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Mutembei, Kellyjoy Makena
Strathmore Institute of Mathematical Sciences
Strathmore University

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MODELLING THE RELATIONSHIP BETWEEN SPOT AND FUTURES PRICES: AN EMPIRICAL ANALYSIS OF THE SOUTH AFRICAN POWER POOL

MUTEMBEI KELLYJOY MAKENA

Submitted in partial fulfillment of the requirements for the Degree of Master of Science in Mathematical Finance at Strathmore University.

Strathmore Institute of Mathematical Sciences
Strathmore University
Nairobi, Kenya

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Declaration

I declare that this work has not been previously submitted and approved for the award of a degree by this or any other University. To the best of my knowledge and belief, the thesis contains no material previously published or written by another person except where due reference is made in the thesis itself.

Mutembei Kellyjoy Makena

Signature: kellyjoy Makena

Date: 24/09/2021

Approval

The thesis of Mutembei Kellyjoy Makena was reviewed and approved by the following:

Mr. Meleah Oleche,
Lecturer, Strathmore Institute of Mathematical Sciences,
Strathmore University

Dr. Godfrey Achono Madigu,
Dean, Strathmore Institute of Mathematical Sciences,
Strathmore University

Dr.Bernard Shibwabo,
Director of Graduate Studies,
Strathmore University

Abstract

This study investigates the relationship between electricity spot and future prices in the South African Power Pool(SAPP). The objectives of the study included investigating whether forward prices in the SAPP are a true and unbiased estimate of the observable spot prices by determining whether or not a forward premium exists in the market. Investigating whether the forward premium (if it exists) can be explained by the behaviour of spot prices in the market in the period preceding delivery and lastly whether current future prices in the SAPP can be used to predict future spot prices in the market. The study used daily electricity spot prices in the SAPP for the period between April 1, 2017 and January 31, 2021 and electricity futures price data for weekly and monthly contracts during the same period.

Relying on methodologies highlighted in the expectation hypothesis to describe the relationship between spot and futures prices, results indicate the existence of positive significant premiums in the market for the sample period. The premiums decrease with increasing maturity with the value of relative forward premiums ranging between 1.23 USD/MWh for peak weekly contracts to 0.46 USD/MWh for peak monthly contracts. Power purchasers in the SAAP are on average incurring a cost that inflates their cost of power by 0.24% to 1.23% depending on the hedging strategy they adopt and type of contracts they select. To explain the risk premia, the study followed methodologies highlighted in the General Equilibrium Model. Ordinary Least Square (OLS) regression results for forward premia modelling suggests that for some of the contracts in the SAPP, forward premiums can be at least partially explained by the mean, variance, standard deviation and skewness of the spot prices in the period preceding delivery. Particularly, the premiums have a negative relationship with average spot prices and a positive relationship with skewness. This implies that the higher the average spot price level, the lower the likelihood of overestimating future prices thus the lower the premium. Additionally, the higher the probability of upward price spikes, the higher the futures price thus the higher the premium.

Lastly, to investigate forecasting ability of electricity futures in the SAPP, the study relied on the fundamentals of futures pricing suggested in the expectation hypothesis. Results reveal that future's prices at the SAPP do not contain significant forecasting power over future spot prices in the SAPP. They reveal that variations in the forward premiums in the market are attributable to time varying risk premiums. The SAPP to a large extent relies on coal and nuclear power for electricity generation thus this could explain the reason why results led to the conclusion of the existence of time varying risk premiums.

Keywords:*Forward Premiums, General Equilibrium Theory, SAPP*

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List of Abbreviations

DAM: Day Ahead Market

CALPX: California Power Exchange

EEX: European Energy Exchange

FPM-M: Forward Physical Monthly Market

FPW-M: Forward Physical Weekly Market

IDM: Intra Day Market

OLS : Ordinary Least Squares

PJM: Pennsylvania, New Jersey, Maryland Power Exchange

SADC: Southern African Development Community

SAPP: South African Power Pool

STEM: Short Term energy Market

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May the Lord bless you all immensely.

Dedication

To my beloved family, friends and teachers.

Chapter 1

Introduction

1.1 Background of the study

Worldwide liberalization of electricity markets has been at the forefront of the structural transformations observed in many electricity markets in different parts of the globe. Liberalization has opened opportunities for power to be traded in a standardized form, in a manner similar to other traditional commodities such as oil, crops and ores. Power exchanges such as the Nordpool, European Energy Exchange (EEX), South African Power Pool (SAPP) and Powernext have revolutionized power trading providing an opportunity for producers and buyers to offer and bid on the supply of a predetermined amount of energy (usually in megawatts) for specified periods.

The settlement model followed in most markets allows for bids and offers to be matched in diverse ways. In extremely developed market places where traders are organized on a continuous bases, bids and offers are slotted within very small time intervals usually an hour or less. In power markets, this paves way for spot power trading. This however is not the only settlement mechanism observed in these markets. Generators may in fact commit to provide power to their customers way ahead of when its needed. Concurrently, buyers can forecast their seasonal necessities by observing their patterns of consumption and place bids accordingly. In several existing power exchanges, forward-delivery contracts have thrived, giving rise to futures markets where agents trade electricity for short-to-medium maturities.

In their work, Shawky, Marathe, and Barrett (2003) point out that the introduction of power exchanges has transformed the behavior of electricity market prices. They asserted that electricity prices are influenced largely by the nature of how electricity is produced and consumed. Power Exchanges in their own right are important as they assist in balancing the supply and demand for electricity. In addition, they also provide an opportunity for market participants to hedge their positions against the typically highly volatile electricity prices. In this regard, electricity futures and forward markets are uniquely equipped to provide a platform to practice proper risk management against adverse market movements (Bessembinder & Lemmon, 2002; Botterud, Bhattacharyya, & Ilic, 2002; Lucia & Torró, 2011).

Hedging against volatility is fundamental for electricity market participants. To conduct proper hedging, a keen knowledge of market dynamics is important. Additionally, participants also need a keen understanding of spot price behaviour and the fundamental relationship between spot and forward prices. The foregoing principle according to economic theory is that forward prices relate to expected spot prices according to basic market expectations. Empirically, power prices seem to ignore this assertion. To a large extent its still widely unexplained why spot power prices sometimes trade below future prices while other times they trade well above them. Speculation has allured this fact to the fundamental characteristics of electricity spot prices. In their works, Lucia and Schwartz (2002), Weron and Misiorek (2006) and Bierbrauer, Menn, Rachev, and Trück (2007) observe that electricity spot prices display: mean-reversion, seasonality, extreme volatility and price spikes. In their paper, Lucia and Schwartz (2002) strongly allude that these behaviors are as a result of the non-storable and non-transportable nature of electricity as a commodity. This limitation strongly limits the standard no arbitrage approach in modeling electricity futures prices. According to Bowden and Payne (2008) inventories cannot in this case be introduced to smooth out electricity supply and demand shocks. To fill this gap, Bessembinder and Lemmon (2002) suggested an alternative electricity forwards pricing rule known as the equilibrium model.

It is therefore important to empirically test this model in order to provide insight on the relationship between spot and future prices in power markets and the implications of this relationship.

The Southern African Power Pool (SAPP), is a cooperation of national electricity companies in the Southern Africa region created under the Southern African Development Community in 1995. Historically, the Southern African region was not highly electrically interconnected and therefore minimal electricity trade between nations took place comprising mostly of bilateral contracts nation to nation. The southern region is encased with rich hydro resources in the north (Congo and Zambezi rivers), rich thermal resources in the south (coalfields of Botswana and South Africa and onshore gas fields in Mozambique). Availability of these resources provided a vibrant hub that would benefit the region in its entirety. The first notable interconnections were between Zambia and Zimbabwe at Lake Kariba in the 1960's. The 1970's also recorded the largest link in the region at the time, with the establishment of the Songo-Apollo High Voltage Direct Current link between Mozambique and South Africa. These developments resulted in two separate interconnected power systems in the northern and southern parts of the region. Towards the end of the millennium, the southern region garnered relative political stability. Emergence of stable governance led to economical integration and this paved way for the creation of an integrated electricity trading platform. The creation of the SAPP was a direct consequence of the construction of the 400 kV line between Matimba (South Africa) and Insukamini (Zimbabwe) merging the preexisting northern and southern networks. SAPP created a platform for electricity trading between these two previously disconnected power systems. However, this trading still remained in the form of bilateral contracts updated and renegotiated on a periodic basis

SAPP was established under an Inter-Governmental Memorandum of Understanding that dictated that only national utilities of SADC countries could participate in the power pool. In 2006 however, the global wave of liberalization and restructuring finally caught up with the African pool and efforts have since been ongoing to extend the scope of membership whilst moving towards a competitive and fully decentralized system. Currently, SAPP comprises of 16 members including national power Utilities, independent power producers, independent transmission companies and Service providers.

SAPP's main agenda in the southern region involves an incentive to provide the least cost, environmentally friendly and affordable energy accessibility to rural communities throughout the region. This mandate was aligned to SADC's mandate in eliminating poverty in the southern region. Lack of electrical power limits access to clean water, food availability all core needs in society. According to a case study on SAPP submitted by the Economic Consulting Associates Limited in October 2009, SAPP is still crippled by some challenges and shortcomings despite being the most advanced power pool in Africa. A lack of sufficient funds, infrastructure and sufficiently skilled labor are some of the the key challenges the pool encounters. To combat these challenges, the report points out that the SAPP has over time undertaken strategies aimed at:establishing new power generation investment projects to substitute the pre existing nuclear power, improving the central grid to boost interconnection between the northern and southern region and most important SAPP has also undertaken measures aimed at strengthening and regulating its competitive sub-markets to better meet consumer needs and boost investor satisfaction.

SAPP's sub-markets support both spot and futures trading. The earliest competitive sub market to be set up was the Short Term energy Market (STEM) in 2001, followed by the Day Ahead Market (DAM)in 2009, the Intra Day Market (IDM) in 2015 and most recently the Forward Physical Monthly Market (FPM-M) and Forward Physical Weekly Market (FPW-M) in 2016. They were introduced to encourage competition, and provide a platform for market participants to trade surplus electricity with an aim of creating profit. Currently, the SAPP is a emerging hub for organized electricity trading in Africa. According to a market report for 2019, the SAPP traded over 2,054.2 Gwh of electricity and approximately USD 107 Million was exchanged through competitive trading in the year. Understanding the pricing dynamics in the market is therefore of great importance and it not only benefits the pre existing market participants but also provides a great benchmark to inform future structural changes. An examination of previous literature on the South African power market reveals that there is very little said on the pricing dynamics and the actual performance of the current competitive structures in the market. Most of the studies focus on the structural aspects of the markets, and possible policy changes to create a more economically vibrant power pool. Moeko and Visser (2013) in their paper focused on infrastructure maintenance management frameworks to be adopted by SAPP utilities to achieve a stable interconnected electrical network that is both sustainable and economically vibrant. Rose (2017) in her paper focused on coming up with a new method to design and incorporate security-motivated bilateral contracts into wholesale markets using implicit auctions with security of supply guarantees in supranational regional markets. Other works by Musaba (2008) majorly focused on examining the fundamental challenges of incorporating competitive sub-markets in the SAPP. The foregoing thought from this examination is that, there exist very little literature examining the behavior of spot prices, how they relate to forward prices in the pool and basic pricing dynamics communicated by the data.

This study therefore mostly centered around the pricing dynamics observed in the SAPP. More specifically, this study focused on examining the relationship between forward and spot prices in the South African Power Pool. The study was keen to investigate whether the forward prices in the South African Power Pool are a true and unbiased estimate of the observable spot prices by determining whether or not a forward premium exists in the market. If the forward premium exists, the study additionally aimed to investigate whether it can be explained by the behaviour of spot prices in the market in the period before delivery. Lastly, the study investigated whether current future prices in the SAPP can be used to predict future spot prices in the market and whether this information is economically viable for market participants.

1.2 Statement of the Problem

The foregoing principle according to economic theory is that forward prices relate to expected spot prices according to basic market expectations. Empirically, power prices seem to ignore this assertion. To a large extent its still widely unexplained why spot power prices sometimes trade below future prices while other times they trade well above them. Additionally, questions arise whether this mis pricing alludes to any forecasting power in the market or simply is attributable to the time varying nature of premiums. These questions thus make it fundamental to understand pricing dynamics in power markets.

