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## Forward Premia in Electricity Markets with Fixed and Flexible Retail Rates: Replication and Extension

Silvester Van Koten



European University Institute  
**Robert Schuman Centre for Advanced Studies**

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## **Abstract**

Bessembinder and Lemmon (2002) analyze forward premia in electricity markets when retail rates are fixed. I run both established and new simulations to replicate their findings for fixed tariffs and extend their analysis to flexible tariffs. Two of their four main predictions for fixed tariffs cannot be replicated, and their proposed regression, used in many empirical studies, seems not capable of reliably capturing the underlying relationships. Their predictions can mostly be extended to the case of flexible rates. The results of this study indicate that empirical studies should explicate if their data concern fixed or flexible rates and adjust their predictions accordingly.

## **Keywords**

Forward Premia, Electricity Markets, Energy Economics, Mean Power Demand, Financial Markets

**JEL Classification:** G13, G17, L94, Q41





## I. Introduction<sup>\*</sup>

Bessembinder and Lemmon (2002) formulate an influential<sup>1</sup> risk premium theory, linking the forward electricity price to the expected spot electricity price. The theory and its predictions are of prime importance for participants in electricity markets, as electricity spot prices, due to the near impossibility of storing electricity in significant quantities, show extreme volume and price volatility.<sup>2</sup> In addition, while in the past electricity producers and retailers were sheltered from risk by the model of vertically integrated utilities operated as regulated (state) monopolies, in the present liberalized model of unbundling and competition, electricity producers and retailers must both shoulder the risk of volatility. Indeed, as a result of the increase in risk, trading in derivatives has increased tremendously over the past decade.<sup>3</sup>

Bessembinder and Lemmon (2002) assume that, through the period up to maturity of the forward contract, the retail rate is fixed, and the period is shorter than the timeframe over which a retail rate is fixed. This assumption was innocuous in the past when most retail rates were regulated and fixed for long periods (as long as up to five years), and when forward contracts were virtually non-existent or had very short maturities. At present, this assumption is no longer valid in many cases. Numerous electricity retail markets have become liberalized and offer flexible retail rates that can change within a short timeframe such as a month – see, for example, the household retail rates in the UK (EDF, 2015).<sup>4</sup> Moreover, flexible rates, including the "pure" form of real-time prices, can be expected to become more prevalent in the (near) future.<sup>5</sup> In addition, in the past decade, electricity markets have introduced electricity forward contracts with extended maturities. For example, at the European Energy Exchange (EEX), forward contracts are traded with maturities up to six years.<sup>6</sup>

Thus when considering forward contracts with maturities longer than the timeframe over which an electricity rate is set, the rate can be considered flexible and the assumptions of Bessembinder and Lemmon (2002) are violated. I therefore use simulations to assess if the theoretical predictions of

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<sup>1</sup> Bessembinder and Lemmon (2002) has been cited 529 times according to Google Scholar, 167 times according to the Web of Science, and 223 times according to Scopus (accessed on 2015.10.18). The theory and the four hypotheses derived from it have been used extensively in publications and studies of electricity price data. See, for example, Longstaff and Wang (2004), Karakatsani and Bunn (2005), Diko, Lawford, and Limpens (2006), Hadsell and Shawky (2006), Douglas and Popova (2008), Lucia and Torro (2008), Weron (2008), Daskalakis and Markellos (2009), Redl, Haas, Huber, and Böhm (2009), Botterud, Kristiansen, and Ilic (2010), Furio and Meneu (2010), Haugom and Ullrich, (2012), Bun and Chen (2013), Handika and Trück (2013), Redl and Bunn (2013), Zator (2013), and Weron and Zator (2014).

<sup>2</sup> The price volatility of electricity can be two orders of magnitude higher than for other commodities or financial instruments (Weron, 2006).

<sup>3</sup> For example, in the EEX market, trading in electricity derivatives increased tenfold from a level of 119 TWh in 2002 to 1264 TWh in 2013 (EEX, 2005, 2013).

<sup>4</sup> Of course, there are still markets with regulated and fixed retail rates. See, for example, the case of household retail rates in Australia (Gardner, 2010; Queensland Competition Authority, 2015).

<sup>5</sup> Moreover, a growing literature shows that shorter timeframes, such as hourly ones (also referred to as real-time pricing or RTP), may be necessary for the electric systems of the near future to integrate large amounts of (renewable) intermittent generation (see, for example, Roscoe and Ault, 2010; Savolainen et al., 2012; Broeer et al., 2014; Finn and Fitzpatrick, 2014; Buryk et al., 2015).

<sup>6</sup> See <https://www.eex.com/en/products/power/power-derivatives-market>, accessed on 2016.01.10.

Bessembinder and Lemmon (2002) can be extended to flexible rates. I use both "established" simulations that were also performed in Bessembinder and Lemmon (2002), the forward premium as a function of expected demand and the demand standard deviation, and new, computationally intensive simulations, the forward premium as a function of price variance and non-standardized skewness. In addition, as their predictions have not received unequivocal support in the empirical literature,<sup>7</sup> I use both the established and new simulations to try to replicate the results of Bessembinder and Lemmon (2002).<sup>8</sup> The paper is organized as follows. Section II presents Bessembinder and Lemmon's (2002) main theoretical elements and predictions. Section III presents numerical simulations, and section IV concludes.

## II. The Bessembinder and Lemmon (2002) Theory

Bessembinder and Lemmon (2002) model the electricity forward premium as the interplay between hedging pressures by wholesale sellers (producers) and buyers (retailers) of electricity.<sup>9</sup> The forward premium is the difference between the forward price and the expected spot price:<sup>10</sup>

$$\text{Forward Premium} = P_{F,t_0,t_1} - E_{t_0}[P_{S,t_1}] \quad (1)$$

In Equation (1),  $t_0$  refers to the present period,  $t_1$  to the future period,  $P_{F,t_0,t_1}$  to the present price of a forward contract with delivery at time  $t_1$ ,  $P_{S,t_1}$  to the future spot price, and  $E_{t_0}[\cdot]$  to the present expectation operator for future outcomes.

