Energy Policy 130 (2019) 311–319

Contents lists available at ScienceDirect

Energy Policy

journal homepage: www.elsevier.com/locate/enpol

Decoupling impact and public utility conservation investment

Richard A. Michelfelder[a,*], Pauline Ahern[b], Dylan D'Ascendis[b]

[a] Rutgers University, School of Business - Camden, 227 Penn Street, Camden, NJ 08102, USA
[b] ScottMadden, Inc. 1900 West Park Drive, Suite 250, Westborough, MA 01581, USA

ARTICLE INFO

Keywords:
Decoupling
Public utility cost of common equity
Energy and water efficiency
JEL classification:
G12
L94
L95

ABSTRACT

Public utilities and regulators are implementing various forms of regulatory mechanisms that decouple revenues from commodity sales to remove a disincentive or create an incentive for utilities to invest in and encourage consumers to conserve electricity, natural gas and water. A major question is whether such regulatory mechanisms affect investor-perceived risk, the cost of common equity and the utility rates of such commodities. This is an important question as regulators in the US are and have been considering the impact of decoupling on investment risk and therefore the cost of common equity in rate proceedings. This matter is also important for regulators globally as they consider decoupling as a policy initiative in setting rates and rate of return. Currently, decoupling is primarily a US ratemaking policy for energy and water utilities as are price caps in Europe. Empirical testing, based on the available data in the US, consistently demonstrates that decoupling has no statistically measurable impact on risk and the cost of common equity. Therefore, at this juncture, policy is moving ahead, at least in the US, without empirical evidence on whether it does have impact on risk and return.

1. Introduction

Beginning in the late 1970s, US policymakers, legislators, regulators and public utilities began to focus on reducing consumers' demand for energy rather than increasing supply. This was mainly a reaction to the oil supply shock in the US in the early 1970s, which began with the National Energy Conservation Act of 1978. Europe was already much more efficient in the use of energy by the 1970s as the BTU content of GDP of many European countries was a substantially small fraction relative to the US.

More recently in the US, regulatory policy has required water utilities to encourage the reduction in water use by their consumers. The US and European utility industries seem to observe each other's experiments in decoupling and price caps before adopting such alternative ratemaking policy movements. Price cap regulation, where utility prices are allowed to rise to a cap set by an inflation index minus a total factor productivity offset that reflects potential cost savings (known as *RPI – X*), was implemented decades ago for British utilities. Only afterward was it adopted by many other utilities in Europe (EU). However, it has largely not been adopted in the US as very few utilities are under price cap regulation except for telecommunications local exchange carriers. On the other hand, decoupling, which effectively disassociates revenue levels from commodity (electric, gas or water) sales has been sweeping across the US in the last two decades for energy and water utilities, while being not adopted in Europe.

Campini and Rondi (2010) show that alternative rate mechanisms in the EU have been in the form of price caps to promote efficient investment and operating expenditures. There is no mention in that article of decoupling. They also point out that since many utilities in the EU are government owned there has not been any major adoption of alternative regulatory rate making methods across the utility industry as government utility rates are not regulated. Therefore, this study is limited to analyzing decoupling in the US, as it is still almost exclusively a regulatory tool implemented in the US.

A major financial impediment preventing investor-owned utilities from encouraging conservation of energy and water usage and sales is the profit disincentive associated with subsequent revenue and profit reductions. Therefore, various regulatory policy mechanisms have been developed to provide utilities with a financial incentive, or, at least, remove the disincentive to utilities to encourage energy and water efficiency. Some mechanisms have been the inclusion of conservation expenditures in rate base so the such expenditures earn a return. Other mechanisms allow for a profit incentive equal to a proportion of the life cycle of net benefits, as well as rate of return premiums for meeting or exceeding conservation goals. Increasingly, revenues are being decoupled from sales volumes so that reductions in sales volumes will

* Corresponding author.
E-mail addresses: richmich@rutgers.edu (R.A. Michelfelder), pahern@scottmadden.com (P. Ahern), ddascendis@scottmadden.com (D. D'Ascendis).