A review of literature investigating the relationship between spot and forward electricity prices generally reveals existence of significant positive premiums in most electricity markets. (Longstaff & Wang, 2004) find positive risk premiums of up to 14% in their review of the PJM day ahead market.Additionally,(Botterud et al., 2002) in their review of shorter term contracts in the Nordpool report positive premiums ranging from 1.3% to 4.4%. A review of what premiums in power markets communicates generally reveals that futures prices possess forecasting power over future spot prices. The general expectation is that forecasting power reduces with increasing maturity.Consistent with this assertion are works by (Botterud et al., 2002) who in their study of the Nord Pool argue that even though futures prices lacked strong prediction power over the spot prices in the market, the predictive power seemed to increase for weekly contracts compared to yearly contracts. Similarly, (Huisman & Kilic, 2012) in their study of the same market find evidence of predictive power in the market. Their study considered monthly,quarterly and yearly contracts between 2005 and 2010 in the Nordpool. Their findings revealed that for all maturities there seemed to be strong evidence that futures prices seemed to possess forecasting power over future spot prices for all maturities.

An extensive review of literature however reveals some inconsistencies about the actual sign of risk premiums for some markets. An example of this conflict can be observed in the EEX market. An examination of monthly, quarterly and yearly contracts at the EEX by Kolos and Ronn (2008) concludes that a negative forward premium exists in the market during the 2002-2003 trading period. Contrary to this, an examination of monthly base load and peak load futures contracts in the same market by (Redl, Haas, Huber, & Böhm, 2009) concludes that the market displays significant positive premiums instead. A third conflicting conclusion of the same market is illustrated in a study by Bierbrauer et al. (2007). In their investigation of short-term futures contracts, the authors conclude on the existence of positive ex-ante risk premiums. In the same paper, the authors also investigated longer term maturity contracts and concluded the opposite.

Additionally, inconsistencies in literature have arisen as to whether premiums in the market imply predictive power or is simply attributable to the time varying nature of returns. The most notable conflict is outlined by Huisman and Kilic (2012) who in their study of the Dutch power market find evidence of time-varying risk-premiums. In their study of the Nordpool, the same authors conclude that there was no evidence of time-varying risk premiums but instead a strong indication of predictive power in the Nordpool. (Huisman & Kilic, 2012) argue that these differences arise due to the nature of electricity generation in the two markets.They conclude that in markets heavily reliant on storable fossil fuels time varying premiums were most likely to be the explanation for significant premiums in the market as opposed to being an indication of the presence of forecasting power. The foregoing thought from sampling some of these papers is that the issue of how forward prices relate to spot prices in power markets is far from concluded.Past literature on the SAPP however has steered clear of this dilemma instead focusing on the structural dynamics of the pool. These gaps meant that there was room to investigate this relationship further and the SAPP would form an integral addition to existing information.

The study focused on the SAPP since it forms the perfect benchmark for upcoming power pools in Africa.Having been operational for more than two decades, the SAPP has had the longest time to learn, and therefore has more information to infer from, making it a vibrant area for empirical studies. In addition, most African countries are operating in comparatively similar socioeconomic and environmental settings. This places the SAPP in a unique position as the most relatable market for all these upcoming pools as it has similar economic and infrastructural resources and limitations.

Lastly,most studies on the topic in literature focus on well developed power pools that are highly decentralized and largely similar economically, politically and geographically. The SAPP is in its formative stage and is only decentralized to a certain extent. An insight on spot price behavior in the SAPP would offer a different perspective to what is available in literature thus forming an insightful addition investigating the pricing dilemma in a developing power pool. This addition would also hopefully form a basis to benchmark the existing systems in the pool and help steer structural reforms towards better fashioned systems that favor African energy markets the SAPP included.

1.3 Research Objectives

1.3.1 General Objective

To investigate the relationship between spot and forward Electricity Prices in the South African Power Pool.

1.3.2 Specific Objectives

(i) To calculate the Realized Risk premia.

(ii) To test whether the bias in futures prices can be explained by spot price behavior in the market.

(iii) To test the forecasting ability of electricity futures in the market.

1.4 Research Questions

The research questions for the study were highlighted as :

(1.) Does a Non Zero premium exists in the South African Power pool?

(2.) If a non zero futures premium exists, can it be explained by spot price behaviour in the market?

(3.) Does the South African Power pool present opportunities for arbitrage?

1.5 Significance of the study

An examination of previous literature investigating the relationship between spot and forward electricity markets yield differing results. Most studies seem to conclude there being existence of significant premiums (both positive and negative) reported in most markets. As discussed above however, different authors obtain different results for the same markets. These differences paved way for the notion that the investigation is far from exhaustive. If anything the forward price spot price dilemma needed to be investigated further. Past literature on the SAPP however has steered clear of this dilemma instead focusing on the structural dynamics of the pool. There is very little said on the performance and pricing dynamics of the current competitive sub markets in the pool.

This study is significant in that it contributes to existing literature by introducing a significantly different market thus providing a different perspective compared to current literature. Most studies focus on well developed power pools that are highly decentralized, the SAPP is in its formative stage and is only decentralized to a certain extent. In addition, most markets evaluated are largely different economically, politically and geographically compared to the SAPP. This addition hopefully contributes to existing literature and additionally forms a basis to benchmark the existing systems in the SAPP with the aim of steering structural reforms towards better fashioned systems that favor African energy markets.

Lastly, this study offers an opportunity for market participants such as power producers, buyers, speculators and policy makers to understand the pricing dynamics in the SAPP. Using the information from this study, stakeholders are in a position to come up with hedging strategies that economically utilize these dynamics wheres maximizing their profits. Results also provide an opportunity for policy makers to benchmark current structural resources and their effectiveness with the hope of basing future structural reforms on these results.

Chapter 2

Literature Review

2.1 Introduction

In this section, the study first outlines a brief overview of the SAPP detailing its history and organization before proceeding to the theoretical background of the study. Lastly, the section also includes a detailed review of past studies and relevant conclusions on the topic.

2.2 The South African Power Pool

The South African Power Pool has over the last two decades undergone a major structural transformation. In the years preceding 2006, the SAPP was majorly comprised of a vertically integrated business model strictly admitting only national utilities of SADC countries. These government-owned utilities used to operate as monopolies performing all generation, transmission, and distribution functions. In 2006 however, the global wave of liberalization and restructuring finally caught up with the African pool and efforts have since been ongoing to extend the scope of membership whilst moving towards a competitive and fully decentralized system. Along with these structural reforms, the pool also embarked on strengthening competition by restructuring and introducing competitive sub markets that allowed market participants to trade surplus electricity with an aim of creating profit.

As outlined in previous sections, the Southern African pool has historically relied solely on bilateral contracts to trade electricity between the national utilities of the respective member countries. The earliest bilateral contracts can be traced back to the 1950's with the first contract recorded being between Zaire (now known as The Democratic Republic of Congo) and Zambia. Bilateral contracts were put in place to provide a reliable platform to meet long-term energy needs. SAPP'S liberalization has not completely eliminated bilateral trading. Currently, both firm and non- firm bilateral contracts are traded in the SAPP. The bilateral market is governed by ensuring that transmission paths are secured in advance and trading volumes and prices are the key parameters considered for any contract. Following its establishment in the 90's, SAPP's first sub market dubbed the Short Term Energy Market (STEM) was established in 2001 as a collaborative market structure within the SAPP to allow for the trading of electricity on a shorter time frame. In 2004 however, the SAPP reformed its architecture by proposing a move from a collaborative sub market to a competitive market where buyers and sellers would compete in the trading of electricity. This resulted in the establishment of the SAPP Day Ahead Market (DAM) in 2009.

The SAPP DAM is a competitive sub market where electricity is traded on a day-ahead basis to meet short term supply and demand balances between market participants. The DAM typically deals with hourly energy contracts for each of the 24 hours of the following day, or a future day. The DAM was established to complement the already existing bilateral contracts. The DAM however had its shortcomings necessitating the creation of a complementary sub market that would accommodate more dynamic demand and supply patterns. This need led to the establishment of the Post-DAM market in 2013 to settle any outstanding imbalances that were still present following DAM trading. In 2015 however, the post DAM market was discontinued and instead replaced with the Intra day Market (IDM). The IDM allows market participants to continuously trade electricity up to one hour prior to delivery. In this market contracts generally consist of hourly energy contracts for one or more hours for periods as specified by the SAPP market operator. Participants are matched on a first-come first-serve basis if a seller's offer price is less than a buyer's bid price and a seller's volume is lower (or equal to) a buyer's volume. The DAM is organized such that bidding closes at 12.00 midnight each day for the next day prices wheres the IDM does not close and trading is continuous.

Futures trading on the SAPP is currently conducted on a weekly and a monthly basis. There are two separate sub-markets in the SAPP dealing with futures trading namely the Forward Physical Market Weekly (FPM-W) and the Forward Physical Market Monthly (FPM-M). The FPM-M was established in April of 2016. It was created to allow market participants to trade either an Off-Peak product for a single month at the same volume and price in Off-Peak hours for the month or a Non-Off-Peak product for a single month at the same specification. On the other hand, the FPM-W was created to allow market participants to trade Off-Peak, Standard and Peak products for a particular week with the same volume and price for all Off-Peak, Standard and Peak hours of the week respectively. It was created to bridge the gap bridge between the FPM-M and DAM. The FPM-M is organized such that bidding closes on the last Wednesday of each month giving market participants at least 5 days before delivery month starts. The FPM-W on the other hand closes off every Thursday in the week prior to the delivery week.

The most instrumental division of the South African power pool is the SAPP Co-ordination Center established in 2002 and based in Harare, Zimbabwe. The Co-ordination Center acts as a regional wholesale electricity market in the SADC region, monitors SAPP transactions between members, carries out technical studies to assess the impact of future projects on the SAPP and coordinates training of members. Despite being the only functional African Power pool, SAPP does not have one market operator. The SAPP is divided into three control areas, each with its own control area system operator. ESKOM serves as the operator for Botswana, Lesotho, southern Mozambique, Namibia, South Africa, and Swaziland. Zimbabwe Electricity Supply Authority (ZESA) is the operator for Zimbabwe and northern Mozambique and Zambia Electricity Supply Corporation (ZESCO) is the operator for Zambia and the DRC. These system operators all operate according to the guidelines specified by the Regional Electricity Regulators Association.

The system operators are in charge of regulating prices in the competitive markets with the exception of the bilateral contracts. These are mostly traded over-the counter with private agreements between parties. These prices are not revealed to other market participants. According to works by (Lucia and Schwartz, 2002) intra day variation in electricity prices to a large extent are influenced by demand patterns in the market. This assertion therefore makes it very important to clearly distinguish between peak and standard delivery periods when studying any market. In the SAPP, the peak period varies region to region and season to season. In the Southern Region specifically controlled by ESKOM the peak period during weekdays is between 7.00 am -10.00 am and 6.00 pm - 8.00 pm. For the northern region controlled by ZESA, the peak period during weekdays is between 7.00 am -11.00 am and 5.00 pm - 8.00 pm wheres during weekends the periods are shorter by one hour. For this reason, prices vary depending on whether delivery is done during the off-peak or the non-off-peak duration.

2.3 Theoretical Background

2.3.1 The Cost of Carry and Expectation Hypothesis Theories

In literature, there are currently two theories highlighted in (Botterud et al., 2002) and (Redl et al., 2009) explaining how spot prices relate to futures prices in commodity markets. The first theory is hedged on explaining how differences between spot and futures prices of a commodity can be explained by the cost and convenience of holding inventories. This theory is popularly referred to as the ‘cost of carry’ approach and was first elaborated by (Kaldor, 1976). In his paper, he argues that the forward price of a commodity can be determined as a function of the current spot price, the interest rate and cost of storage. A convenience yield as defined in (Fama & French, 2016) generally represents the productive benefit one derives by holding inventories to meet unexpected demand. Holding the physical commodity is considerably favorable as its shields the holder against losses as a result of demand shifts, production shortages and delivery failures compared to futures contracts that hedge against price fluctuations only (Rose, 2017). Electricity as a commodity does not follow the conveniences of basic commodities as it’s produced and consumed instantaneously and continuously. This very integral attribute disqualifies the standard cost of carry approach when evaluating electricity spot and forward prices.