Bessembinder and Lemmon (2002) use an equilibrium approach and, under the assumptions of no uncertainty in spot markets, perfect competition, and abstracting from the interest rate, derive a formula showing that the forward premium depends on the distribution of electricity spot prices:

$$P_{F,t_0,t_1} - E_{t_0}[P_{S,t_1}] = -\frac{N_P}{(N_P + N_R)} \frac{RA}{ca^x} (c\bar{P}_R \text{Cov}[P_{S,t_1}^x, P_{S,t_1}] - \text{Cov}[P_{S,t_1}^{x+1}, P_{S,t_1}]) \quad (2)$$

In Equation (2),  $N_P$  is the number of (identical) producers;  $N_R$  is the number of (identical) retailers;  $c > 2$  is the cost convexity parameter that figures in the (convex) cost function of electricity producers,  $C[q] = f + \frac{a}{c}q^c$ ;  $f$  is the fixed cost and  $a$  the variable cost parameter in the cost function of electricity producers; assuming mean-variance utility functions,  $RA$  stands for the degree of risk aversion of retailers and producers;  $x = \frac{1}{c-1} < 1$ ; and  $\bar{P}_R = r \cdot E[P_S]$  refers to the regulated or otherwise temporarily fixed retail price of electricity at which retailers can sell electricity to consumers (with  $r > 1$ ).

The cost convexity parameter  $c$  and the variable cost parameter  $a$  reflect the size and composition of a generating asset portfolio consisting of different power plants with different marginal costs. The

<sup>7</sup> See p.7, Table 1, in this paper for a list of empirical studies testing Bessembinder and Lemmon (2002).

<sup>8</sup> Replication has, fairly recently, gained in prominence. For example, Chang and Li (2015) report that, with help of the authors, they could replicate only half of the research published in 13 well-regarded economics journals.

<sup>9</sup> Bessembinder (1992) reports supporting evidence for the role of hedging pressures for forward premia in foreign currency and agricultural markets.

<sup>10</sup> See Weron and Zator (2014) for alternate definitions and a discussion of the confusion the interchangeable use of different definitions has caused in the literature.

cost function is convex, as with an increase in production, producers must utilize power plants with increasingly higher marginal costs.<sup>11</sup>

The retail rate  $\bar{P}_R = r \cdot E[P_S]$  is generally fixed for a certain period. As discussed above, the length of this period can vary widely, depending on the country and type of contract.

An important distinction between retail rates is whether they are, over the maturity of the forward contract under consideration, fixed and thus based on the present average prices,  $\bar{P}_R = r \cdot E_{t_0}[P_{S,t_0}]$ , or flexible and thus based on the future average prices,  $\bar{P}_R = r \cdot E_{t_0}[P_{S,t_1}]$ . Bessembinder and Lemmon (2002), while not explicitly making the distinction between fixed and flexible rates, arguably consider the case of fixed rates.

Bessembinder and Lemmon (2002) further derive, using second-order Taylor series expansions to approximate Equation (2), a simplified approximate relationship that can be tested with regressions using the forward price and the statistical properties of expected spot prices. Equation (3) shows the results of this approximation.

$$P_F - E[P_S] = b_1 \text{Var}[P_S] + b_2 \text{Skew}[P_S], \text{ where:} \quad (3)$$

$$b_1 = -\frac{N_P(x+1)A}{(N_P + N_R)ca^x} (\bar{P}_R E[P_S]^{x-1} - E[P_S]^x) \text{ and } b_1 < 0$$

$$b_2 = \frac{N_P(x+1)A}{2(N_P + N_R)ca^x} (xE[P_S]^{x-1} + (1-x)\bar{P}_R E[P_S]^{x-2}) \text{ and } b_2 > 0$$

$$\text{and } \text{Skew}[P_S] = \frac{1}{n} \sum (p_i - \bar{p})^3 \text{ is the 3}^{\text{rd}} \text{ non-standardized moment.}$$

In Equation (3), the forward premium is decreasing in the variation and increasing in the non-standardized skewness<sup>12</sup> of the spot price distribution, as  $\bar{P}_R = r \cdot E[P_S] > E[P_S]$  and  $x = \frac{1}{c-1} < 1$ .

Bessembinder and Lemmon (2002) give an intuitive explanation based on the facts that electricity prices are highly correlated with demand, that the profits of retailers are decreasing in price (a profit-decreasing price effect) but increasing in demand (a profit-increasing volume effect) and the assumption that retailers are risk-averse. A low (high) level of demand leads to a low (high) electricity price.

With a low level of spot price variation, a small increase in variation will increase the number of high demand realizations and initially increase the profit of electricity retailers, as the profit-increasing volume effect of higher demand initially dominates the profit-decreasing effect of a higher electricity price. An increase in variation will also increase the number of low demand realizations and this lowers the profits of the electricity retailers. Electricity retailers thus have an incentive to hedge the risk of low demand realizations by selling electricity forward (or at least not wanting to buy as much as producers like to sell), resulting in lower forward prices.

<sup>11</sup> Power plants vary widely in their marginal costs as they are of different types, use different kinds of fuels and are of different vintages. Moreover, even when a given plant is running at full capacity, producers can eke out still more electricity, but at the (very high) cost of a reduction in plant lifetime (Harris, 2006, p.51 and p.485-487).