https://doi.org/10.1016/j.enpol.2019.04.006
Received 15 January 2019; Received in revised form 1 April 2019; Accepted 6 April 2019
Available online 18 April 2019

potentially stabilize profits rather than reduce them.[1] Decoupling revenues from sales volumes was first implemented in California in 1982 and in New York in the 1980s. Although decoupling did not gain momentum outside of California and New York for decades afterward, it has recently been implemented in various state regulatory jurisdictions across the US for electric, natural gas, and water public utilities. Fig. 1 is a map depicting the extent of decoupling across the US developed by the National Resources Defense Council (2018). Although it shows the extent of decoupling across the US for electricity and natural gas utility industries, it does not show the same for water/wastewater utility industries. Fig. 1 shows that as of August 2018, 26 states have adopted gas decoupling (compared with 20 in 2013) and 17 have adopted electricity decoupling (compared with 14 in 2013).

The types of decoupling generally fall into three categories: fixed and variable mechanisms, lost revenue recovery from commodity sales reductions due specifically to energy or water efficiency programs, and fixed revenue true-up mechanisms. Fixed and variable rate mechanisms have a high fixed rate component that may or may not include a set maximum volume of the commodity included in the fixed rate and the variable component is the rate for partial or all volume use. The fixed rate is meant to cover all or most fixed costs. They are rarely used in the electric or gas utility industries but are frequently used for water utilities. Lost revenue recovery mechanisms allow the utility to collect the revenue lost directly from the specific sales reductions due to energy or water efficiency programs. True-up mechanisms set a fixed overall level of revenues and the utility can recover a shortfall in revenues from the set level in higher rates. Nadel and Herndon (2014) discuss the future of the energy utilities industries and the role that decoupling as a form of alternative ratemaking may play in that future. Also, see Carter (2001), Cavanaugh (2013), Eto et al. (1997) and the American Council for an Energy Efficient Economy and Natural Resource Defense Council websites for discussion on the trends, theory and implementation of decoupling and various decoupling mechanisms.

One key consideration in many US rate proceedings and policy discussions is the impact of decoupling on the investment risk of a public utility and its cost of common equity (and therefore the allowed rate of return set by regulators). Since decoupling disassociates revenues with sales volumes, the intended impact is that it generates an increasingly stable and non-declining level of revenues and net income if sales do decline. Therefore, the public utility is expected to be perceived by investors as having lower investment risk, which would lead to a lower cost of common equity capital, i.e., the investor required return.

Decoupling can also be viewed as exacerbating investment risk rather than decreasing it. To the extent that investors are concerned about a changing regulatory regime, uncertainty about the measurement of the savings impacts of conservation programs, partially implemented or gamed mechanisms, to name a few potential issues associated with such an alternative ratemaking mechanism, may exacerbate investors' perceived risk and the cost of common equity.

Decoupling is implemented with the intention to reduce or eliminate volume risk and therefore potentially the cost of common equity as stated above. If the utility hedges volume risk due to weather, which is the most likely cause of demand shocks to electric, gas or water commodities, hedging derivatives[2] allow the utility to insure such risk. If the utility hedges most of the commodity demand risk while meeting demand regardless of compensation mechanisms, the risk may fall if the volume risk is systematic. Whether such weather risk is systematic or not is questionable as weather shocks do not affect most common stocks in a highly diversified portfolio nor the business cycle that drives the systematic risk of a market portfolio. It may not be systematic even within a utility-only portfolio as weather patterns can be diversified away with geographical diversification. If weather happens to have a systematic effect on the risk of the public utility common stock, it is conceivable that cost-effective hedges may reduce risk and the cost of common equity. Should the utility hedge risks that do not materialize into an adverse effect such as a demand shock, they incur costs to do so, and the hedges do not payoff. That is, they spend too much on hedged positions or insurance or take title to commodity that they cannot sell, such as with a take-or-pay contract, thus facing increased risk, costs and higher costs of common equity. Therefore, volume risk is not actually alleviated with decoupling. Essentially, the question is that although the risk of the business is not changed by reward mechanisms, as demand shocks (positive or negative) still occur, do investors perceive, as do some regulators and utility management, that decoupling reduces risk? A change in the reward structure does not change the fundamental riskiness of a firm. It is the investors' perceived risk that affects the cost of common equity. This would not seem to occur in an efficient market, but it is not so obvious that financial markets are efficient.