The second and more applicable theory in electricity markets is referred to the Expectation Hypothesis. Suggested in (Keynes, 1930), its based on considering an equilibrium in expectations and risk aversion by market participants with varying needs in the market. This theory defines the forward price as the expected spot price plus an the expected risk premium of the market also known as the ex-ante risk premium. This definition implies that current forward prices would contain power to forecast spot prices. The ex-ante risk premium can be interpreted as compensation for bearing the spot price risk (Bessembinder & Lemmon, 2002; Longstaff & Wang, 2004).According to (Huisman & Kilic, 2012), the expectations hypothesis operates under the assumption of an efficient arbitrage-free market where information is incorporated in the futures prices in a timely manner. A major setback of this methodology is that the ex ante premium is an expectation of the future making it un-observable in the present. To bridge this gap, empirical analysis often considers the realized or ex post forward premium instead defined as:

$$\text{Realized Premium}_{\text{t,T}} = \text{F}_{\text{t,T}} - \text{S}_{\text{T}} \tag{1}$$

where:

$\text{F}_{\text{t,T}}$ denotes the Forward Price quoted at time t, for delivery at time T.

S_{T} denotes the realized/average spot price at time T.

Alternatively, the forward premium can be normalized by dividing it by S_{T} to obtain the Relative Realized Forward Premium given as:

$$\text{Relative Realized Premium}_{\text{t,T}} = \frac{\text{F}_{\text{t,T}} - \text{S}_{\text{T}}}{\text{S}_{\text{T}}} \tag{2}$$

To support this provision, Redl et al. (2009), in their paper suggest that the realized forward premium is simply the ex ante premium plus a random error attributable to electricity spot price volatility between t and T. They concluded that under the assumption that the error follows a normal distribution, the realized premium is arguably a consistent estimator of the ex ante premium.

The most notable shortcomings of the expectations theory are explored by (Fama & French, 2016). Their reservations on the theory are hinged around whether futures prices contain expected premiums or have power to forecast spot prices. To support their assertions, their paper revealed that out of a total of 21 commodity futures prices studied only 10 contained conclusive evidence of containing forecasting power. This led them to conclude that the theory of storage was than the expectations hypothesis in explaining the differences between futures prices and spot prices. These assertions shall be explored further below.

2.3.2 The General Equilibrium Model

General equilibrium theory is centered about how supply and demand in an economy with many markets interact dynamically and eventually culminate in an equilibrium of prices. Electricity departs from typical commodities due to its unstorable nature. As argued by, (Bessembinder & Lemmon, 2002; Botterud et al., 2002; Huisman & Kilic, 2012) electricity can be stored in relatively small quantities by filling up hydro power reservoirs or charging batteries when electricity prices are low. Storing large quantities of electricity is however not economically viable. As a consequence of this, electricity prices are extremely volatile and in this case inventories cannot be used to smooth supply or demand shocks in the market (Bessembinder & Lemmon, 2002). This characteristic therefore disqualifies the standard no-arbitrage approach to pricing electricity future contracts.

In their paper, Bessembinder and Lemmon (2002) propose an alternative pricing rule to bridge this gap referred to as the equilibrium approach. In their study of the California Power Exchange (CALPX) and Pennsylvania, New Jersey, Maryland (PJM) markets, they suggested that the one-month forward premium was dependent on the mean, variance and standard deviation of electricity demand. From their theoretical model, they defined the forward premium as:

$$\text{Realized premium}_{\mathrm{i,T}} = \alpha_0 + \alpha_1 \mathrm{MEAN}_{\mathrm{i,T}} + \alpha_2 \mathrm{STD}_{\mathrm{i,T}} + \alpha_3 \mathrm{VAR}_{\mathrm{i,T}} + \mathrm{n}_{\mathrm{i,T}} \qquad (3)$$

where:

> Realized $\text{premium}_{\mathrm{i,T}}$ denotes the Forward Premium that equals the one-month-forward price for delivery in month T minus the cost-based estimate of the

expected spot price in month T for market i.

$\text{MEAN}_{i,T}$ is the average normalized load for month T in market i.

$\text{STD}_{i,T}$ is the standard deviation of the daily load during month T in market i.

$\text{VAR}_{i,T}$ is the square of $\text{STD}_{i,T}$ and,

$n_{i,T}$ is the associated standard error.

Based on their model, the authors suggested that the general expectation was of a convex forward premium increasing with mean demand, initially decreasing and then increasing in demand risk. This assertion therefore creates the expectation that the standard deviation would have a negative coefficient and the variance a positive one(Handika, Trück, et al., 2012). The general conclusion of the study was on the existence of a forward premium. A further investigation of the individual components of the premium, revealed that demand level had a positive impact on the premium consistent with their assertions. The standard deviation and variance of the demand were however found to be insignificant for the selected period. Countless other works have borrowed from the model, modifying the parameters influencing the level of the forward premium. In their paper, (Redl et al., 2009) adopted a similar approach to examine the ex-post premium in the Nordpool electricity market and the EEX. Their work had slight modifications and incorporated the volatility and skewness of spot prices in the month preceding delivery. Their work also included the consumption and general index. They concluded that in both markets there existed significant premiums. Peljo et al. (2013) in their study of the Nordic electricity market adopted the same methodology with slight modifications. The study suggested that electricity price behaviour and the forward's premium were influenced by coal prices, water reservoir levels and electricity demand levels in the market. The main conclusion of the study was that for the period between 2000-2011, there existed positive forward premiums in the Nordpool. Additionally, the study concluded that coal prices and overall electricity demand had a positive relationship with electricity prices wheres fluctuations in water reservoir levels had an negative relationship with electricity prices in the selected period. Lastly a study of the Australian regional electricity markets by Handika et al. (2012) between 2001 and 2010 considered the influence of spot price characteristics such as the mean, standard deviation among others on the forwards premium. Their study concluded that for the selected period a positive and significant risk premium could be observed for several of the considered regions. Additionally, they concluded that the significant variables partially explaining this premium were the mean, standard deviation, skewness and kurtosis of spot prices in the month preceding delivery.

2.3.3 The Forecasting ability of electricity futures

To analyze the forecasting ability of electricity futures in the SAPP the study relied on the fundamentals of futures pricing suggested in the expectation hypothesis. The underlying idea being that current futures prices are comprised of the expected future spot price at time T and a risk premium such that:

$$\mathrm{F_{t,T} = E_t(S_T) + P_{t,T}} \tag{4}$$

where:

$\mathrm{F_{t,T}}$ is the futures price for delivery at time T

$\mathrm{E_t(S_T)}$ is the expected future spot price $\mathrm{S_T}$ at t and,

$\mathrm{P_{t,T}}$ is the Market Risk Premium

Based on works by Fama and French (1988) and Huisman and Kilic (2012), subtracting the current spot price from both sides of the Equation (4) yields:

$$\mathrm{F_{t,T} - S_t = E_t(S_T) - S_t + P_{t,T}}$$

where:

$\mathrm{F_{t,T} - S_t}$ The current futures premium consists of the expected change in the spot price between t and T ($E_t(S_T) - S_t$) and the expected risk premium ($P_{t,T}$).

Based off this postulation the Market Risk Premium is presented as $P_{t,T} = F_{t,T} - E_t(S_T)$. Following (Fama & French, 1988; Huisman & Kilic, 2012) and working under the assumption of rational market expectation, spot price changes and the futures premium may be estimated using the following regression equations:

$$S_T - S_t = \beta_1 + \beta_2(F_{t,T} - S_t) + u1_{t,T} \tag{5}$$

and

$$F_{t,T} - S_T = \mu_1 + \mu_2(F_{t,T} - S_t) + u2_{t,T} \tag{6}$$

Fama and French (1988) in their paper assert that when β_2 is positive, the current futures premium ($F_{t,T} - S_t$) identified at t has the ability to predict the spot price change from t to T given as ($S_T - S_t$) and consequently the futures price $F_{t,T}$ has forecasting power over the future spot price S_T. Additionally, a positive μ_2 implies that the realized futures premium $F_{t,T} - S_T$ can be used to infer the expected Market Risk Premium expressed as $P_{t,T} = F_{t,T} - E_t(S_T)$. Both assertions hold under the assumptions defined in the expectations hypothesis.

In their work, Fama and French (1988) postulate that both equations (5) and (6) are subject to an adding-up constraint. Their assertions were hedged on the fact that fundamentally, the realized premium $F_{t,T} - S_T$ and the change in spot price $S_T - S_t$ from t to T sum up to the current futures premium $F_{t,T} - S_t$ therefore the sum of the slope coefficients in equations (5) and (6) must not be statistically different from one. They concluded by asserting that these regressions allocate all the variation in the current futures premium either to the expected market risk premium, the expected change in the spot price or a combination of both. These equations were instrumental in examining, whether the variation in the current futures premium is attributable to forecasting power, to the time varying nature of risk premiums, or both.

2.4 Previous Literature on select Electricity Markets

A review of literature reveals that empirical studies have generally found significant positive premiums in electricity forward markets. In their review of the PJM day ahead market, (Longstaff & Wang, 2004) find positive risk premiums of up to up to 14%. Additionally, (Redl et al., 2009) have similar conclusions in their review of the Nordpool and EEX markets. Their study revealed premiums ranging from 8% for considered base load forward contracts in the Nordpool market wheres the base load and peak load contracts in the EEX ranged between 9% and 13% respectively. Thirdly, (Botterud et al., 2002) in their review of shorter term contracts in the Nordpool report premiums ranging from 1.3% to 4.4%.

Extensive studies have also been carried out to investigate the significance of forward premiums in various electricity markets. Most studies seem to conclude there being existence of significant premiums (both positive and negative) reported in most markets. The most notable works centered around this include, (Weron & Misiorek, 2008) investigating the Nordpool, (Daskalakis & Markellos, 2009) for the EEX, Nordpool and Powernext Market, (Diko, Lawford, & Limpens, 2006) for APX, (Hadsell, Marathe, & Shawky, 2004) for the NYISO among others. Inconsistencies however have arisen as to the actual sign of the risk premium even for the same markets. An example of these inconsistencies was predominant in the following studies on the EEX. An examination of monthly, quarterly and yearly contracts at the EEX by Kolos and Ronn (2008) concludes that a negative forward premium exists in the market during the 2002-2003 trading period. Contrary to this, an examination of monthly base load and peak load futures contracts in the same market by Redl et al. (2009) concludes that the market displays significant positive premiums instead. A third conflicting conclusion of the same market is illustrated in a study by Bierbrauer et al. (2007). In their investigation of short-term futures contracts, the authors conclude on the existence of positive ex-ante risk premiums. In the same paper, the authors also investigated longer term maturity contracts and concluded the opposite. A brief overview of these results can lead one to conclude that that most authors observed positive risk premiums, a key point that this paper was keen to investigate in the SAPP.

The significance of key regressors in the risk premia model also constitute a rather significant area when dealing with the general equilibrium model. Most authors in literature seem to focus on variance, standard deviation and skewness with most inconsistencies arising on the significance of the variance and skewness. An example in the PJM market, Bessembinder and Lemmon (2002) find a negative coefficient for the variance and a positive coefficient for the standard deviation of the daily load in the market. The downturn of this result however is that, their findings are not statistically significant. Similarly, Douglas and Popova (2008) in their study of the same market observe a negative coefficient for the variance and a positive coefficient for the skewness their findings are however statistically significant. Another case of inconsistencies has also been observed in studies on the Nordpool. Torró, Lucia, et al. (2008) in their study of the market observe different results for different time periods. In their review of the period between 2003 and 2007 they observe a positive insignificant coefficient for the variance and a negative coefficient for the skewness of spot prices. A further review of an earlier period spanning the year 1998 to 2002 in the same market reveals a negative significant coefficient for the variance and a positive one for the skewness. In both periods skewness is statistically significant. Similarly, (Botterud et al., 2002) observe negative coefficients for both variance and skewness of the spot price in the market further revealing that the only significant variable was variance in the study period.

Other studies with similar inconsistencies include:Furió and Meneu (2010) in their study of the Spanish market who uncover negative coefficients for both variance and skewness. Similar to (Botterud et al., 2002), they conclude that only variance is statistically significant. Redl et al. (2009) in their study of the EEX observe a positive significant coefficient for the variance in the peak delivery period and a positive significant coefficient of the skewness in the base period. In their study of the Nordpool, they however observe a positive coefficient for the variance and a negative coefficient for the skewness parameter.

