winter, at a reference price of 2.2 cents per kWh, and a price elasticity of demand of -1/3.

The graphs show the price, generation and profit for a range of contract quantities roughly corresponding to 30% to 110% of the competitive output levels for each firm. The first set of graphs shows the mean weekly levels, the second set shows the weekly standard deviations in these levels. Note that the only variance in this model is from the variance in inflow levels, there is no stochasticity in the pricing. Change in contracts for Firm Two is shown across the horizontal axis. Change in contracts for Firm One (the hydro station) is shown across the different lines on the graph.

The first and most obvious trend in the graphs is that as the level of contracting for a firm increases, so does the output from that firm. In the graph of generation for Firm One this can be seen as an increase in output moving from one line to the next. In the graph of generation for Firm Two this is seen in the upward slope of the lines. As the level of contracting for the firms increases, so does the total market generation, and those lines are both upward sloping and consistently increasing from line to line. These trends are a direct result of the incentives that the contracts give to the firms. Each firm will produce somewhere between their competitive level and their contract quantity. (Scott [10].) Also, when the contracting exactly matches the competitive level the firms will produce at exactly their competitive levels, and the market will mimic the centrally co-ordinated solution. As the generation increases the market price falls (since we have a downward sloping demand curve). This again is clearly shown in the graph.

Not so obvious from the outset are the results shown in the graphs of the profit for the two firms. As contracting increases profits fall, and not only do they fall as the firm's own contracting increases, but also very noticeably as the other firm's contracting increases. This is more the case for Firm One's profits than for Firm Two's, mostly because Firm Two is the dominant player over most of the range studied. They may generate an average of more than 300 GWh per week compared to under 250 GWh for Firm One. This gives them a greater influence over the market price, and this also follows through to the weekly variations.

From a portfolio analysis perspective a Firm is interested both in maximising returns and in minimising risk. For the firms in the electricity market there may be considerable uncertainty in the hydrological inflows, and these can have a substantial impact on the spot market prices, which carry over to the profit figures. We explore this further in the second set of graphs, those showing the weekly standard deviations.

The variance in generation for Firm One is increasing as the level of contracting increases, both for themselves and for Firm Two. The reason is that at low levels of contracting Firm One is with-holding generation from the market, choosing to spill water rather than depress the market price. Hence the variation in inflows is producing a variation in spill rather than in hydro generation. This effect also leads to higher storage trajectories than would be the case in a perfectly competitive market.

At low levels of contracting the firms behave more as oligopolists, pushing the price higher. At high levels of contracting where they are effectively buying back large quantities from the spot market, the firms try to keep the price down. In terms of variance, this means that at low levels of contracting when the hydro inflow is low and the hydro firm cuts back, the thermal firm will not increase its output much to compensate. However at high levels of contracting if the hydro firm cuts back its production due to low inflows, the thermal firm will increase its output to compensate and try and keep the price down. Hence at high levels of contracting the variance in total generation is much less than the sum of the variances of the individual generation levels.

Interestingly, again it seems because of the relative generation levels of the two firms, the variance in the profit for Firm One seems to be affected more by the level of contracting of the other firm than its own. It appears that there are several influences driving the variance in profit. At low levels of contracting the variance in profit seems largely driven by the variance in the spot price. But as the contracting for Firm Two increases the variance in profit for both firms seems to be more strongly correlated to the variance in generation for Firm Two. Recall however that the only stochasticity we have modelled is the hydrological inflows, so any variation in Firm Two's generation is a response to variation in Firm One's generation. However the variance in profit is at most in the order of five percent, so mean-variance analysis will still be dominated by the trend in the mean levels, indicating that the generating firms will be the most well off when they all have low levels of contracting. The question that remains is how high can they push the price without triggering new entry?

5. Further Work

The difficulty in interpreting the results from Scott's work is that in his profit calculations, the strike price in the contracts was assumed to be the spot price. What is required is a strike price that is directly related the equilibrium of supply of and demand for contracts. One can assume that the price of contracts will be considerably lower if both generators are 100% contracted than if they were 30% contracted.