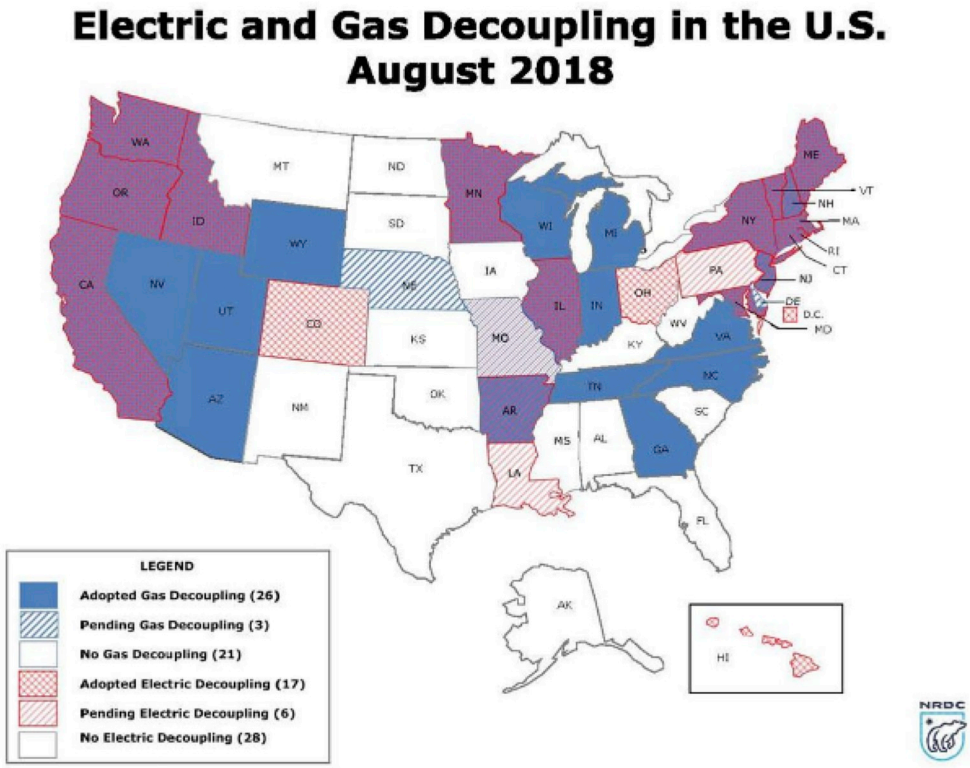
An efficient market is one of a number of assumptions that has been relaxed in the derivation of the generalized consumption asset model (GCAPM) used in this paper. As one example of inefficiency, cash flows generate the fundamental value of a firm, yet the best predictor of common stock prices statistically is earnings per share growth rates, not cash flow per share growth. Investors seem to erroneously price common stocks with earnings, not cash flow based on their perceptions of what affects common equity financial value.

The topic of this paper has been the subject of only a few empirical investigations so far by Wharton and Vilbert (2015) and Vilbert et al. (2016). Moody's (2011) has estimated the change in business risk and credit metrics due to decoupling, but not the impacts on the cost of capital. There are no empirical studies on water utilities such as those performed herein.