Lastly, the assertion that futures prices possess forecasting power over the future spot price seems to be yield different conclusions from different authors. In their study of the Nord Pool between September 1995 and December 2001, (Botterud et al., 2002) argue that futures prices lack a strong prediction power over spot prices with prediction ability increasing for weekly contracts compared to yearly contracts. Their assertions are somewhat consistent with the general expectation that the longer the forecasting horizon the lower the forecasting accuracy. Similarly, (Gjolberg & Brattested, 2011) in their study of the same market observe forecast errors ranging between 7.4% to 9.3%. They however attribute these results to market inefficiencies citing that the figures were too large to represent actual market movements. Contradictory to these works, (Huisman & Kilic, 2012) find evidence of the forecasting ability of futures prices in their investigation of the Nord pool. They conclude that predictability in a market depends on how electricity is predominantly produced and the level of storability observable in the market. They observed that electricity futures price for perfectly storable fuels displayed higher predictive power usually communicating about future price movements and the time varying nature of risk premiums (Huisman & Kilic, 2012).

The foregoing thought is that overall previous findings about existence of risk premiums in power markets are quite consistent. However inconsistencies as to the sign of risk premiums, the level of predictability in the market, and the time varying nature of futures premiums appear across various markets. Thus, previous literature leaves room for further studies on this topic.

Chapter 3

Methodology

3.1 Introduction

This chapter outlines the methodology that was used for this study.

3.2 Research Design

The study is a quantitative research as statistical inferences were made to draw conclusions on the topic. It adopted a descriptive design aimed at establishing the relationship between forward prices and spot prices in the South African Power Pool. Secondary data on spot prices and forward prices recorded on the SAPP official trading website were used in the study and the General Equilibrium model was employed in the study. The study heavily relied on R statistical software to conduct the investigation. Deductive reasoning was employed to inform conclusions based on the results of the study.

3.3 Data

The study used electricity spot and futures prices for the entire SAPP region recorded on the official SAPP Trading Website. The empirical analysis considered daily electricity spot prices for the period between April 1, 2017 to January 31, 2021 recorded from the DAM Market. In the SAPP market, futures trading is done on a monthly and weekly basis. The study evaluated weekly and monthly off peak, standard load and peak load futures obtained from the FPW-M and FPM-M for the same period as the spot prices. This period represents the four years that the competitive sub markets have both been operational in the SAPP. This period therefore captures the pioneering information on pricing dynamics in the SAPP to form a basis for more informed future structural reforms targeting the competitive sub markets. The SAPP records both spot and futures prices for the various sub markets in American Dollars (USD/MWh) or South African Rand(ZAR/MWh) per Megawatt hour. The study used the former taking into account foreign exchange risk that could have skewed the results considering inflation.

To evaluate several components of the SAPP market,the analysis involved obtaining the descriptive statistics of daily electricity spot prices for the proposed study period. Some of the attributes considered included average daily spot prices. This was crucial in informing market behavior specifically volatility and how it varies throughout the selected period. An analysis of average quarterly spot prices was also conducted to inform on the seasonality patterns observable in the market. This was important to provide inference as to how spot prices relate to forward prices in the specific seasons.

3.4 Modelling Framework

3.4.1 Obtaining the Risk Premiums

This step of the analysis involved obtaining the ex-post/realized risk premiums in the market if they exist. The premiums were calculated as the difference between the quote for the futures contract with delivery in time period T on the last trading day before the beginning of the delivery period and the realized average spot price during the delivery period. The study examined both monthly contracts and weekly contracts to examine the potential differences between longer term and shorter term contracts. In addition, the study distinguished between off-peak, standard and peak load contracts in the different markets to observe the potential differences.

This examination was to determine whether a nonzero futures premium exists in the SAPP. Additionally, the study would make inferences as to the sign, seasonality, and development of the premium over the sample period. In their study of the Nordic Market between 1995 and 2001, (Botterud et al., 2002) postulate that the risk premia results from the levels of risk aversion among producers and consumer. An example, positive premiums in the market would inform that that consumers in the market are risk averse and are willing to pay an additional premium in the electricity forward market to protects their holdings against adverse price movements.

Apart from investigating the existence and nature of the forward premium, the relative magnitude and economical significance of the premium was investigated. To test its relation to electricity spot prices the study computed associated Relative Forward Premiums as described in Equation (2) above. To examine whether or not the premiums are economically significant, statistical tests such as the Student t-test were conducted.

3.4.2 Explaining the Risk Premia

As highlighted in the literature review above, existing literature on empirical forward premia modeling typically focuses on risk aversion measured by higher central moments of the spot price distribution, demand levels or shocks in infra marginal generation typically hydro power. Adopting the methodologies highlighted in works by (Bessembinder & Lemmon, 2002; Botterud et al., 2002; Redl et al., 2009; Torró et al., 2008). The study sought to investigate whether the bias in the futures price/forward premium could be explained by the behaviour of spot prices during the month or week prior to delivery of the futures contracts. To achieve this, the study carried out an Ordinary Least squares (OLS) regression analysis where the premium measures obtained from Equation (1) were regressed against the mean, standard deviation, variance, skewness and kurtosis of electricity spot prices prior to the delivery period of the futures contract in the regression estimation:

$$\mathrm{Realized\ Premium}_{t,T} = \alpha_0 + \alpha_1\ \mathrm{MEAN}(S_t) + \alpha_2\ \mathrm{STD}(S_{t,}) +$$

$$\alpha_3\ \mathrm{VAR}(S_t) + \alpha_4\ \mathrm{SKEW}(S_t) + \alpha_5\ \mathrm{KURT}(S_t) + n_t \qquad (7)$$

where:

$\mathrm{RealizedPremium}_{t,T}$ is the difference between the quote for the futures contract with delivery in time period T on the last trading day before the beginning of the delivery period and the realized average spot price during the delivery period.

MEAN_t is the average of daily spot prices in period t/ the period before delivery.

STD_t is the standard deviation of the spot daily prices in period t/ the period before delivery.

VAR_t is the square of STD_t

$SKEW_t$ is the realized skewness of the daily spot prices in period t/ the period before delivery.

$KURT_t$ is the realized Kurtosis of the daily spot prices in period t/ the period before delivery and,

n_t is the standard error.

An area of focus was on the resulting coefficients of the different regressors, which provided more insight on the market participants behaviour and their influence on spot prices. A key are of interest was to observe whether the results are consistent with assertions on convexity of the forward premium as suggested by (Bessembinder & Lemmon, 2002). This concept typically indicates robust risk averse behaviour in the market and the study was keen to investigate whether the SAPP behaves in this regard. Higher moments specifically, the kurtosis of spot prices were introduced to capture the effect of rare extreme deviations from the mean on the forward premium. Generally, a positive influence of the kurtosis of spot prices on the premium is expected therefore this was investigated in this setting.

To investigate the the explanatory power of the model significance tests for the regression coefficients were conducted for all the considered contracts. Measures such as the Student t test statistic, R^2 and Adjusted R were used to determine whether or not each independent variable contributes to the forward premium or not. Additionally, the study applied a step-wise regression to the data to determine the best model fit.

3.4.3 Testing the forecasting ability of electricity futures in the market.

To analyze the forecasting ability of electricity futures in the SAPP the study hedged on ideas suggested by (Fama & French, 1988) and (Huisman & Kilic, 2012) and considered equation (5)such that:

$$S_T - S_t = \beta_1 + \beta_2(F_{t,T} - S_t) + u1_{t,T}$$

where:

$S_T - S_t$ is the difference between the realized average spot price during the delivery period T and the spot price quote on the last trading day before the beginning of the delivery period.

$F_{t,T} - S_t$ is the difference between the quote for the futures contract with delivery in time period T on the last trading day before the beginning of the delivery period and spot price quote on the last trading day before the beginning of the delivery period.

u1 is the standard error.

(Fama & French, 1988) in their paper assert that when β2is positive and significantly different from zero, the current premium $F_{t,T} - S_t$ identified at t has the ability to predict the spot price change from t to T given as $S_T - S_t$ and consequently the futures price $F_{t,T}$ has forecasting power over the future spot price S_T.

To conduct this analysis, the study considered daily spot prices in the DAM between April 1, 2017 and January 31, 2021 and the futures price for both Weekly and Monthly contracts on the SAPP market. The analysis regressed the spot price changes against current forward premiums in the market using the OLS regression technique. Key areas of interest were on the sign and statistical significance of the regression coefficients in the model, providing insight as to whether current future prices at the SAPP can be used to predict future spot prices in the market.

As an extension to the above section, the study also examined whether the variation in the current premium $F_{t,T} - S_t$ is attributable to forecasting power, to time varying risk premiums or a combination of both. To evaluate this the study additionally considered equation (6)defined as :

$$F_{t,T} - S_T = \mu_1 + \mu_2(F_{t,T} - S_t) + u2_{t,T}$$

where:

> $F_{t,T} - S_T$ s the difference between the quote for the futures contract with delivery in time period T on the last trading day before the beginning of the delivery period and the realized average spot price during the delivery period.
>
> $F_{t,T} - S_t$ is the difference between the quote for the futures contract with delivery in time period T on the last trading day before the beginning of the delivery period and spot price quote on the last trading day before the beginning of the delivery period.
>
> u2 is the standard error.

Following the methodologies highlighted by (Fama & French, 1988) and (Huisman & Kilic, 2012), the assertion is that both equation (5) and (6) are subject to an adding up constraint. To assert the existence of time varying premiums, the slope coefficients β_2 and μ_2 must be significantly different from zero and add up to one.

To conduct this analysis, the study considered daily spot prices in the DAM between April 1, 2017 and January 31, 2021 and the futures price for both weekly and monthly contracts on the SAPP market. The analysis regressed the realized premiums against the current premiums in the market. Key areas of interest were on the sign, statistical significance of the regression coefficients in the model and their resulting summations. Resulting summations of β_2 and μ_2 values significantly different from one confirm the lack of time-varying risk premiums in the South African Power market.

Chapter 4

Data Analysis and Results

4.1 Data Description

The sample data set for this research includes electricity spot and futures prices from the DAM, FPW-M and FPM-M markets in the South African Power Pool. These markets were selected since future trading in the SAPP is only conducted on a weekly and monthly contract basis. The empirical analysis considered daily electricity spot prices, weekly futures prices and monthly futures prices for the period between April 1, 2017 and January 31, 2021 as provided by the official SAPP website. [1].

The analysis considered peak, standard and off peak weekly forward contracts. In the monthly market, both peak and off peak contracts were considered. Both Spot and futures prices are quoted in US dollars per Megawatt hour (US$/MWh).

Table 1 below shows the descriptive statistics of the daily electricity spot prices in the market for the sample period. Table 1 also includes statistics for the different quarters within the sample period to examine seasonality. Additionally, Figure 1 provides a time series plot of daily and quarterly electricity prices during the considered period.

Table 1: Descriptive Statistics of Daily and Quarterly Electricity Spot Prices

	Mean	Variance	Sd	Maximum	Minimum
All Periods	59.19	568.58	23.84	131.24	12.65
Quarter 1	58.54	420.77	20.51259	128.66	18.36
Quarter 2	51.27	449.86	21.21	118.70	12.65
Quarter 3	62.24	598.26	24.46	118.07	19.44
Quarter 4	64.53	681.69	26.11	131.24	24.46

Table 1 describes the spot prices in the Market for the Period 1st April 2017 to 31st January 2021.