<sup>12</sup> For brevity and consistency with Bessembinder and Lemmon (2002), I will use "non-standardized skewness" and "skewness" interchangeably to refer to the 3<sup>rd</sup> non-standardized moment. I will reserve the term "standardized skewness" to refer to the Fisher-Pearson coefficient of skewness,  $\sigma_p^{-3} \frac{1}{n} \sum (p_i - \bar{p})^3$  (Pearson and Hartley, 1970).

In contrast, an increase in the non-standardized skewness results in price spikes that are large relative to the increase in demand. As a result, the profit-decreasing effect of a higher electricity price dominates the profit-increasing volume effect of higher demand and profits are affected negatively. Electricity retailers thus have an incentive to hedge risk by buying electricity forward, resulting in higher forward contract prices.

Different demand parameters change the demand distribution and the resulting prices and thus, as Equation (2) and (3) show, change the forward premium. It is therefore an interesting question how changes in the demand parameters or the resulting prices affect the forward premium. Deriving these effects analytically seems very difficult, and Bessembinder and Lemmon (2002) thus use simulations based on Equation (2) and the approximation in Equation (3) to derive four hypotheses regarding the effects of changes. I treat the assumption that regression Equation (3) can reliably capture the underlying relationships as a fifth hypothesis, written in *italics* below:

- Hypothesis 1: The equilibrium forward premium decreases in the anticipated variance of wholesale prices, *ceteris paribus*.
- Hypothesis 2: The equilibrium forward premium increases in the anticipated non-standardized skewness of wholesale prices, *ceteris paribus*.
- Hypothesis 3: The equilibrium forward premium is convex, initially decreasing and then increasing, in the variability of power demand, *ceteris paribus*.
- Hypothesis 4: The equilibrium forward premium increases in mean power demand, *ceteris paribus*.
- *Hypothesis 5: The equilibrium forward premium can reliably be modeled as*

$$b_1 \text{Var}[\mathbf{P}_s] + b_2 \text{Skew}[\mathbf{P}_s] + \varepsilon$$

Hypotheses 3 and 4 are derived from numerical simulations using the main theory as expressed in Equation (2), while Hypothesis 1, 2, and 5 are derived from the approximation in Equation (3). All hypotheses refer to the case of fixed rates.

I run simulations, generating "artificial", theory-derived data using Equation (2) to test the hypotheses of Bessembinder and Lemmon (2002), as an extension, for flexible rates and, as a replication, for fixed rates. The motivation for trying to extend the theory for flexible rates, is that the effects with flexible rates may very well be different from those with fixed rates. The exposure to risk for a retailer with respect to a certain future date will be smaller if the retail rate at the future date is adapted to the future demand distribution than if the future retail rate is the same as in the past (and thus maladapted to the future demand distribution). With flexible rates, the retailer thus faces a lower risk and this changes the shape of the retailer demand for forward contracts and thus affects the equilibrium price of forward contracts, resulting in different forward premia. The precise change between these two cases, however, is not obvious.

**Table 1: Overview of empirical tests of Bessembinder and Lemmon (2002)**

<b>Empirical tests of Hypotheses 1 and 2</b>		
	Study	Data used
Support	Longstaff and Wang (2004)	Hourly spot and day-ahead prices of PJM
	Diko et al. (2006)	Daily data of EEX, Powernext, and APX
	Hadsell and Shawky (2006)	Day-ahead and real time data of NYISO
	Douglas and Popova (2008)	Day-ahead and real time data of PJM
	Viehmann (2011)	Hourly day-ahead data of EEX and EXAA
	Fleten et al. (2015)	Monthly, quarterly and annual data of Nordic NASDAQ OMX and German/Austrian EEX
Partial support	Lucia and Torro (2008),	Weekly contracts of Nord Pool
	Redl et al.(2009)	Monthly contracts of EEX and Nord Pool
	Botterud et al.(2010)	Weekly contracts of Nord Pool
	Furio and Meneu (2010)	Monthly data of the Spanish OMEL market
No support	Bunn and Chen (2012)	Daily and monthly data from the British market
	Haugom and Ullrich (2012)	Day-ahead and real time data of PJM (Repeating Longstaff and Wang, 2004)
	Handika and Trück (2013)	Quarterly and yearly data of the Australian market Month-ahead futures of EEX
	Redl and Bunn (2013)	Day-ahead and intra-day data of EEX and EXAA
	Ronn and Wimschulte (2009)	Weekly contracts of Nord Pool (Repeating Botterud et al., 2010)
	Weron and Zator (2014)	
<b>Empirical tests of Hypotheses 1 and 2</b>		
	Study	Data used
Support	Bessembinder and Lemmon 2002	Monthly data of the PJM and CALPX markets.
	Karakatsani and Bunn, 2005	Day-ahead and intra-day data of the British market
	Lucia and Torro, 2011	Weekly contracts of Nord Pool
	Furio and Meneu, 2009	Monthly data of the Spanish OMEL market
	Handika and Trück, 2013	Quarterly and yearly data of the Australian market

The motivation for the replication, testing the predictions for the fixed rates as used in Bessembinder and Lemmon (2002), is that the predictions received mixed support from empirical studies. Table 1 gives an overview of empirical literature that performed tests of the hypotheses in Bessembinder and Lemmon (2002), and indicates if the tests provide support, partial support or no support. Most of the empirical tests focused on Hypotheses 1 and 2,<sup>13</sup> regarding the effect of price variance and non-standardized skewness on the forward premium, and the tests are approximately evenly divided between supportive, partial supportive and unsupportive. The empirical tests focused on Hypothesis 4 provide support. With the empirical support thus being mixed, I test if I can replicate the theoretical predictions using artificial data. As the artificial data is derived from the theory itself, the data is factually biased to support the hypotheses and the replication test should thus be regarded as a minimal requirement.