Wharton and Vilbert (2015) developed an index of decoupling exposure for public utility and utility holding company common stocks and estimated the after-tax weighted average cost of capital (ATWACC) using the dividend discount model to estimate the cost of common equity. They regressed the ATWACC on an index of decoupling intensity for each public utility in their sample and observed the slope to

[1] In response to the challenges to achieving the allowed return on common equity due to expected significant capital expenditures to repair and replace utility infrastructure, as well as declining per capita commodity consumption, the National Association of Regulatory Utility Commissioners (NARUC) recommends that regulators carefully consider and implement appropriate ratemaking measures so that water and sewer utilities have a reasonable opportunity to earn their allowed rate of return on common equity. Decoupling, or revenue adjustment stabilization mechanisms (RAM) separate rates/revenues from electricity, gas or water volumes sold. Such mechanisms address the effects of the more efficient use of the commodity and declining per capita consumption, for water, and to a lesser extent, electricity, while maintaining the financial soundness and viability of the utilities. With RAMs, utilities are made whole for revenue shortfalls from allowed revenues used to design rates, which generally result from weather and conservation efforts by customers. RAMs allow for the recovery/crediting of differences between actual and allowed quantity charge revenues. RAMs seem to be effective in mitigating the effects of regulatory lag and improving utilities' opportunities to earn their allowed returns on common equity while upgrading infrastructure, ensuring safe and reliable service, removing the incentive to sell more commodity, and helping to protect valuable natural resources. However, in base rate cases for utilities that have such mechanisms, the question often arises as to whether and to what extent the presence of such mechanisms reduces the utility's investment risk as well and to what extent such a perceived or actual reduction in risk should be reflected in the allowed return on common equity.

[2] Water derivatives, although not traded in markets as are gas and electricity futures and forwards, are created through private contracts. Some water distribution systems are interconnected to others and have various contracting structures for buying water if a demand shock should cause the need for more water that the incumbent system cannot supply. Some sewer systems have similar contracts to transfer excessive wastewater flows to another utility's treatment plant if their own capacity reaches its limit.



	2013		2018	
	Utilities	States	Utilities	States
Gas	49	20	64	26
Electric	24	14	41	17
Total	73	25	105	32

Fig. 1. Trend in Energy Utility Decoupling in the US. Source: https://www.nrdc.org/resources/gas-and-electric-decoupling, accessed March 31, 2019

estimate the impact. Although the slope of the regression is negative, it is not statistically significant. They concluded that decoupling has no statistically significant measurable impact on the public utility cost of common equity. They found that decoupling may reduce revenue volatility, but it may not reduce investment risk. They find that it may actually exacerbate risk as decoupling regulatory policy is viewed as a new and uncertain regime and may be used to promote other regulatory policy goals and create regulatory risk.[3]

Reductions in peak loads and the commodity sales impacts of consumer energy or water efficiency measures are difficult and expensive to estimate. This difficulty introduces an additional regulatory risk that may result in exposure to regulatory financial penalties due to the uncertainties associated with such efficiency estimation. Thus, Wharton and Vilbert (2015) concluded that on a net basis, decoupling may increase the investment risk of utilities.

Chu and Sappington (2013) developed a social welfare model that investigated under what conditions a utility would provide a welfare maximizing level of energy efficiency services to its consumers. Their investigation is important to our discussion as decoupling is implemented as a tool to incent utilities to encourage consumers to invest in the optimal level of end-use efficiency resources. In considering the use of decoupling, Chu and Sappington (2013) found that, generally, decoupling alone is not sufficient to induce utilities to provide the socially optimal level, that is, enough energy efficiency services. One problem is that end-use energy efficiency resources cause a rebound effect {Khazzoom (1980, 1987)} whereby lower utility bills cause consumers to increase their energy use as they buy more comfort with the savings.