We intend to design a model that uses results from Scott's model that will be largely unaffected by his valuation of contracts – fundamental system parameters such as spot price, spot variance and generation. We can use Scott's model to gain knowledge of the nature of these functions, and use them in an optimisation which seeks to maximise generator profit

$$\max_{g_j} L(g_j) = p(g)\left[g_j - f_j\right] - c_j(g_j) + f_j q$$

with a first order condition with respect to contracts as well as generation:

$$\frac{dL}{dg_j} = \frac{dp(g)}{dg_j}\left[g_j - f_j\right] + p(g) - \frac{dc_j(g_j)}{g_j}$$

$$\frac{dL}{df_j} = \frac{dp(g)}{df_j}\left[g_j - f_j\right] - p(g) - \frac{dc_j(g_j)}{df_j} + q + f_j \frac{dq}{df_j}$$

which shows that the generator has some knowledge of the demand curve for contracts, indicated by the last term in the second first-order condition.

An important part of this analysis will be determining how consumers build their demand curve. One possibility is that they naively form their demand curve by observing the latest spot prices and variance of spot prices, re-adjust as new information comes to hand. They too may have some estimation of how a change in their contract position will aggregately affect the market.

Temporal issues must be addressed, especially if we are to assume that contracts may be bought and sold on a relatively continuous basis. A firm's contracting position may not be accurately reflected by how many contracts they have sold at a particular point in time, but more likely the rate at which the current contracts will expire over the next 6, 12, 24…months. A possibility is to approximate the decay rate of a portfolio of contracts (eg exponential) within a dynamic programming framework.