For an easy overview, I summarize the hypotheses in Table 2 and, as a preview of the results of this study, indicate my findings for the predictions of Bessembinder and Lemmon (2002) for fixed (my replication) and for flexible tariffs (my extension).

**Table 2: Predictions for forward premium by Bessembinder and Lemmon (2002) and the results for fixed (my replication) and for flexible tariffs (my extension).**

	<b>Fixed retail tariffs</b> Bessembinder and Lemmon (2002) The forward premium:	<b>Fixed retail tariffs</b> Van Koten, replication of Bessembinder and Lemmon (2002)	<b>Flexible retail tariffs</b> Van Koten, extension of Bessembinder and Lemmon (2002)
H1	decreases in variance of prices	<b>not supported</b>	<b>supported</b>
H2	increasing in non-standardized skewness of price	<b>not supported</b>	<b>supported</b>
H3	initially decreases and then increases in demand standard deviation	<b>supported</b>	<b>supported</b>
H4	increases in mean demand	<b>supported</b>	<b>mostly supported</b>
H5	$= b_1 \text{Var}[P_s] + b_2 \text{Skew}[P_s] + \varepsilon$	<b>not supported</b>	<b>partly supported</b>

### 3. Simulations

#### 3.1 Testing the underlying theory: Hypothesis 3 and 4

As in Bessembinder and Lemmon (2002), I use established simulations, using Equation 2 above to calculate the spot prices, forward prices and forward premia for different normal distributions of demand with the mean ranging from 75 to 125 and the standard deviation ranging from 1 to 40.<sup>14</sup> I then create graphs of the forward premium as a function of the mean demand and demand standard

<sup>13</sup> Two of the studies in this overview, Haugom and Ullrich (2012) and Weron and Zator (2014), are attempts to replicate earlier empirical studies.

<sup>14</sup> For these ranges I use increments of 1, thus resulting in a total of  $40 * 51 = 2040$  data points. Each data point is based on a sample of 10 million draws.

deviation. I do this both for the fixed (for the replication) and flexible (for the extension) retail rates. Table 3 presents the parameters used for the simulations.

**Table 3**  
**Parameters of the Graphs in Figure 2 testing Hypothesis 3 and 4**

Basic parameters		
	Hypothesis 3:	Hypothesis 4:
Scaling parameter $a$	$a = 30(N_p / 100)^{c-1}$	
Risk aversion $RA$	$RA = 0.8 \cdot 2^{-c}$	
Numbers of retailers $NR$	20	
Numbers of producers $NP$	20	
Cost convexity parameter $c$	2-5	4
Range of mean demand	100	75 – 125
Range of demand standard deviation	1-40	

Retail rate	
<b>FIX</b> (replication): $R = 1.2 \cdot E[P_S   \bar{D} = 100, \sigma_D = 20]$	<b>FLEX</b> (extension): $R = 1.2 \cdot E[P_S   \bar{D}, \sigma_D]$

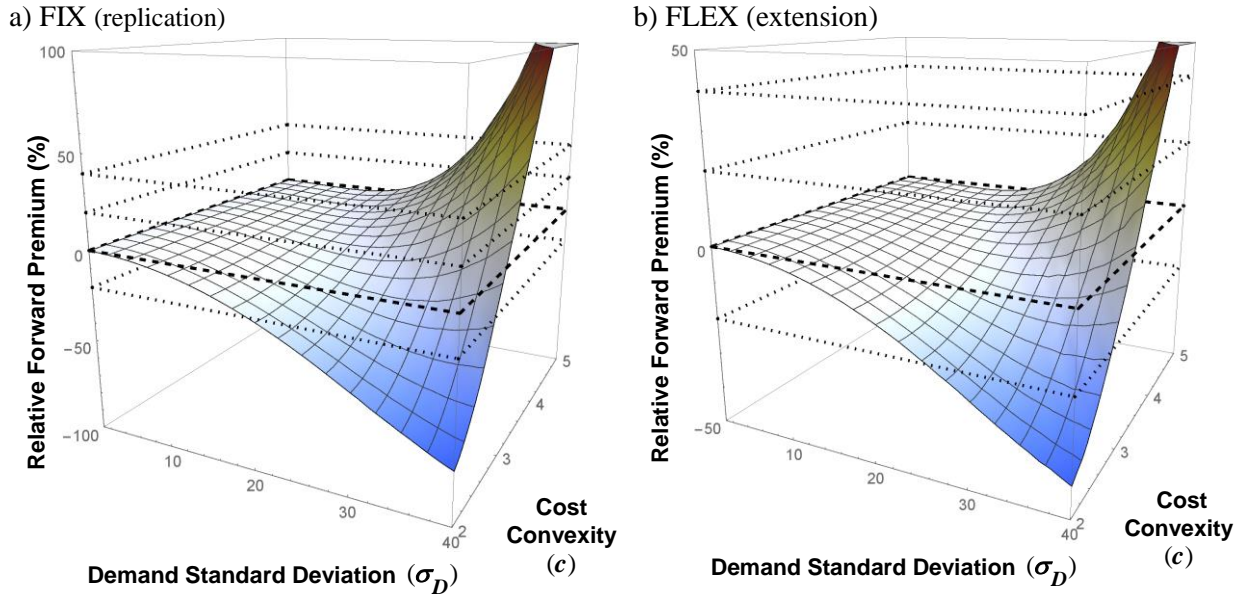
With fixed rates (FIX), the retail rate is fixed for all demand distributions at 1.2 times the expected price for a demand distribution with a mean demand of 100 and a demand standard deviation of 20.5, thus  $R = 1.2 \cdot E[P_S | \bar{D} = 100, \sigma_D = 20.5]$ . With flexible rates (FLEX), the retail rate is set for each demand distribution at 1.2 times the expected price,  $R = 1.2 \cdot E[P_S | \bar{D}, \sigma_D]$ .<sup>15</sup>