Chu and Sappington (2013) also discuss that, if the price of electricity is above the private marginal cost (in contrast to social marginal cost), falling sales reduce the utility's profits.[4] Since public utility ratemaking uses average cost to set rates, this is a highly unlikely occurrence to find price above marginal cost. Depending on the specific conditions facing a utility, decoupling may not generate a profit motive for utilities to reduce sales through energy or water efficiency. Utilities could be placed into the position of delivering the predicted amount of energy savings expected by regulators but possibly without any profit motive other than the avoidance of regulatory penalties for not meeting a goal. This disincentive has become a major topic relative to alternative ratemaking mechanisms, as the growth in electricity sales is less correlated with the growth rate in the US GDP relative to the past, with such sales growing more slowly than the general economy has been in recent years.[5]

Brennan (2010) developed a social welfare model to derive conditions under which utilities would be incented to provide energy efficiency services, showing that decoupling must separate revenues from the generation of electricity and not just revenues and sales from the

[3] Since multiple types of risk are discussed, we generically define risk as the chance of a disappointment in financial performance.

[4] The key problem with the over-use of utility services is that public utility pricing is based on average versus marginal cost pricing. Utility services have an excess demand (over-consumed) and end-use efficiency resources have an excess supply (under-consumed) with general equilibrium not attained. The authors of this study are hard-pressed to find where the actual price of electricity is above private marginal cost.

[5] US electricity use is expected to experience an annual average growth rate of 0.9% compared with a 2.4% US GDP annual growth rate between 2011 and 2040, according to the US Energy Information Administration (EIA) forecast in 2013, as demonstrated in the EIA graph below.

distribution of electricity, leading to a highly complex form of electricity pricing regulation, rather than just the simpler separation of sales to the consumer and the related revenues collected. Brennan (2010a) compared incentive regulation using price caps versus decoupling. His paper analyzed the difference between separating profits from management decision-making and incentive-based regulation in the form of price caps which are meant to promote better input decision-making than rate of return regulation that provides an opportunity to earn a set rate of return, somewhat regardless of the outcomes of input choice decision-making. Brennan (2010a) concluded that utilities will encourage energy savings or more usage under price caps depending upon whether the price is below or above marginal cost, respectively.

Since the US is widely adopting decoupling (revenue caps) whereas the EU is doing the same with price caps, it is an ongoing natural experiment that allows for comparisons of the consumer surplus and shareholder value performance (collectively, social welfare) from EU price cap utilities and US decoupled utilities. Since the EU has adopted price caps and US has adopted decoupling, the data are not available to include EU decoupled utilities in this investigation.

Since decoupling, as a regulatory policy tool, is being adopted rapidly in the US {Edison Electric Institute, the US electric utility trade association, EEI (2015)}, questions arise in rate proceedings regarding the impacts on the cost of common equity. Due to the importance of this issue and the lack of related literature, we investigate the impact of decoupling on the investor perceived risk of public utilities and resultant cost of common equity. The next section discusses the models that are the basis of the analysis. Section 3 discusses the empirical methodology. Section 4 describes the data. Section 5 discusses the results and Section 6 provides concluding remarks, policy recommendations and areas for future research.

2. The modeling approach

This paper uses the GCAPM developed by Michelfelder and Pilotte (2011) to estimate the impact of decoupling on the public utility cost of common equity. The model is based on generalizing variants of intertemporal capital asset pricing models. The literature discussing the development of the model based on more restrictive versions is voluminous and summarized by Michelfelder and Pilotte (2011) and therefore not repeated here. The GCAPM was empirically applied by Michelfelder and Pilotte (2011) to the full spectrum of assets on the US Treasury yield curve. The GCAPM is a financial valuation model recently developed as an alternative to the CAPM and the dividend discount model for estimating the cost of common equity. Ahern et al. (2011) and as Michelfelder (2015) review and apply the GCAPM to estimate public utilities' cost of common equity.