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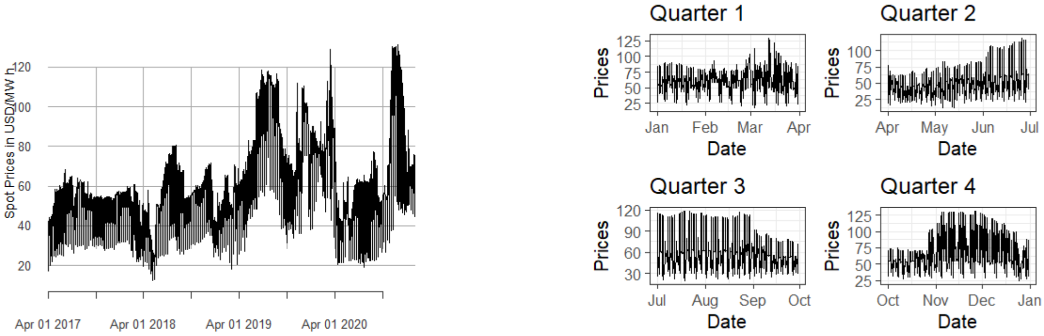
[1] `http://www.sappmarket.com/`

Figure 1: Daily and Quarterly Spot Prices



(a) Daily Electricity Spot Prices **(b) Quarterly Electricity Spot Prices**

Figure 1 shows Daily and Quarterly Electricity Spot Prices for the Period 1st April 2017 to 31st January 2021

The results indicate that for the considered period, the average daily electricity spot price is 59.19 USD/MWh and the standard deviation is 23.84. There is a considerable gap between the observed prices with a maximum of 131.24 USD/MWh and a minimum price of 12.65 USD/MWh. As is typical of electricity markets figure 1 confirms high price volatility with the plot indicating large price swings throughout the study period. A further examination of the quarterly plots in figure 1 also reveals a similar pattern of spot price movements across the years considered with prices experiencing an upward spike in the fourth quarter in each year. In a similar manner,a downward dip is observable in the second quarter across the considered period.

To examine seasonality in the market the analysis included calculating average spot prices for the different quarters in the sample period. Seasonality is evident with the highest average prices of 62.24 USD/Mwh and 64.53 USD/MWh being observed in quarter 3 and 4 which typically cover the winter and spring seasons in the region. Quarter 1's average price is also considerably higher as is typical of summer months. With the high temperatures power plants require more water for cooling driving up operating costs that translate to increased spot prices. The lowest averages of 51.27 USD/MWh are observed in the autumn. This outcome is consistent with assertions by Bessembinder and Lemmon (2002) about electricity prices displaying strong seasonality.

4.2 Realized Risk Premiums

4.2.1 Overview of Premiums

This section sought to answer the first research question as highlighted in subsection 1.4, whether a non zero premium exists in the SAPP. The premiums were calculated as the difference between the quote for the futures contract with delivery in time period T on the last trading day before the beginning of the delivery period and the realized average spot price during the delivery period i.e $\mathrm{F}_{\mathrm{t,T}} - \mathrm{S}_{\mathrm{T}}$. Additionally, to test the economic significance of the forward premiums with relation to price level, this section also included computing the Relative Forward Premiums calculated as: $\frac{\mathrm{F}_{\mathrm{t,T}} - \mathrm{S}_{\mathrm{T}}}{\mathrm{S}_{\mathrm{T}}}$.

Thirdly, the analysis also included an examination of the sign and statistical significance of the premiums. As suggested in literature by (Botterud et al., 2002; Gjolberg & Brattested, 2011), the general expectation electricity prices tend to follow a contago-relationship thus risk premiums are on average positive in most markets. This assertion generally suggests that electricity purchasers face greater pressure to hedge their purchases against price volatility than the electricity producers (Peljo et al., 2013).

The analysis was conducted on the weekly and monthly forward market for peak, off peak and standard contracts during the sample period. Table 2 and Table 3 below display the descriptive statistics for the absolute and relative forward premiums respectively.

Table 2: Descriptive statistics for the Absolute Forward Premiums

	Obsvs	Mean	T Stat	Sd	Max	Min	Pos Values (%)
Peak Weekly	193	70.54	24.36**	40.22	162.70	-66.75	99.48%
Standard Weekly	193	11.22	9.02**	17.27	126.30	-66.75	80.83 %
0ff Peak Weekly	193	-27.22	–28.55**	13.25	6.57	-69.71	2.07 %
Peak Monthly	36	24.15	4.70**	30.84	110.86	-90.05	94.44 %
Off Peak Monthly	36	-23.25	–28.55**	14.35	4.99	-65.66	8.33%

Table 2 shows the descriptive statistics for the Absolute Forward Premiums in USD/MWh during the sample period, calculated as $\mathrm{F}_{\mathrm{t,T}} - \mathrm{S}_{\mathrm{T}}$. The t-statistic represents the one-sample t-statistic for the mean, the asterisks ***, **, and * denoting confidence at 99%, 95%, and 90% confidence levels, respectively.

The results for both the weekly and monthly market are consistent. They indicate existence of positive premiums for peak and standard contracts in both markets wheres off peak contracts are seen to have negative premiums in both markets. These results are consistent with literature, where several authors argue that peak electricity contracts are generally priced higher compared to off peak contracts. In their article, Dutta and Mitra (2017) argue that this mis pricing arises since electricity generation costs tend to be higher during peak demand periods thus translating to higher prices. The size the premiums generally seems to be larger for weekly contracts than for monthly contracts. The highest premiums is attributed to peak weekly contracts where future quotes exceed realized spot price during delivery by USD/MWh 70.54. The lowest premium in the market is attributed to off peak weekly contracts at USD/MWh -27.22. The standard deviations and the spreads between minimum and maximum basis values are very high, indicating a highly volatile electricity market. To investigate the proportion of positive premiums in the market, results indicate proportions of 99.48% for peak weekly contracts to 2.07% for off peak weekly contracts. This shows strong clustering of observations on either side. The differences in proportions for the various contracts prompted a further examination of the premiums as a whole. The resulting values was that 60.79% of the weekly premiums were positive wheres 51.39% of the monthly premiums were positive. This led to the conclusion that, the SAPP generally has positive ex-post premiums.

These proportions communicate the proportions of absolute premiums but fails to infer as to the size of the premiums on average. This necessitates an examination of the relative forward premiums to confirm the existence of positive premiums in the SAPP. The relative premiums are a relative measure not affected by changes in overall electricity price levels, ensuring they are more comparable and dependable over time as opposed to absolute premiums.

Table 3: Descriptive statistics for the Relative Forward Premiums

	Obsvs	Mean	T Stat	Sd	Max	Min	Pos Values (%)
Rel Peak Weekly	193	1.23	23.26**	0.73	3.75	-1.00	99.48%
Rel Standard Weekly	193	0.24		8.74**	0.37	3.05	80.83%
Rel 0ff Peak Weekly	193	-0.44	–45.86**	0.13	0.30	-0.68	2.07 %
Rel Peak Monthly	36	0.46	5.46**	30.51	1.51	-1.00	94.44%
Rel Off Peak Monthly	36	-0.37	–12.49**	0.18	0.12	-0.69	8.33%

Table 3 shows the descriptive statistics for the Relative Forward Premiums in USD/MWh during the sample period, calculated as $\frac{F_{t,T}-S_T}{S_T}$.The t-statistic represents the one-sample t-statistic for the mean, the asterisks ***, **, and * denoting confidence at 99%,95%, and 90% confidence levels, respectively

Similar to the absolute premiums, the highest average relative premiums are recorded as USD/Mwh 1.23 for peak weekly contracts wheres the lowest premiums of USD/MWh -0.44 are recorded for Off peak weekly contracts. The relative premiums are however significantly smaller and closer to zero compared to the absolute premiums. The standard deviations are also smaller with the smallest value being 0.73 for the peak weekly contracts and increasing with maturity to 30.51 for peak monthly contracts. The proportions of positive values follow the same patterns as the absolute premiums displaying strong clustering on the positive and negative sides for peak and off peak contracts respectively. An evaluation of the total sample however reveals that 60.79% of the weekly relative premiums are positive wheres 51.39% of the monthly relative premiums are positive. These values confirm the assertion that forward premiums in the SAPP seem to be more weighted towards being positive, confirming the existence of a contago relationship between spot and future prices in the market.

The statistical significance of the premiums was tested and the student t static values are displayed in table 2 and 3 above. Working under the null hypothesis that the premiums in the market were statistically not different from zero, the results lead us to reject the null and conclude that for all maturities the premiums in the SAPP were statistically different from zero at 95% confidence level. This led to the conclusion that there exists significant non-zero premiums in the SAPP.

Figure 2: Weekly Realized Risk Premiums

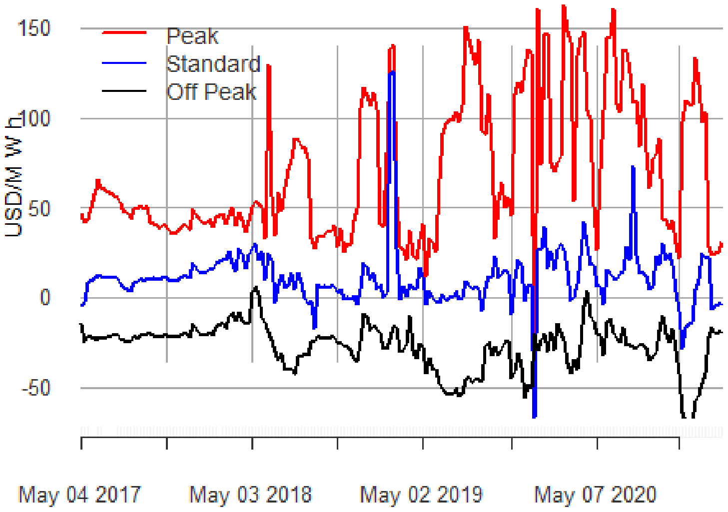


Figure 2 shows Realized Risk Premiums for Peak, Standard and Off Peak Weekly Contracts for the Period 1st April 2017 to 31st January 2021

Figure 3: Monthly Realized Risk Premiums

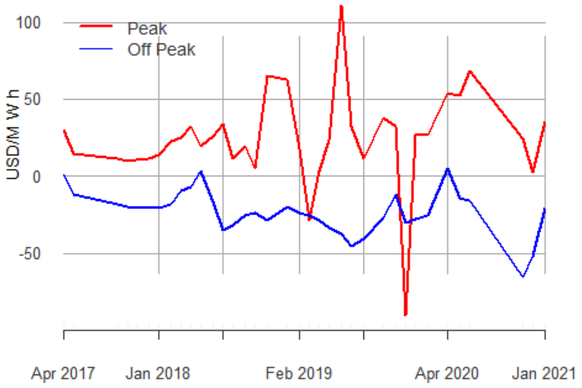


Figure 3 shows Realized Risk Premiums for Peak and Off Peak Monthly Contracts for the Period 1st April 2017 to 31st January 2021

Lastly, to confirm volatility and seasonality in the market, realized premiums in the weekly and monthly markets were plotted in figure 2 and 3 respectively as shown above. Figure 1 and 2 confirm the high volatility of the realized risk premium for peak, standard and off peak contracts through time. The figures also display some element of seasonality with premiums showing considerable upward surges in the third and fourth quarters and downward surges in the first and second across the sample period in both markets.

In summary, it may be concluded that for the considered study period, there exists non zero significant premiums in the SAPP. Further, it may be concluded that futures prices on average seem to be above spot prices for all maturities implying the existence of a contago relationship in the SAPP. These results are consistent with assertions made by:Longstaff and Wang (2004); Daskalakis and Markellos (2009); Redl et al. (2009) that for shorter-term maturities retailers or consumers are highly motivated to hedge the risk of price spikes and are therefore willing pay an additional premium to lock in prices in the short term. The general implication of this is that the market will display positive short-term risk premiums as it has been observed in our examination of the SAPP. Consequently, with the confirmation of the existence of a non zero premium in the SAPP, the next section examined whether the premium could be explained by spot price behaviour in the period preceding delivery.

4.2.2 Explaining the Risk Premiums

In this section, the analysis involved investigating whether the non zero premium could be explained by the behaviour of the spot prices during the week or month prior to delivery of the futures contract. Based off methodologies highlighted in works by:Bessembinder and Lemmon (2002); Redl et al. (2009) the analysis references (7) to determine whether realized forward premiums can be explained by the mean, standard deviation, variance, skewness and kurtosis of electricity spot prices prior to the delivery period of the futures contract. The analysis was conducted for both weekly and monthly markets and the peak, standard and off peak contracts in each market were considered. Ordinary Least Squares regression estimation was applied in this case, and the explanatory variables were all based on spot price behaviour in the week or month preceding delivery respectively.

The regression estimation revealed that some of the explanatory variables were not statistically significant. This consequently meant that step wise regression was a necessary addition to the analysis. To this regard, step wise backward regression was applied, beginning with a model that includes all explanatory variables and then sequentially removing insignificant variables from the model to obtain an optimal fit.

Results for the estimated models including all variables and the optimal model based on the step wise regression are highlighted in table Table 4 and Table 5 below.