### 3.1.1 Hypothesis 3

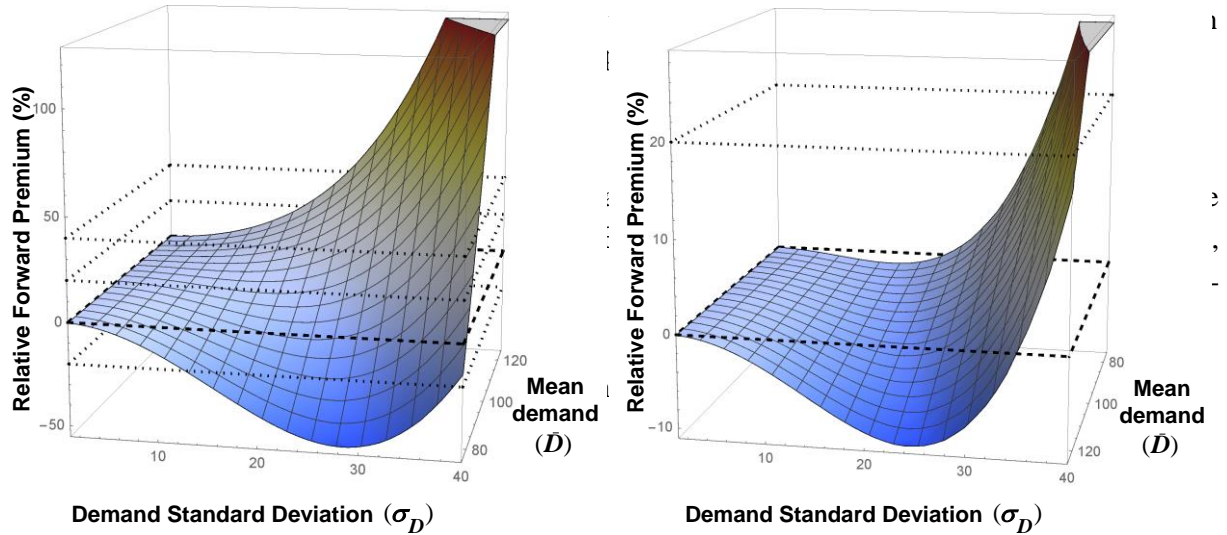
Figure 1 shows the results of the simulations regarding Hypothesis 3. The z-axis shows the relative forward premium in percentages,  $(P_F - E[P_S]) \cdot (E[P_S])^{-1} \cdot 100\%$ , labeled as "Relative Forward Premium", as a function of the standard deviation of demand (on the x-axis) and the cost convexity parameter  $c$  (on the y-axis).

<sup>15</sup> Bessembinder and Lemmon (2002) do not report what values of mean demand and demand standard deviation they use for their simulations. It should be noted that some parts of the description of the simulation in Bessembinder and Lemmon (2002) may cause confusion about the precise parameters used, and thus whether they consider fixed or flexible rates. They reported on p.136 under Figure 3 that "The retail price is set as  $R = 1.2 \cdot E[P_w | c]$ ", which clearly expresses that the retail price is fixed between different values of the cost convexity parameter  $c$ , but which does not unambiguously state that the retail rate is fixed over different values of demand standard deviation and mean demand. The computer code that was used for the simulations in Bessembinder and Lemmon (2002) could definitively settle the precise procedures used, but, unfortunately, the program is lost (written communication with Bessembinder, 2015). Also with respect to the scaling factor, some parts of the description may be confusing. Bessembinder and Lemmon (2002) report on page 1359 "the variable cost parameter is set as  $a = 30(N_p / 100)^{c-1}$ ", but then on page 1361 under Figure 3 "... we set  $a = 30(N_p / \bar{D})^{c-1}$ ". The latter expression might give the impression that they set the scaling parameter for each demand distribution separately, but this is not the case (written communication with Bessembinder).

**Figure 1: Forward premium and demand standard deviation and cost convexity**



The graphs with fixed retail rates (FIX) initially decrease and then increase in the demand standard deviation, thus replicating the results of Bessembinder and Lemmon (2002) for Hypothesis 3. The graphs with flexible (FLEX) rates have a nearly identical shape, also initially decreasing and then increasing in the demand standard deviation and increasing in the cost convexity. This result thus supports the extension of Hypothesis 3 for flexible rates also. Quantitatively, the effects with flexible rates are of a somewhat lower magnitude than those with fixed rates. This seems to confirm the



The graphs with fixed retail rates (FIX) increase in the mean demand, thus replicating the results of Bessembinder and Lemmon (2002) for Hypothesis 4.<sup>16</sup> The graphs with flexible (FLEX) rates has