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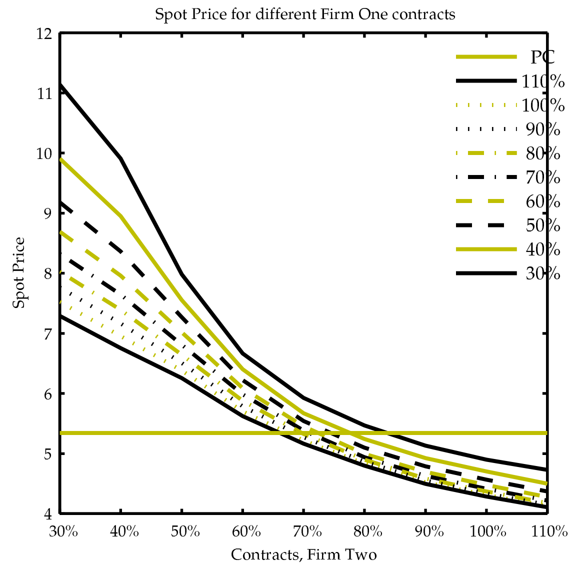
Spot Price for different Firm One contracts
Spot Price
Contracts, Firm Two
4
5
6
7
8
9
10
11
12
30%
40%
50%
60%
70%
80%
90%
100%
110%
PC
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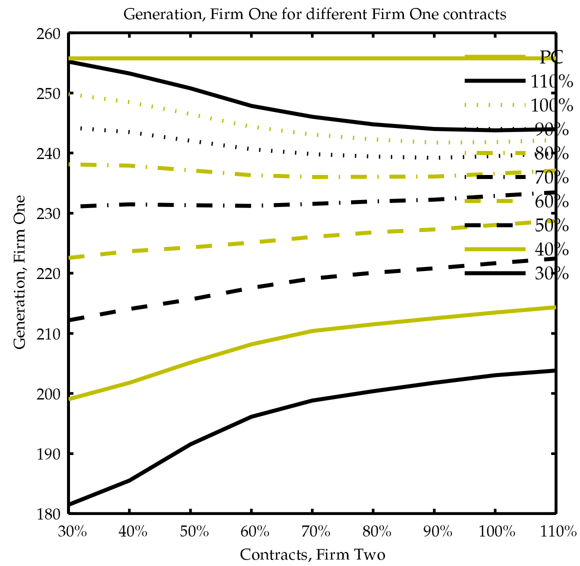
Generation, Firm One for different Firm One contracts
Generation, Firm One
Contracts, Firm Two
180
190
200
210
220
230
240
250
260
30%
40%
50%
60%
70%
80%
90%
100%
110%
PC
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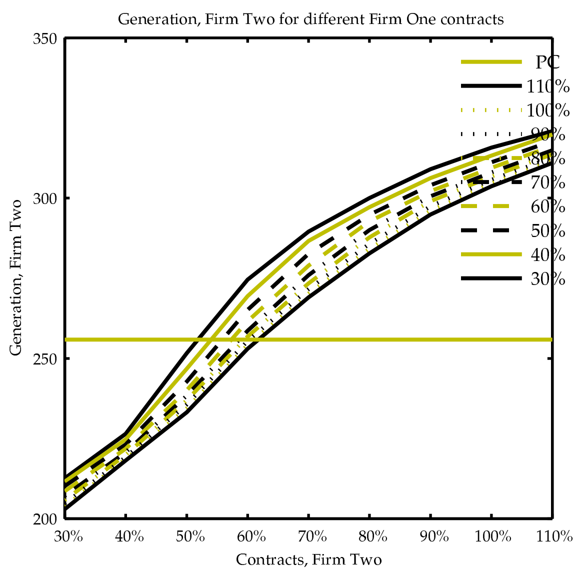
Generation, Firm Two for different Firm One contracts
Generation, Firm Two
Contracts, Firm Two
200
250
300
350
30%
40%
50%
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70%
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90%
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PC
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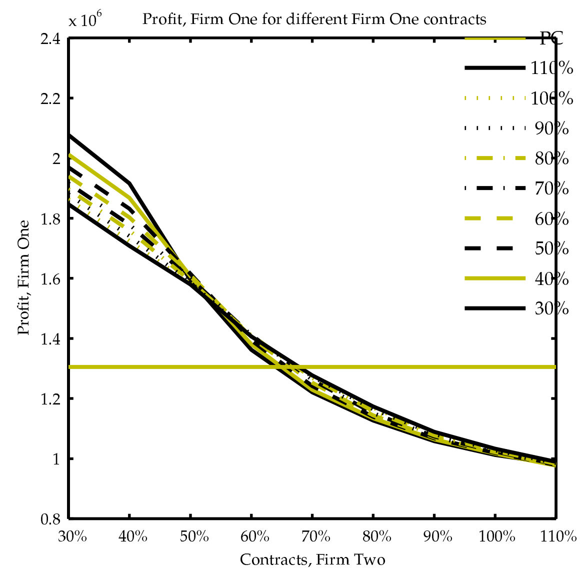
Profit, Firm One for different Firm One contracts
x 10^6
Profit, Firm One
Contracts, Firm Two
0.8