On examining the regression analysis results in Table 4, there are notable differences for the different maturities and contract types in the SAPP. The coefficient of determination for the weekly market ranges from 0.19 for peak contracts to 0.11 and 0.84 for the standard and off peak contracts respectively. In the monthly market the values range from -0.09 for peak contracts to 0.81 for off peak contracts. A prevailing observation is that the R^2 values for peak contracts are seemingly lower in both the weekly and monthly market. This implies that the explanatory power for the regression models for peak contracts is consistently low in the SAPP. On comparing these values with findings from previous studies, the analysis concludes that the values for the coefficient of determination in the SAPP fall within the same range as previous findings, being slightly higher or lower for some contracts. Redl et al. (2009) in their study of monthly futures contracts in the European EEX and Nordpool market applied similar methodologies and obtained R^2 values ranging from 0.02 to 0.11.

An analysis of the considered variables gives a wide range of conclusions. Considering the average level of spot prices in the periods preceding delivery, the estimated coefficients are negative for all the contracts except the peak weekly contracts. This implies that an increasing spot price average level translates to a decreasing realized risk premium, thus lowering the chances for the futures quote to overestimate the average spot price during the delivery period. Additionally, the average level is significant for all contracts with the exception of peak monthly contracts.

Table 4: General Equilibrium Model Regression Analysis

	α_0 t-Stat	Mean t-Stat	Var t-Stat	Sd t-Stat	Skew t-Stat	Kurt t-Stat	R^2	Adj R^2	F Stat
Weekly Market									
Peak	10.74 0.56	0.67 2.98**	-0.04 -0.97	2.75 1.42	9.16 1.64	-0.098 -0.04	0.19	0.18	9.18
Standard	22.14 2.56*	-0.25 -2.44*	-0.02 -0.98	0.65 0.74	0.56 0.22	-0.71 -0.57	0.11	0.08	4.51
Off Peak	13.94 4.9***	-0.46 –13.7***	0.004 0.63	-0.87 –3.01**	1.63 1.95	-0.64 -1.57	0.84	0.83	190.6
Monthly Market									
Peak	12.5 0.76	-0.35 0.62	-0.05 0.58	3.4 0.52	7.1 0.68	0.8 0.94	0.07	-0.09	0.44
Off Peak	3.69 0.47	-0.36 –2.66*	-0.04 -1.9	0.85 0.83	10.78 3.3**	2.61 1.14	0.83	0.81	30.68

Table 4 reports the results for the OLS regression estimation of equation (7). Realized Risk Premia are the dependent variable wheres, α_0 is the intercept. The rest of the explanatory variables are based on the spot price behaviour during the period prior to the delivery period of the futures contract. The analysis was conducted for realized futures premium of Peak, Standard and Off peak weekly and Monthly contracts in the SAPP for the sample period. The t-statistics are reported in below the coefficient estimates of the explanatory variables, the asterisks ***, **, and * denoting confidence at 99%, 95%, and 90% confidence levels, respectively.

Table 5: Best Fit Model Regression Analysis

	α_0 t-Stat	Mean t-Stat	Var t-Stat	Sd t-Stat	Skew t-Stat	Kurt t-Stat	R^2	Adj R^2	F Stat
Weekly Market									
Peak	25.90 2.53*	0.67 3.24**		0.99 1.58	9.26 1.78		0.19	0.18	15.06
Standard	28.78 1.2^{-11}***	-0.29 7.2^{-6}***					0.10	0.09	21.28
Off Peak	12.47 7^{-13}***	-0.46 2^{-16}***		-0.7 9^{-11}***	1.62 0.05	-0.65 0.1	0.84	0.83	238.9
Monthly Market									
Peak	24.2 4.7***								
Off Peak	6.6 1.7	-0.24 1^{-2}*	-0.03 13^{-3}***		13 2.7^{-5}		0.8	0.81	51.4

Table 5 shows the results for step wise regression for realized futures premium of Peak, Standard and Off peak weekly and Monthly contracts in the SAPP for the sample period. Explanatory variables are based on the spot price behaviour during the period prior to the delivery period of the futures contract.

Secondly, an examination of the estimated coefficients for skewness reveals positive estimations for all contracts in the market. This assertion implies that realized premiums generally tends to increase with increasing skewness of the spot prices in the period preceding delivery. These results are consistent with assertions made by Bessembinder and Lemmon (2002) as to the underlying relationship between skewness and forward premiums in the electricity market. Positive skewness implies an increased probability of upward spikes in electricity prices, for this reason the forward price and ultimately forward premiums should be positively related to skewness. The estimated coefficients for skewness are largely not significant with the exception of off peak monthly contracts as indicated in Table 4 and Table 5.

These results are consistent with past findings by authors such as Torró et al. (2008) and Botterud et al. (2002) in their study of the Nordpool or (Furió & Meneu, 2010) in their study of the Spanish market. Contrary to this study all these authors find negative coefficients for the skewness parameter but consistent with our findings they conclude that coefficients are not significant. The results for the estimated coefficient for the kurtosis differ with maturity. Weekly contracts all have a negative coefficient wheres the monthly contracts have positive coefficients. These results generally imply that in longer time frames, an increased likelihood of extreme prices ultimately increases the realized premiums.

Lastly, the analysis focused on examining the coefficients for variance and standard deviation and their relationship with premiums. Bessembinder and Lemmon (2002) in their paper assert that, in electricity markets the general tendency is the occurrence of a convex equilibrium premium, initially decreasing then increasing in the variability of power demand and electricity spot prices. The expectation from this is that the model would exhibit a negative coefficient estimate for the standard deviation while the coefficient for variance would be positive. An examination of Table 4 and Table 5 reveal that for all contracts the models contradict this assertion with the exception of off peak weekly contracts. Important to note however, for the off peak weekly contract the resulting model has the highest explanatory power with the most significant variables making it the most optimal model in the market. Hedged on this, we may conclude that the concept of convexity of the forward premium holds to a certain degree in the SAPP market.

4.3 The Forecasting Ability in the Market

4.3.1 The Forecasting Ability of Electricity Futures in the Market.

To investigate the ability of electricity futures to forecast future spot prices, the analysis considered equation (5). The differences between the future spot price and current spot price in the SAPP were regressed against realized forward premiums for the sample period. Following methodologies highlighted by Fama and French (1988); Huisman and Kilic (2012), under rational market expectations, the forecast errors are random and have a zero mean, the coefficient β_2 for the realized forward premium, the constant β_1 and the error term $1_{t,T}$, are equal to the spot price difference. The implication is that, a positive β_2 that is significantly different from zero indicates that the realized forward premium has the ability to predict the spot price change from t to T, thus futures prices in the market have forecasting power over future spot prices.

Table 6: The Forecasting Ability of Futures

	β_1	β_1 T stat	β_2	β_2 T stat	R^2
Weekly Market					
Peak	-0.12	-11.6^{***}	-0.03	-2.25^{*}	0.003
Standard	-0.14	-22.56^{***}	-0.02	-1.08	0.01
Off Peak	-0.01	-0.802	0.17	7.31^{***}	0.22
Monthly Market					
Peak	-0.14	-5.44^{***}	-0.05	-1.71	0.08
Off Peak	0.02	0.28	0.26	3.14^{**}	0.45

Table 6 presents the results for the regression estimation of equation(5) where $S_T - S_t$ denotes the change in the spot price from t to T, $F_{t,T} - S_t$ the current premium, and β_2 is the slope coefficient for the current premium showing its forecasting power over the future spot price, while β_1 represents the intercept and $u1_{t,T}$denotes the error term. The t-statistics are reported in their own columns and the asterisks ***, **, and * denote confidence at 99%, 95%, and 90% confidence levels, respectively.

Table 6 above presents OLS regression results for peak, standard and off peak contracts in the weekly and monthly markets at the SAPP during the sample period. The natural logarithms of the spot and future price data are used for the analysis since the logarithmic transformation of time series data follows the normal distribution more closely than the arithmetic price observations(Lauterbach & Ungar, 1995; Osborne, 1959).

Considering the weekly contracts, the estimated β_2 coefficients produce varying results ranging from 0.17 for off peak contracts to -0.03 for peak contracts. The main observation is that the majority of β_2 coefficients for weekly contracts are not statistically different from zero with the exception of off peak contracts. Comparing these results with those highlighted by Huisman and Kilic (2012), the results imply that weekly futures in the SAPP do not seem to contain any information about spot prices in the market at the beginning of the delivery period with the exception of off peak contracts. Arguably, shorter term futures especially one week or two weeks are generally said to naturally possess forecasting power over near-term spot prices in most markets thus the need to consider longer term futures before making conclusions.

The general expectation is that forecasting power reduces with increasing maturity. Findings by Huisman and Kilic (2012) however reveal that longer term electricity futures posses significant forecasting power over future spot prices in the Nordpool. Their study considered monthly contracts between 2005 and 2010 in the Nordpool. They obtained β_2 coefficient estimates significantly different from zero ranging between 0.83 and 0.84 for 3-month and 2-month futures respectively. Additionally, considering longer maturities they obtained β_2 coefficients ranging between 0.66 to 1.00 for quarterly contracts and between 0.77 to 1.42 for yearly contracts. These results led the authors to conclude that electricity futures at the Nordpool market possess forecasting power over the future spot price in all maturities.

Evaluating the results for monthly futures at the SAPP as highlighted in Table 6, we note that the β_2 coefficient estimates range from -0.05 for peak contracts and 0.26 for off peak contracts. Similar to weekly futures, the estimates are not statistically different from zero with the exception of off peak contracts. This implies that monthly futures in the SAPP do not seem to contain any information about spot prices in the market at the beginning of the delivery period with the exception of off peak contracts.

Comparing these results with previous literature on the subject the analysis uncovers inconsistencies. Fama and French (1988) in their work conclude that future's display forecasting power when dealing with highly perishable products with high storage costs such as hogs, cattle, pork bellies among other products. Additionally the results differ with conclusions made by Huisman and Kilic (2012) that electricity futures at the Nordpool market possess forecasting power over the future spot price. These differences therefore lead to the conclusion that in the SAPP electricity market, future's prices do not seem to contain significant forecasting power over future spot prices with the exception of off peak contracts for all maturities.

4.3.2 Time Varying Risk Premiums

Apart from examining whether variations in the current premium $\mathrm{Ft, T - St}$ are attributable to forecasting power its important to determine whether they are instead attributable to time varying risk premiums or a combination of both. To investigate this, the analysis considered equation (5) and (6). Similar to the previous section, the analysis followed methodologies highlighted by Fama and French (1988) and Huisman and Kilic (2012). Considering (6), the realized futures premiums at T in the SAPP were regressed against current forward premiums for the sample period. In their work, (Fama & French, 1988) postulate that both equations(5) and (6) are subject to an adding-up constraint. Their assertions were hedged on the fact that fundamentally, the realized premium $\mathrm{Ft, T - ST}$ and the change in spot price $\mathrm{ST - St}$ from t to T sum up to the current futures premium $\mathrm{Ft, T - St}$ therefore the slope coefficients in equations(5) and (6) must sum up to one. Table 7 below presents OLS regression results for peak, standard and off peak contracts in the weekly and monthly markets at the SAPP during the sample period.

Table 7: Time Varying Risk Premiums

	μ_1	μ_1 T stat	μ_2	μ_2 T stat	R^2
Weekly Market					
Peak	0.12	11.6***	1.03	7.25***	0.97
Standard	0.14	22.56***	1.02	62.80***	0.96
Off Peak	0.01	0.802	0.83	36.71***	0.88
Monthly Market					
Peak	0.14	5.44***	1.05	31.932***	0.97
Off Peak	-0.02	0.28	0.74	8.95**	0.7

Table 7 presents the results for the regression estimation of equation(6) where $F_{t,T} - S_T$ denotes the risk premium realized at time T, $F_{t,T} - S_t$ the current premium, and μ_2 is the slope coefficient for the current premium indicating time-varying risk premiums. μ_1 represents the intercept and $u2_{t,T}$denotes the error term. The t-statistics are reported in their own columns and the asterisks ***, **, and * denote confidence at 99%, 95%, and 90% confidence levels, respectively.

The μ_2 estimated coefficients are all statistically different from zero for all maturities ranging from 1.05 for the peak monthly contracts to 0.74 for off peak monthly contracts. Additionally, the summations for β_2 and μ_2 are all statistically equal to one and therefore it may be concluded that these results present evidence of time varying risk premiums in the SAPP market.