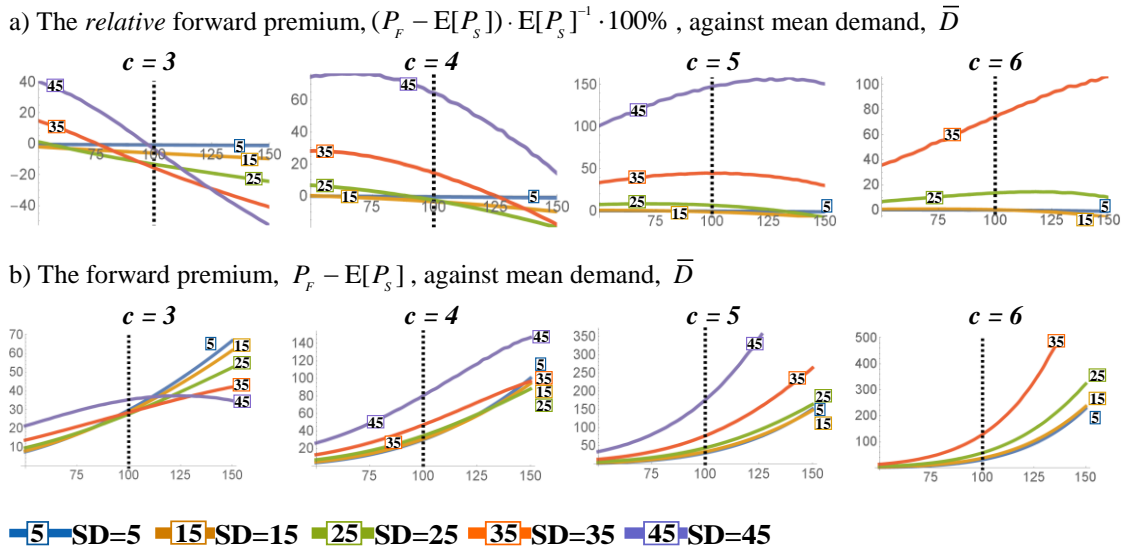
<sup>16</sup> The graph for fixed retail rates (FIX) in Figure 2.a) is virtually identical to the one in Bessembinder and Lemmon (2002), except that the one in this paper shows a quantitatively stronger effect. The quantitative difference may be caused by the choice of different fixed retail rates. As mentioned, for calculating the fixed retail rate I used the demand distribution with



similar shape, and as we saw before in the simulations for Hypothesis 3, effects are less strong with flexible rates. However, in addition, the axis of mean demand is numbered in the graphs with flexible rates (FLEX) in a direction opposite to that of fixed rates (FIX). With a movement (in the North-East direction) along the axis of mean demand, the value increases in the graph with fixed rates, but decreases in the graph with flexible rates. The relationship between the relative forward premium and mean power demand is thus inverted with flexible rates. It seems that the reduction of retailer risk that is brought by the flexible rates makes the retailer less vulnerable to variation in demand than the producer, thus causing the forward premium to fall with an increase in mean demand.

For a better understanding of the effects, in Figure 3 I create two-dimensional countour graphs of both the *relative* forward premium in percentages,  $(P_F - E[P_S]) \cdot (E[P_S])^{-1} \cdot 100\%$ , (the upper panel) and the forward premium,  $P_F - E[P_S]$ , (the lower panel) as a function of mean demand over a range from 50 to 150 for different values of the demand standard deviation and the convexity cost parameter  $c$ .<sup>17</sup>

**Figure 3: Forward premium and mean demand with flexible rates (extension).**



The contour graphs show the relative forward premium in percentages (upper panel) and the forward premium (lower panel) as a function of mean demand for different values of the demand standard deviation and the cost convexity parameter. The row directly above the graphs indicates the value of the convexity cost parameter  $c$ . The graphs are created by calculating the (relative) forward premium for 50 values of the mean demand and connecting the resulting points.

The contour graphs in Figure 3 show that while, in the majority of parameter values considered here, the *relative* forward premium is decreasing in mean demand, the forward premium is still mostly increasing in mean demand. The reduction in retailer risk is thus strong enough to reverse the relationship between mean demand and the *relative* forward premium in most cases, but not strong enough to do the same for the relationship between mean demand and the forward premium. This result thus supports the extension of Hypothesis 4 also for flexible rates, though the support is less unequivocal than for Hypothesis 3.

(Contd.)

mean 100 and standard deviation 20.5. Unfortunately, Bessembinder and Lemmon (2002) do not report the demand distribution they used for the fixed retail rate.

<sup>17</sup> To prevent the computation time from becoming impractically long, I use increments of 2 for these ranges.

### 3.2 Testing the approximate equation: Hypothesis 1 and 2

I run new simulations, using Equation 2 above, to determine spot prices and their variance and skewness, forward prices and the forward premia for different normal distributions of demand with the mean ranging from 75 to 125 and the standard deviation ranging from 1 to 40.<sup>18</sup> I then create graphs of the forward premium as a function of the price variance and the non-standardized skewness of price.<sup>19</sup> Table 4 presents the parameters used for the simulations to test Hypotheses 1 and 2.