1
1.2
1.4
1.6
1.8
2
2.2
2.4
30%
40%
50%
60%
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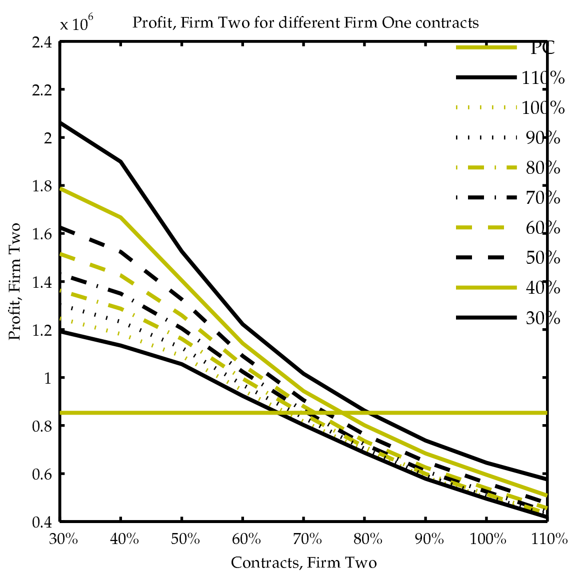
Profit, Firm Two for different Firm One contracts
x 10^6
Profit, Firm Two
Contracts, Firm Two
0.4
0.6
0.8
1
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1.8
2
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2.4
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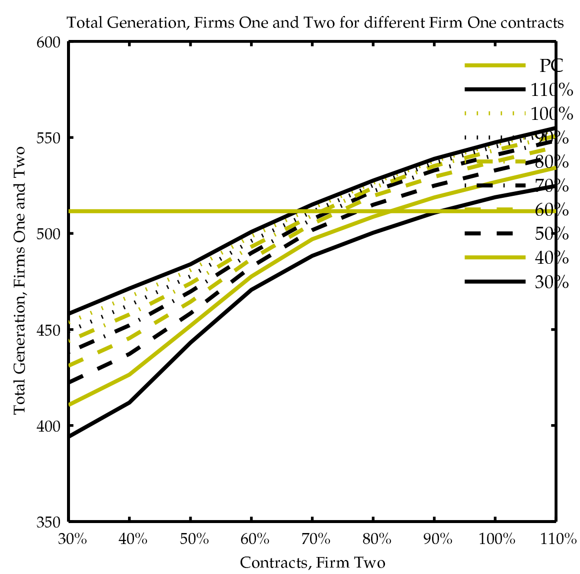
Total Generation, Firms One and Two for different Firm One contracts
Total Generation, Firms One and Two
Contracts, Firm Two
350
400
450
500
550
600
30%
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50%
60%
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110%
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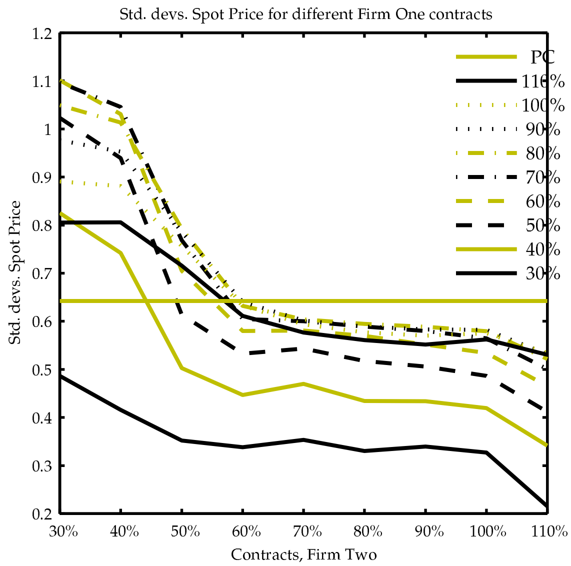
Std. devs. Spot Price for different Firm One contracts
Std. devs. Spot Price
Contracts, Firm Two
PC
110%
100%
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40%
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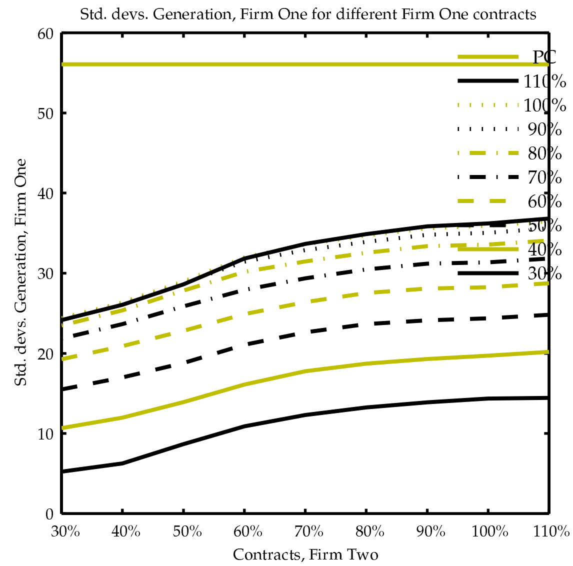