The GCAPM model has the following characteristics. It does not have restrictions on the coefficient of risk aversion in investors' utility function as do most models. It allows for a negative relation between the rate of return and volatility.[6] This relation will occur for assets with prices that move in the opposite direction of the business cycle. Unlike the CAPM, the GCAPM prices the total risk actually faced by the investor and does not assume that all unsystematic risk is diversified away, which is a key foundation of the standard CAPM. There is no perfect portfolio that removes all idiosyncratic risk as assumed in the development of the CAPM. Unsystematic risk is reduced but not completely mitigated with a highly diversified portfolio and the standard CAPM understates the cost of common equity as it does not price all risk exposure. The priced risk in the GCAPM is based on the level of risk actually faced by the investor, not the risk theoretically imposed by the CAPM. Fama and French (2004) find that the CAPM understates returns and risk, based on a large empirical study of portfolios of common stocks with a continuum of low to high betas. The GCAPM also does not assume or require the efficient markets assumption as does the CAPM.

Ahern et al. (2011) find that the CAPM generates lower costs of common equity than the GCAPM. Michelfelder (2015) applied the GCAPM to estimate the cost of common equity to public utilities concluding that the CAPM does not price all risk faced by the investor and that the CAPM understates the cost of common equity for public utilities. The GCAPM is specified as:

$$E_t[R_{i,t+1}] - R_{f,t} = -\frac{vol_t[M_{t+1}]}{E_t[M_{t+1}]} vol_t[R_{i,t+1}] corr_t[M_{t+1}, R_{i,t+1}], \quad (1)$$

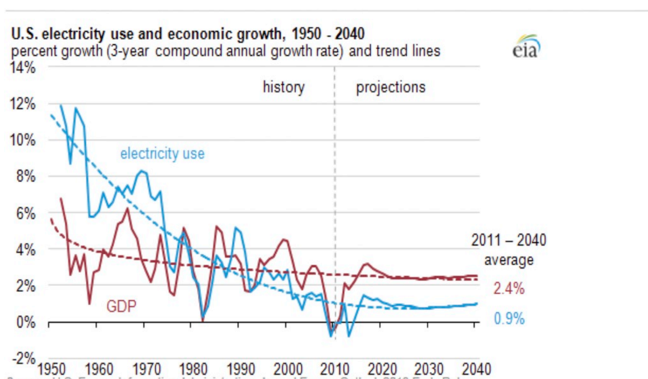
where the anticipated risk premium on an asset i depends on the conditional volatility of the asset; $R_{i,t+1}$ is the ex ante return on asset i; $R_{f,t}$ is the rate of return on a risk-free asset at time t; M_{t+1} is the stochastic discount factor (SDF); vol_t is the conditional volatility of the rate of return; and $corr_t$ is the conditional correlation coefficient. The SDF is the intertemporal marginal rate of substitution in consumption, which is the ratio of expected future marginal utility to the current marginal utility of consumption. This is an important factor to discuss as this model specification allows for the empirical estimation to determine if decoupling results in more stable revenues for utilities relative to changes in the business cycle. If this holds true for a utility during a recession, then investment in the common stock of public utilities could be a business cycle hedge. The SDF is:

$$M_{t+1} = \left(\frac{1}{1+k}\right)\frac{U_{c,t+1}}{U_{c,t}}, \quad (2)$$

where the U_c's are the marginal utilities of consumption and k is the discount rate for the period from t to $t+1$. The ratio M_{t+1} rises if expected future consumption falls below the current level due to the standard concave (to the origin) shape of investors' consumption utility function. This property allows the model to accommodate the business cycle (represented by consumption expenditures) hedging property of a given asset.

If the conditional volatility of intertemporal consumption, or consumption risk, rises, investors will price a greater risk premium into the asset. The sign of the relation between risk premium and its conditional volatility is defined by the correlation ($corr_t$) of the risk premium and the SDF. The sign of the risk premium-to-volatility relation is opposite to the sign of the correlation of the asset return and the ratio of the marginal utilities. A decline in business cycle consumption increases investors' marginal utility. An asset that generates positive returns

(footnote continued)



[6] It seems counterintuitive, yet some investors are willing to pay (give up return) for more volatility in an asset's return rather than less, if the pattern of that volatility is desired by those investors. Some researchers confuse risk and volatility as synonymous. For example, gold returns have a tendency to spike upward during recessions and downturns in stock markets. Thus, gold can hedge the downturn in an investor's portfolio and offset the reduction in income from employment. Systematic upward spikes in gold prices increase volatility. Such increases in volatility are generally associated with reductions in the market returns to gold. Such assets with negative relations among returns and volatility are business cycle hedges.

when the business cycle is in a contraction with falling consumption, is a business cycle hedge. Therefore, a negative risk premium-to-volatility slope identifies the asset as a business cycle hedge.