**Table 4**  
**Parameters of the Graphs in Figure 2 testing Hypotheses 1 and 2**

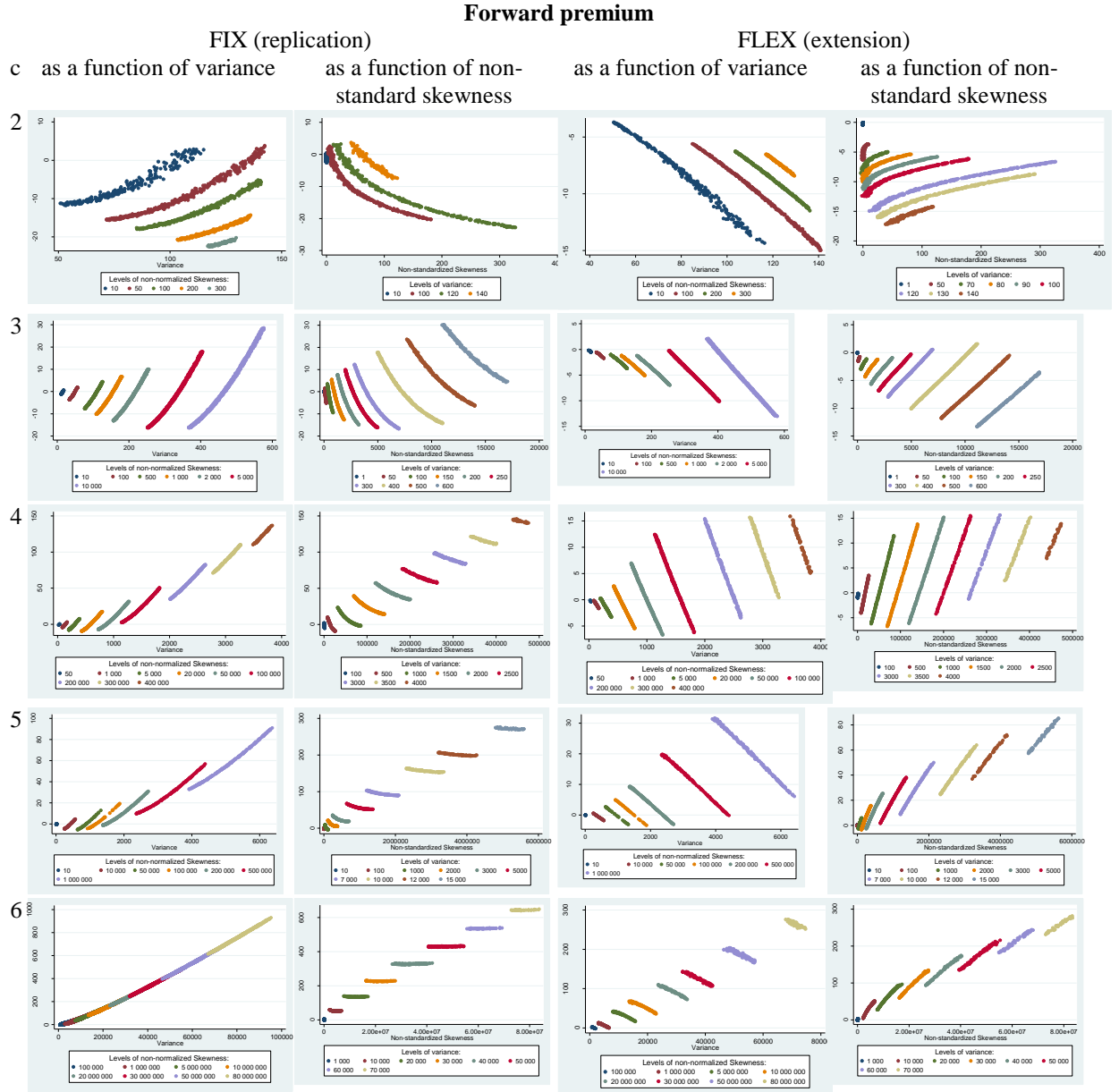
Scaling parameter $a$	$a = 30(N_p / 100)^{c-1}$
Risk aversion $RA$	$RA = 0.8 \cdot 2^{-c}$
Numbers of retailers $NR$	20
Numbers of producers $NP$	20
Range of cost convexity parameter $c$	2-6
Range of mean demand	75 – 125
Range of demand standard deviation	1-40
Retail rate	
<b>FIX</b> (replication): $R = 1.2 \cdot E[P_s   \bar{D} = 100, \sigma_D = 20.5]$	<b>FLEX</b> (extension): $R = 1.2 \cdot E[P_s   \bar{D}, \sigma_D]$

Three-dimensional pictures are very difficult to interpret in this case, and I therefore draw two-dimensional contour graphs. Figure 4 presents the results.

<sup>18</sup> For these new simulations, to collect sufficient data points, I use increments of 0.1, thus obtaining a total of  $391 * 501 = 195.891$  data points. Each data point is based on a sample of 1 million draws. Computation takes about 36 hours per dataset (for two graphs) on a relatively powerful desktop computer (AMD A8-5600K, 32GB RAM).

<sup>19</sup> Bessembinder and Lemmon (2002) did not present such graphs.

**Figure 4: Forward premium as a function of skewness and variance**



The graphs show the relationship between the forward premium and price variance and the non-standardized price skewness, both for the fixed (FIX) and flexible (FLEX) rates. The first column on the left shows, for each row of graphs, the value of the cost convexity parameter  $c$ .

The graphs in Figure 4 with fixed retail rates (FIX) show that the simulations do not replicate the predictions of Hypotheses 1 and 2 in Bessembinder and Lemmon (2002). For all values of the cost convexity parameter between two and five, forward premia increase in price variance and decrease in non-standardized skewness of price, thus showing relationships that are opposite to those predicted in Bessembinder and Lemmon (2002). Only when the cost convexity parameter is equal to six, forward premia seem to conform to the prediction in Bessembinder and Lemmon (2002), increasing (somewhat) in non-standardized skewness. The graphs in Figure 4 with flexible retail rates (FLEX) show that the simulations support the extension of the predictions for flexible rates. For all values of the cost convexity parameter simulated, the forward premium decreases in variance and increases in the non-standardized skewness.

To test Hypothesis 5, if the forward premium can be captured by the regression  $\text{Forward Premium} = b_1 \text{Var}[P_s] + b_2 \text{Skew}[P_s] + \varepsilon$ , I run the regression for each value of the cost convexity parameter  $c$  and for flexible and fixed rates separately and report the results in Table 5.<sup>20</sup>

**Table 5: Regression results**  $\text{Forward Premium} = b_1 \text{Var}[P_s] + b_2 \text{Skew}[P_s] + \varepsilon$ .

$c$	FIX (replication)				FLEX (extension)			
	$var$	$skew_{ns}$	Observations	R-squared	$var$	$skew_{ns}$	Observations	R-squared
2	-0.0529	<b>-0.0614</b>	195,891	0.759	<b>-0.11</b>	<b>0.022</b>	195,891	0.759
3	-0.0151	0.00143	195,891	0.235	<b>-0.0271</b>	<b>0.00061</b>	195,891	0.89245
4	-0.0033	0.00031	195,891	0.878	<b>-0.0051</b>	<b>8.61E-05</b>	195,891	0.5412
5	<b>0.0040</b>	3.97E-05	195,891	0.978	0.00054	<b>1.36E-05</b>	195,891	0.978
6	<b>0.0041</b>	<b>4.54E-06</b>	195,891	0.995	0.00159	<b>2.07E-06</b>	195,891	0.995