Std. devs. Generation, Firm One for different Firm One contracts
Std. devs. Generation, Firm One
Contracts, Firm Two
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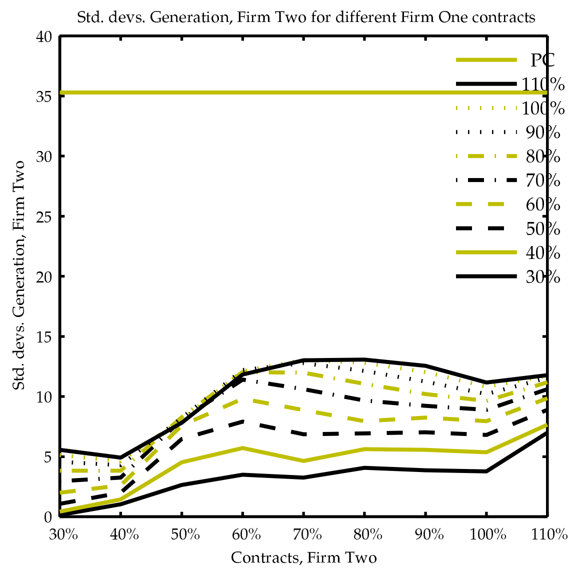
Std. devs. Generation, Firm Two for different Firm One contracts
Std. devs. Generation, Firm Two
Contracts, Firm Two
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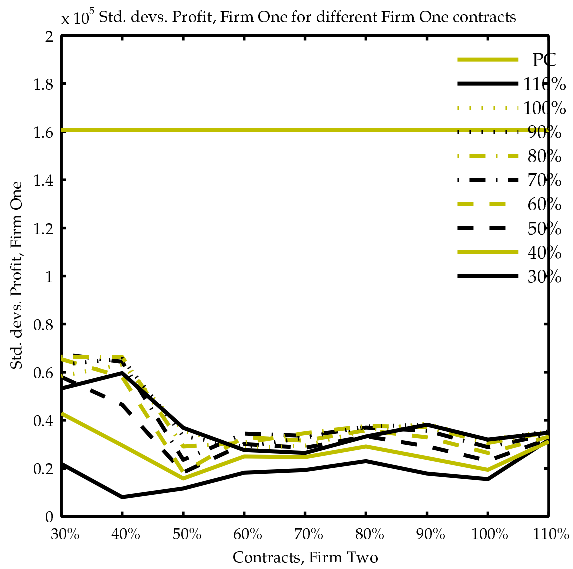
x 10^5 Std. devs. Profit, Firm One for different Firm One contracts
Std. devs. Profit, Firm One
Contracts, Firm Two
PC
110%
100%
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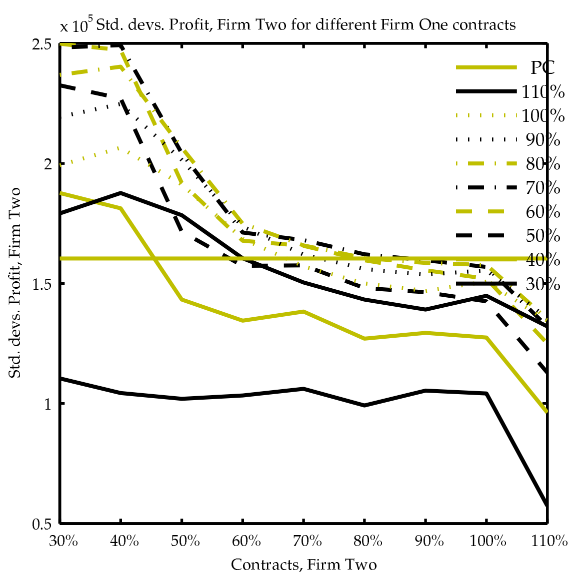
x 10^5 Std. devs. Profit, Firm Two for different Firm One contracts
Std. devs. Profit, Firm Two
Contracts, Firm Two
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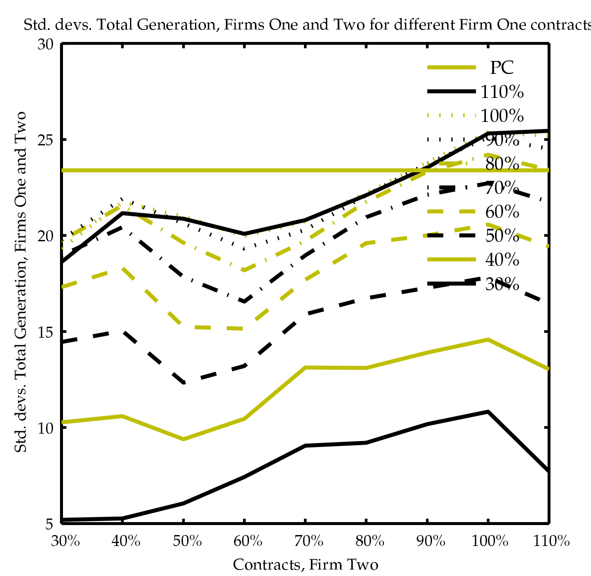
Std. devs. Total Generation, Firms One and Two for different Firm One contracts
Std. devs. Total Generation, Firms One and Two
Contracts, Firm Two
PC
110%
100%
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