This property allows us to infer whether decoupling causes a public utility common stock to be a business cycle hedge. If profits rise or are flat as GDP declines with lower commodity sales and stable revenues, the common stock price could systematically rise when the business cycle is contracting.[7] A public utility with a strong level of decoupling would conceivably experience stable revenues during a contraction in the business cycle. Therefore, utility profits may rise, or at least not fall, when commodity sales fall generated by consumer end-use efficiency and contracting GDP.

To calibrate the GCAPM, we perform a simple test of this property by estimating the model with the risk premium on gold (percent change in the price of gold per troy ounce minus a risk-free rate). Gold is commonly known to be a business cycle and common stock market hedging asset {Hillier et al. (2006)}. The correlation coefficient between the quarterly percent changes in the price of gold and real GDP (data are publicly available from the St. Louis Federal Reserve Database) from 1968 to 2017 is −0.058. Hillier et al. (2006) show that gold is a common stock market hedge, especially during abnormally high periods of common stock market volatility. We used the daily and monthly US gold commodity cash price data and futures price data to estimate the GCAPM. The risk-premium-to-volatility slope "α" (see footnote 10) is either negative and significant or insignificant using daily and monthly data and many rolling time frames for estimation. These calibration test results for the GCAPM show that the model does detect a hedging asset.[8]

The GCAPM can be applied to any asset that is traded in any financial market and therefore can be applied to all traded public utility common stocks. The GCAPM has the added advantage that the decoupling impact on changes in common stock returns as well as the conditional volatility of these returns can be estimated separately within the same model using the GARCH-in-Mean (GARCH-M) method initially developed for asset model estimation. The GARCH-M method is discussed in the next section.

Decoupling is expected to lower the variance of the operating cash flows of a public utility due to the increased stability of revenues {Moody's (2011)}. The variance of operating cash flows should be driven mainly by the variance of costs as follows: Operating Cash Flows (*OCF*) is Revenues (*R*) – Cost (*C*), therefore the variance of *OCF* is *VAR (R-C) = VAR (R) + VAR (C) + 2COV (R,C)*. Since the volatility of revenues is theoretically equal to zero with decoupling, the covariance of revenues and costs is zero as revenues do not vary, and volatility of *OCF* is purely driven by costs only as *VAR (R-C) = VAR (C)*. Therefore, in comparing the variance of operating cash flows with and without decoupling, the *VAR (OCF with decoupling) = VAR (C) < VAR (OCF without decoupling) = VAR (R) + VAR (C) + 2COV (R,C)* as *VAR (R) = 0* and *COV (R,C) = 0* with decoupling and *VAR (R) > 0* and *COV (R,C) ≠ 0* without decoupling. This is essentially the model used by Moody's (2011) which found that utilities with decoupling experienced a reduction in business risk as measured by the change in the standard deviation of the growth rate in gross profit before and after decoupling.

We also estimate changes in systematic investment risk resulting from decoupling by analyzing the change in the short-term CAPM beta. This short-term beta (12-month), a measure of systematic risk, should be more sensitive to regime changes for a common stock relative to the standard betas estimated with five years of data typically employed to assess investment risk. Beta is expected to decline with decoupling.[9]

The only other studies on the impact of decoupling on the utility cost of capital, Wharton and Vilbert (2015), estimated the impact of decoupling on the cost of capital for the overall electric and gas utility industries. They also addressed the issue that decoupled utilities may represent substantially less than the entire portfolio of assets reflected in the common stock price of a holding company. Using the standard dividend discount model to estimate the cost of common equity portion of their weighted average cost of capital estimates, they regressed this cost of capital on an intensity index of decoupling for each publicly-traded utility common stock with a panel-data regression to estimate the industry impact. They found no statistically significant impact of decoupling on the cost of capital.