The regressions for the fixed rates (FIX) show that the results do not replicate Bessembinder and Lemmon's (2002) prediction that the regression reliably captures the relationships between forward premia and price variance and non-standardized skewness (Hypothesis 5). Only four of ten coefficients (in bold typeface) have the correct sign, resulting in all regressions but one having one or both signs wrong. The regressions for the flexible rates (FLEX) fare somewhat better: eight out of ten coefficients have the right sign (in bold typeface), resulting in three regressions having the correct signs and two having one or both signs wrong. As the regressions are correct for the low values of the cost convexity parameter, I interpret this as giving partial support to the prediction that the regression reliably captures the relationships (Hypothesis 5). The contour graphs in Figure 4 indicate that the relationship between forward premium and variance and non-standardized skewness is in many cases non-linear. This may have biased the estimates.

### 3.3 Discussion

The motivation for this paper is that, as nowadays retail tariffs are being adjusted with higher frequency and electricity forward contracts with longer maturities are traded, the predictions of Bessembinder and Lemmon (2002) may no longer apply. I therefore study to what degree their predictions can be extended to cases where tariffs are flexible. In addition, due to the mixed support of empirical tests, I also run the simulations for the original case of fixed rates, thus aiming to replicate the findings of Bessembinder and Lemmon (2002). The results of the simulations are summarized in Table 6 below.

<sup>20</sup> All coefficients have a very high level of significance, but as this is the result of the very high number of data points, I do not attribute special importance to this fact and do not report the significance levels.

**Table 6: Predictions for forward premium by Bessembinder and Lemmon (2002) and the results for fixed and flexible tariffs**

	<b>Fixed retail tariffs</b> Bessembinder and Lemmon (2002) The forward premium:	<b>Fixed retail tariffs</b> Van Kote, replication of Bessembinder and Lemmon (2002)	<b>Flexible retail tariffs</b> Van Kote, extension of Bessembinder and Lemmon (2002)
H1	decreases in variance of prices	<b>not supported:</b> increases in price variance	<b>supported</b>
H2	increasing in non-standardized skewness of price	<b>not supported:</b> decreasing in non-standardized skewness of price	<b>supported</b>
H3	initially decreases and then increases in demand standard deviation	<b>supported</b>	<b>supported</b>
H4	increases in mean demand	<b>supported</b>	<b>mostly supported:</b> decreases for some extreme parameters
H5	$= b_1 \text{Var}[P_s] + b_2 \text{Skew}[P_s] + \varepsilon$	<b>not supported:</b> five out of five regressions have one or both coefficients incorrect	<b>partially supported:</b> three out of five regressions have correct coefficients

The simulations, using data generated in perfect consistency with the underlying theory, cannot replicate the predictions of Bessembinder and Lemmon (2002) for Hypothesis 1, 2, and 5 in the original case of fixed tariffs. For Hypotheses 1 and 2, the results are opposite to the predictions. The forward premium is found to increase in price variance and decrease in the non-standardized skewness of price, while the regression does not capture well the relationship in the data. The simulations can, however, replicate Bessembinder and Lemmon's (2002) predictions for Hypotheses 3 and 4. With fixed tariffs, the forward premium initially decreases and then increases in demand standard deviation and increases in mean demand.

With flexible rates, the simulations support extending the predictions of Bessembinder and Lemmon (2002) for Hypotheses 1, 2, and 3 fully and for Hypothesis 4 mostly. The contour plots in Figure 4 show that, for the parameters analyzed, the forward premium decreases in variance and increases in non-standardized skewness (Hypotheses 1 and 2). The graphs in Figure 3 show that the forward premium initially decreases and then increases in demand standard deviation and increases in mean demand (Hypotheses 3 and 4). The effects for Hypothesis 3 are quantitatively somewhat weaker. For Hypothesis 4, possibly some exceptions can be found for some extreme parameter values (a very low cost convexity parameter and a very high standard deviation of demand). The reason for the quantitatively weaker effect in Hypothesis 3 and the possible exception in Hypothesis 4 is likely the reduction in exposure to risk for retailers, as the tariff is adapted for the new demand distribution (and thus increased for a demand distribution that results in a higher average price). For the same reason, where the forward premium still mostly increases in mean demand, the *relative* forward premium with flexible rates is decreasing in the mean demand, a relationship opposite to the one with fixed rates.

Thus, the simulations support the validity of the original Hypotheses for studies with flexible rates, but support only the last two Hypotheses for those with fixed rates. The distinction between fixed and flexible rates is thus critical for the first two Hypotheses, predicting the relationship between forward premia and variance and non-standardized skewness. Empirical studies should thus explicate if their data concern fixed or flexible rates and adjust their predictions accordingly.

#### **IV. Conclusion**

Using simulations, I was able to replicate two hypothesis in Bessembinder and Lemmon (2002), regarding the relationship between the forward premium and the demand standard deviation and the mean demand. I was not able to replicate the two hypotheses of Bessembinder and Lemmon (2002) regarding the relationship between the forward premium and price variance and the non-standardized skewness of price. The relationships I found were opposite to the ones predicted. In addition, the simple regression did not capture the relationship reliably. This may explain the mixed support the predictions of Bessembinder and Lemmon (2002) have received in empirical tests. The simulations support extension of the predictions to the case of flexible tariffs for four of the Hypothesis in Bessembinder and Lemmon (2002). Empirical studies should thus explicate if their data concern fixed or flexible rates and adjust their predictions accordingly.

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