These findings are consistent with Huisman and Kilic (2012) who in their study of the Dutch power market find evidence of time-varying risk-premiums. In their study of the Nordpool, the same authors conclude that there was no evidence of time-varying risk premiums in the Nordpool. Huisman and Kilic (2012) argue that these differences arise due to the nature of electricity generation in the two markets. The Nordpool is highly dependent on hydro power generation wheres the Dutch Market is heavily reliant on storable fossil fuels for electricity generation. In similar fashion the SAPP is heavily reliant on coal, and nuclear power for electricity generation thus these similarities to the Dutch Market might explain the similarity in results. The results therefore allow one to conclude that the variations in the current premium $Ft, T - St$ are not attributable to forecasting power but rather to time varying risk premiums at the South African Power Pool.

Chapter 5

Discussions and Conclusions

This study sought to investigate whether a forward premium exists in the South African Power Pool. If the premium exists, the study additionally sought to investigate whether it can be explained by the behaviour of spot prices in the market in the period before delivery. Lastly, the study investigated whether forward prices in the SAPP possess forecasting power over future electricity spot prices providing arbitrage opportunities. This section highlights the primary findings and their implications on these highlighted areas.

As highlighted in subsection 4.2.1 above, the results for both the weekly and monthly markets were consistent. They indicated existence of positive premiums for peak and standard contracts in both markets wheres off peak contracts were seen to have negative premiums in both markets. These results are consistent with literature, where several authors argue that peak electricity contracts are generally priced higher compared to off peak contracts. In their article, Dutta and Mitra (2017) argue that this mis pricing arises since electricity generation costs tend to be higher during peak demand periods thus translating to higher prices. The relative premiums values ranged from USD/MWh 1.23 to USD/MWh -0.44 for the weekly market and from USD/MWh 0.46 to USD/MWh -0.37 for the monthly market. The size of the premiums was generally seen to be larger for weekly contracts than for monthly contracts, implying decreasing premiums with term to maturity but this assertion could not be explored further since there were no longer term contracts in the market to investigate.

To investigate the proportion of positive premiums in the market, results indicate proportions of 99.48%for peak weekly contracts to 2.07% for off peak weekly contracts. This shows strong clustering of observations on either side. The differences in proportions for the various contracts prompted a further examination of the premiums as a whole. The resulting values was that 60.79% of the weekly premiums were positive wheres 51.39% of the monthly premiums were positive. This results lead to the conclusion that on average, there exists non-zero positive forward premiums in the SAPP market. These results suggest that hedging needs between buyers and sellers in the SAPP are not balanced and are consistent with assertions made by:Longstaff and Wang (2004); Redl et al. (2009); Daskalakis and Markellos (2009) that for shorter-term maturities retailers or consumers are highly motivated to hedge the risk of price spikes and are therefore willing pay an additional premium to lock in prices in the short term.

Section 4.2.2 aimed at investigating whether, the non zero premium could be explained by the behaviour of the spot prices during the period preceding delivery of the futures contract. Results suggests that for some of the contracts in the SAPP, forward premiums can be at least partially explained by the mean, variance, standard deviation and skewness of the spot prices in the period preceding delivery. Particularly, the premiums had a negative relationship with average spot prices. This implies that on average at the SAPP, a higher average spot price level translates to reduced overestimation of future prices ultimately reducing forward premiums in the market. Additionally, results revealed a positive relationship between forward premiums and skewness. This assertion is consistent with literature since, positive skewness implies an increased probability of upward spikes in electricity prices, for this reason the forward price and ultimately forward premiums should be positively related to skewness.

The last objective of the analysis aimed at investigating whether electricity futures in the SAPP possessed forecasting power over future electricity spot prices at the SAPP. Results in subsection 4.3.2 reveal that future's prices at the SAPP do not contain significant forecasting power over future spot prices with the exception of off peak contracts in the weekly and monthly contracts. On further examination, results uncover that variations in the forward premium $\mathrm{Ft, T - St}$ are not attributable to forecasting power but rather to time varying risk premiums. These findings are consistent with (Huisman & Kilic, 2012) who in their study of the Dutch power market that is heavily reliant on storable fossil fuels for electricity generation find evidence of time-varying risk-premiums. The authors argued that the existence of time varying premiums in the electricity market was due to the nature of electricity generation in the market. They concluded this after conducting a similar study on the Nordpool that is heavily reliant on hydro power generation and concluding that time varying premiums did not exists. The SAPP to a large extent relies on coal and nuclear power for electricity generation thus this could explain the reason why results led to the conclusion of the existence of time varying risk premiums.

In conclusion, the findings of this study provide insight as to the pricing dynamics in the SAPP and contributed to the existing literature as to the fundamental relationship between spot and future prices in electricity markets. Past studies on the topic have focused on well developed power pools that are highly decentralized, the study has provided a different perspective since the SAPP is in its formative stage and is only decentralized to a certain extent. Additionally, this study provides insight to both purchasers and producers in the SAPP in trying to understand how the existing pricing dynamics affect them since little attention has been paid to uncovering this in the market.

The existence of positive forward premium in the SAPP suggests that the hedging demand in the SAPP is unbalanced such that its higher for purchasers than for power producers. Power purchasers in the SAPP are on average incurring a cost that inflates their cost of power by 0.24% to 1.23% depending on the hedging strategy they adopt and type of contracts they select. An analysis of how long term average costs for hedging compare to this cost would be particularly important to inform as to whether the cost is economically reasonable and whether the pricing mechanism in the market is optimal. Speculators in the market may see these results as an opportunity to earn profits by taking on the risk of price spikes on behalf of power purchasers. The results have however shown strongly that futures prices in the market have no predictive power over future spot prices. This therefore implies that stakeholders in the market, including spectators need a comprehensive understanding of other fundamental variables driving electricity prices in the SAPP before attempting to make an economic gain on the pricing imbalances observed.

Chapter 6

Recommendations

The focus of this study was analyzing the the relationship between the electricity future prices and the spot prices in the SAPP. The SAPP comprises of 14 different countries that have their own different characteristics with regards to electricity production, demand and supply, temperature among other characteristics. This study examined the pool as a whole without focusing on these differences. A further examination comparing how future and spot prices relate in the different countries would be a good addition to existing literature.

Secondly, this study focused on risk aversion components when modelling the forward premia in the SAPP. This was captured by attempting to explain the forward premia using higher central moments such as mean, variance and the skewness of spot prices in the market. In literature, forward premia modelling spans three broad areas spanning risk aversion, demand level data and infra marginal generation. Redl and Bunn (2010) argue that having a clear understanding of forward premia drivers in any electricity market allows for proper regulation and pricing designs. To a large extent, the SAPP can be seen as a rigid market due to the level of liberalization in the market. It would be therefore beneficial to explore production based pricing methods that offer a different perspective to what was explored in the study.

A review of literature reveals several authors that have explored production based pricing techniques such as: Gjolberg and Johnsen (2001) who in their study of the Nordic market focus on the theory of storage in an attempt to explain the relationship between future and spot prices in the market. Considering hydro reservoirs storage levels in relation to storage costs and convenience yields, they concluded that the Nordic market reacts strongly to changes in storage levels and forward prices typically exceed spot prices as signalled by very high premiums in the market. The authors however conclude that these results are seemingly too high and thus could have been skewed by model inaccuracies or general market structures. The SAPP features hydro-powered electricity generation and thus a study that explores such a model would be an integral addition to literature.

Another study focusing on infra marginal generation by Redl and Bunn (2010) in the German market is also a rich example of production based models that could be considered. The authors postulate that the price risks of fuels substantially affect the risk premia of electricity prices. The SAPP is very rich in storable fossil-fuels used to generate electricity. A study considering how the price of these fuels affects pricing in the market would be a rich addition to literature.

Lastly, during the course of conducting this study an area of improvement suggested by examiners was adding a comparative angle to the study comparing the results in the SAPP to another power pool. A comparison of the SAPP and the Nordpool was originally planned to be examined in the study however this was not conducted due to failure to obtain price data for the Nordpool on time. A comparison of this nature would be great source of information. In his forum paper, Andrews-Speed (2016) postulates that the South African Power Pool made most of their structural changes based off the success witnessed in the Nordic region, implemented by Norway-based Nord Pool ASA. A study of this kind could potentially provide insight as to the differences between a young and highly developed market. Additionally it could provide information as to the economic viability of current structural framework in the SAPP and potential areas for improvement.

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Appendix I

R Codes

Obtaining the Descriptive Statistics of the data

```
library(readxl)
library(xts)
library(ggplot2)
library(dplyr)
library(lubridate)
library(tidyverse)

setwd("C:/Users/user/Documents/STRATHMORE 2020/SEM 3/RESEARCH
    METHODS FOR MATHEMATICAL SCIENCES/Final Research Document/Final
    Research Thesis/DATA")
spotpricedata<-read_excel("Day Ahead Market Data.xlsx",sheet=1)

prices<-as.data.frame(spotpricedata[,2])#Obtaining just the prices

MEANall<-mean(as.matrix(prices))
VARall<-var(as.matrix(prices))
SQRTall<-sd(as.matrix(prices))
Maxall<-max(prices)
Minall<-min(prices)


# Evaluating Different Quarters

Q1<-read_excel("Day Ahead Market Data.xlsx",sheet = 2)
Q1<-as.data.frame(Q1[,2])#Obtaining just the prices

MEANQ1<-mean(as.matrix(Q1))
VARQ1<-var(as.matrix(Q1))
SQRTQ1<-sd(as.matrix(Q1))
maxq1<-max(Q1)
minq1<-min(Q1)

#The same was done for Quarter 2, Quarter 3 and Quarter 4.
Names<-c("ALLDATA","QUARTER 1","QUARTER 2","QUARTER 3","QUARTER 4")

Table1<-data.frame("ITEM"=Names,"MEAN"=c(MEANall,MEANQ1,MEANQ2,
    MEANQ3,MEANQ4),"VAR"=c(VARall,VARQ1,VARQ2,VARQ3,VARQ4),"SD"=c(
    SQRTall,SQRTQ1,SQRTQ2,SQRTQ3,SQRTQ4),"MAXIMUM"=c(Maxall,maxq1,
    maxq2,maxq3,maxq4),"MINIMUM"=c(Minall,minq1,minq2,minq3,minq4))
```

```
# Daily Electricity Spot Prices Plot
xspotdata <- xts(spotpricedata[-1], order.by = as.Date(spotpricedata
   $Delivery.Date,"%Y/%m/%d"))

plotxts(xspotdata$Price..USD.MWh.,yaxis.right = FALSE,xlab="Year",
   ylab="Spot Prices in USD/MW h",main = "Daily Electricity Spot
   Prices",type = "l",lwd = 1,lty = 1)


#Quarterly Plots

options(stringsAsFactors = FALSE)

Q1data<-read.csv("C:/Users/user/Documents/STRATHMORE 2020/SEM 3/
   RESEARCH METHODS FOR MATHEMATICAL SCIENCES/Final Research
   Document/Final Research Thesis/DATA/plots/Q1 Data.csv",header =
   TRUE)

str(Q1data)

Q1data <-Q1data %>%
  mutate(DATE1 = as.Date(Delivery.Date, format = "%m/%d/%y"))

 Q1<-ggplot(Q1data,aes(x = DATE1, y =Q1)) +
  geom_line(color = "black") +

  labs(title = "Quarter 1",
       y = "Prices",
       x = "Date") + theme_bw(base_size = 15)
Q1
#The same was done for Quarter 2, Quarter 3 and Quarter 4.


library("gridExtra")
grid.arrange(Q1,Q2,Q3,Q4,
          ncol = 2, nrow = 2)
```

Obtaining and Evaluating Risk Premiums

```
FPweeklypeak<-read_excel("Forward Pysical Weekly Data.xlsx",sheet=
   2)
peakweeklypremiums<-FPweeklypeak[5]

peakweeklypremiums<-as.numeric(unlist(peakweeklypremiums))
   peakweeklyno<-length(peakweeklypremiums)
peakweeklyavg<-mean(peakweeklypremiums)
peakweeklystd<-sd(peakweeklypremiums)
```

```
peakweeklytstat<-t.test(peakweeklypremiums,peakweeklyavg=0)
peakweeklytstat<-peakweeklytstat$statistic
peakweeklymin<-min(peakweeklypremiums)
peakweeklymax<-max(peakweeklypremiums)
peakweeklyposval<-(length(peakweeklypremiums[peakweeklypremiums>0])/
   length(peakweeklypremiums))*100

#Tabulating the Statistics

Names<-c("FP WEEKLY PEAK ","FP WEEKLY STANDARD","FP WEEKLY OFFPEAK")

Table2<-data.frame("ITEM"=Names,"NO OF OBSERVATIONS"=c(peakweeklyno,
   standardweeklyno,offpeakweeklyno),"MEAN"=c(peakweeklyavg,
   standardweeklyavg,offpeakweeklyavg),"T-STATISTIC**"=a, "STANDARD
   DEVIATION"=c(peakweeklystd,standardweeklystd,offpeakweeklystd),"
   MAXIMUM"=c(peakweeklymax,standardweeklymax,offpeakweeklymax),"
   MINIMUM"=c(peakweeklymin,standardweeklymin,offpeakweeklymin),"
   POSITIVE VALUES IN (%)"=c(peakweeklyposval,standardweeklyposval,
   offpeakweeklyposval))

#Obtaining the Proportions of Overall Positive values
weeklydata<-read_excel("Forward Pysical Weekly Data.xlsx",sheet = 8)
head(weeklydata)
names(weeklydata)<-NULL
weeklydata<-as.numeric(unlist(weeklydata))
length(weeklydata)
weeklydataposval<-length(weeklydata[weeklydata>0])/length(weeklydata
   ) *100


#Plotting the Premiums
data1<-read.csv("C:/Users/user/Documents/STRATHMORE 2020/SEM 3/
   RESEARCH METHODS FOR MATHEMATICAL SCIENCES/Final Research
   Document/Final Research Thesis/DATA/plots/Weeklyplot Data.csv")

#Time Series
library(xts)

xdata1 <- xts(data1[-1], order.by = as.Date(data1$Date,"%m/%d/%Y"))

plotxts(xdata1$Peak.Weekly, xlab="Year", ylab="USD/M W h",main="Ex
   Post Forward Premiums Weekly Market",col="red")
lines(xdata1$Standard.Weekly, lwd = 2, col="blue", lty=1)
lines(xdata1$Off.Peak.Weekly, lwd = 2, col="black", lty=1)


# Adding a legend
addLegend("topleft", on=1,legend.names = c("Peak", "Standard","Off
```

```
   Peak"),lty=c(1, 1,1), lwd=c(2,1,1),col=c("red", "blue", "black"))

#The same was repeated for Peak,Standard and Off peak Weekly and
   Monthly contracts. #Additionally, Respective Relative Premiums
   were also evaluated in a similar manner.
```

Explaining the Risk Premiums

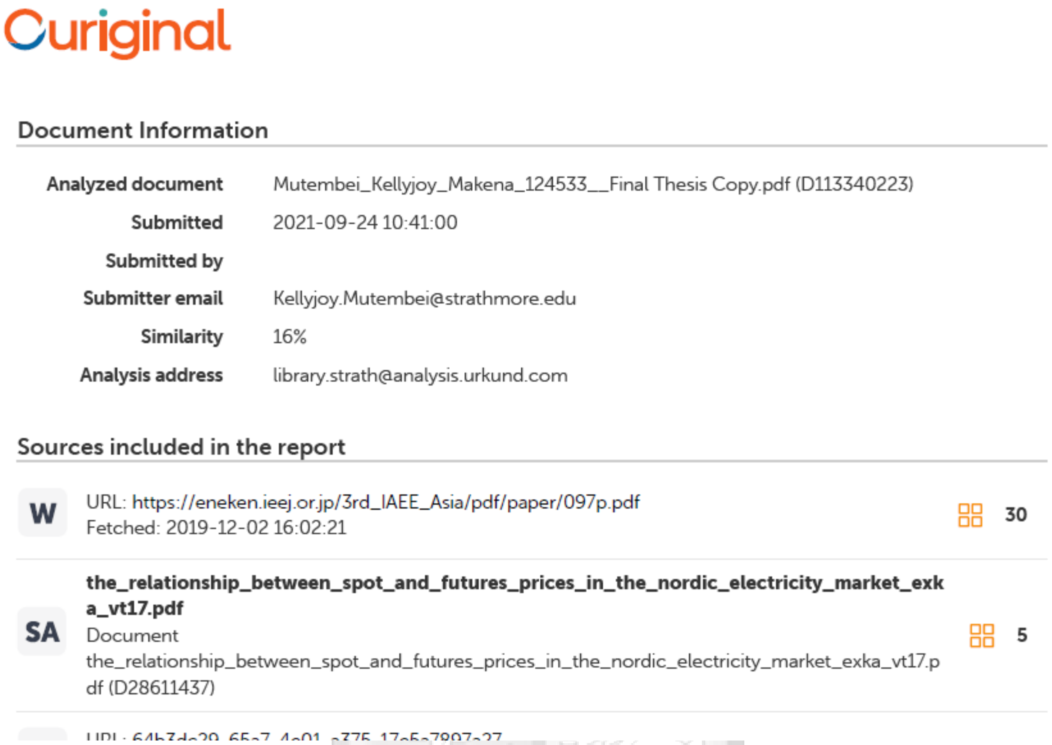
```
peakweekely<-read_excel("Forward Pysical Weekly Data.xlsx",sheet=2 )
peakweekelydata<-peakweekely[c(5,7:11)]
head(peakweekelydata)

#Regression Modeling

model1<-lm(peakweekelydata$`Forward Premium` ~ peakweekelydata$MEAN+
   peakweekelydata$VARIANCE+peakweekelydata$`STANDARD DEV`+
   peakweekelydata$SKEWNESS+peakweekelydata$KURTOSIS,data=
   peakweekelydata)
summary(model1)

stepfit1<-step(model1,direction = "backward")
summary(stepfit1)

#The same was repeated for Peak,Standard and Off peak Weekly and
   Monthly contracts.
```

Testing the forecasting Power in the market

```
peakweeklyforecast<-read_excel("Forward Pysical Weekly Data.xlsx",
   sheet =3 )
peakweeklyforecastdata<-peakweeklyforecast[5:11]
head(peakweeklyforecastdata)

peakweeklyforecasteqn1<-lm(peakweeklyforecastdata$`ST- St`~
   peakweeklyforecastdata$`Ft,T - St...9`)
summary(peakweeklyforecasteqn1)

peakweeklyforecasteqn2<-lm(peakweeklyforecastdata$`Ft,T-ST`~
   peakweeklyforecastdata$`Ft,T - St...11`)
summary(peakweeklyforecasteqn2)

y1<-peakweeklyforecasteqn1$coefficients
z1<-peakweeklyforecasteqn2$coefficients
peakweeklyforecastconfirmation<-y1[2]+z1[2]
peakweeklyforecastconfirmation

#The same was repeated for Peak,Standard and Off peak Weekly and
   Monthly contracts.
```

Appendix II

Ouriginal Report Similarity Checker



Ouriginal

Document Information

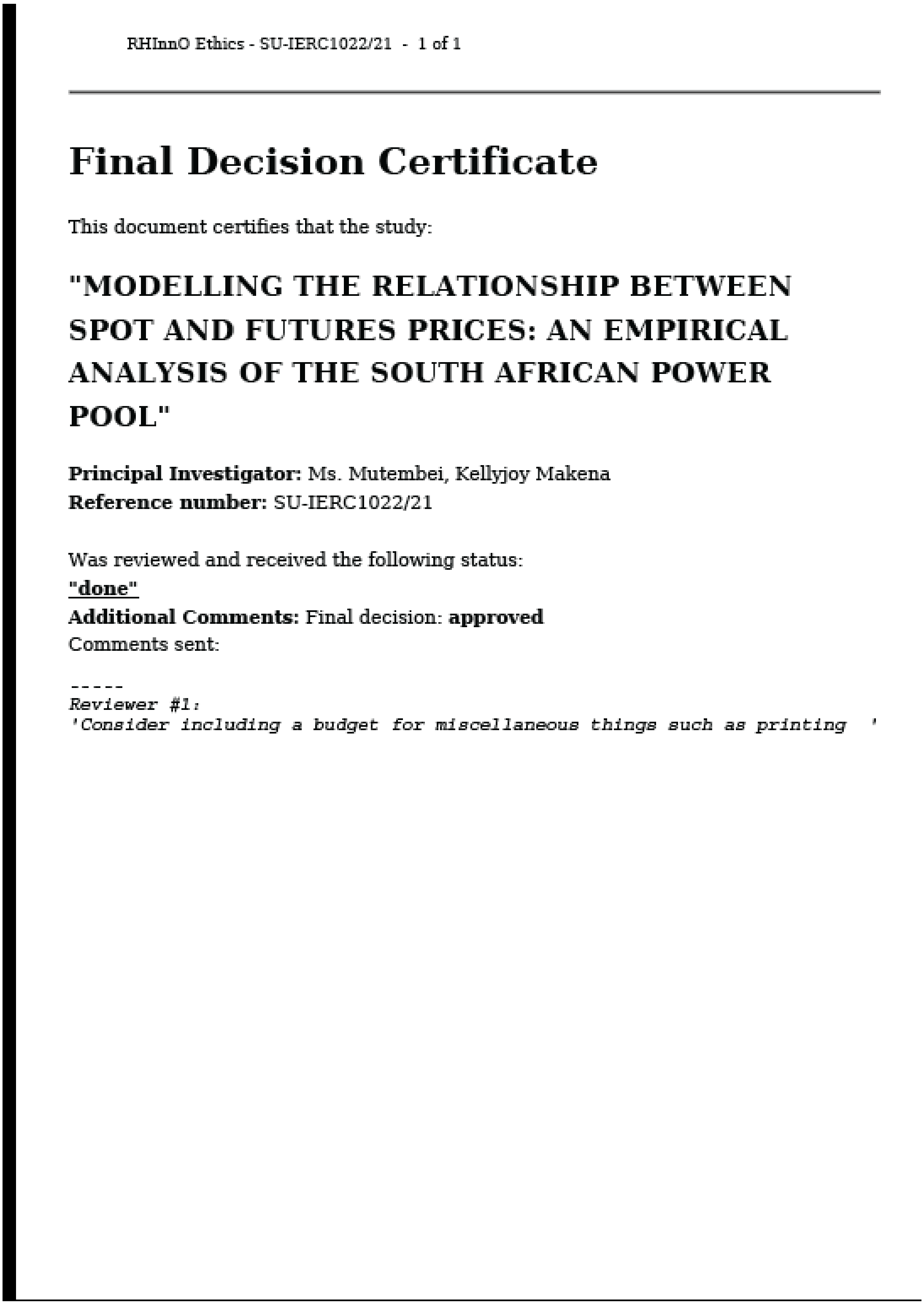
Analyzed document	Mutembei_Kellyjoy_Makena_124533__Final Thesis Copy.pdf (D113340223)
Submitted	2021-09-24 10:41:00
Submitted by	
Submitter email	Kellyjoy.Mutembei@strathmore.edu
Similarity	16%
Analysis address	library.strath@analysis.urkund.com

Sources included in the report

W	URL: https://eneken.ieej.or.jp/3rd_IAEE_Asia/pdf/paper/097p.pdf Fetched: 2019-12-02 16:02:21	⊞	**30**
SA	**the_relationship_between_spot_and_futures_prices_in_the_nordic_electricity_market_exka_vt17.pdf** Document the_relationship_between_spot_and_futures_prices_in_the_nordic_electricity_market_exka_vt17.pdf (D28611437)	⊞	**5**
	URL: 64b3de29-65a7-4e01-a375-17e5a7897a27		

Appendix III

Ethics Review Approval Certificate



RHInnO Ethics - SU-IERC1022/21 - 1 of 1

Final Decision Certificate

This document certifies that the study:

"MODELLING THE RELATIONSHIP BETWEEN SPOT AND FUTURES PRICES: AN EMPIRICAL ANALYSIS OF THE SOUTH AFRICAN POWER POOL"

Principal Investigator: Ms. Mutembei, Kellyjoy Makena
Reference number: SU-IERC1022/21

Was reviewed and received the following status:
"done"
Additional Comments: Final decision: **approved**
Comments sent:

Reviewer #1:
'Consider including a budget for miscellaneous things such as printing '