The present study estimates the impact on the cost of common equity of the decoupled firm individually rather than that on an industry as a whole. We use the GCAPM and changes in beta before and after the implementation of decoupling to estimate the impact on risk and the cost of common equity.

3. Methodology

The GCAPM is estimated with the GARCH-M method.[10] GARCH-M specifies the conditional risk premium as a linear function of its conditional volatility, which is the specification of the GCAPM in equation (1). Since the returns data contains ARCH effects (available on request), another benefit of using GARCH-M is that it improves the efficiency of the estimates. Engle et al. (1987) developed the GARCH-M method and used it to estimate the relation between US Treasury and corporate bond yield risk premiums and their volatilities.

Two versions of the GCAPM-GARCH-M model are estimated. The first estimation includes a binary variable that reflects the implementation of decoupling for the specific utility ($D_i = 1$ if decoupled, 0 otherwise) in the risk premium equation only and the volatility equation the same:

$$R_{i,t+1} - R_{f,t} = \alpha_{i,t}\sigma_{i,t+1}^2 + \alpha_{i,D}D_{i,t} + \varepsilon_{i,t+1} \tag{3}$$

where "αi, D" is an estimate of the decoupling impact on the risk premium.

The second estimation has the same variable in the volatility equation of the GARCH-M model only and the return equation does not (as shown in footnote 10 in the second set of equations):

$$\sigma_{i,t+1}^2 = \beta_0 + \beta_1\sigma_{i,t}^2 + \beta_2\varepsilon_{i,t}^2 + \beta_{i,D}D_{i,t} + \eta_{i,t+1} \tag{4}$$

[7] One of the most effective "energy efficiency tools" to generate energy use reduction is a recession. Although the energy-use-US-GDP correlation has declined, it remains substantially positive {EIA (2013), as shown in the figure in footnote 4 above, www.eia.gov/todayinenergy/detail.php?id=10491}.

[8] All empirical results on gold are available on request.

[9] Systematic risk is defined as $\beta_i = \rho_{i,m}\ \sigma_i/\sigma_m,$ where $\rho_{i,m}$ is the correlation coefficient of the individual stock (*i*) and the market (*m*) total rates of return and σ_i and σ_m are the standard deviations of the individual stock and market returns, respectively. Defining variables with superscript "*D*", to denote decoupling, σ_i^D and $\rho_{i,m}^D$ should be lower as the volatility of the utility's returns are lower with decoupling and the utility's return has a lower correlation with the market return as the utility's revenues and profits are decoupled from the business cycle. Therefore systematic risk is lower with decoupling and defined as $\beta_i^D = \rho_{i,m}^D\ \sigma_i^D/\sigma_m$. Therefore, β_i^D is less than β_i as.

$$\rho_{i,m}^D\sigma_i^D/\sigma_m^D \ < \ \rho_{i,m}\sigma_i/\sigma_m$$

[10] The GCAPM was estimated with the GARCH-M method. The estimated models are.

$$R_{i,t+1} - R_{f,t} = \alpha_{i,t}\sigma_{i,t+1}^2 + \alpha_{i,D}D_{i,t} + \varepsilon_{i,t+1}$$

$$\sigma_{i,t+1}^2 = \beta_0 + \beta_1\sigma_{i,t}^2 + \beta_2\varepsilon_{i,t}^2 + \eta_{i,t+1},$$

And $R_{i,t+1} - R_{f,t} = \alpha_{i,t}\sigma_{i,t+1}^2 + \varepsilon_{i,t+1}$

$$\sigma_{i,t+1}^2 = \beta_0 + \beta_1\sigma_{i,t}^2 + \beta_2\varepsilon_{i,t}^2 + \beta_{i,D}D_{i,t} + \eta_{i,t+1}.$$

where "βi, D "is an estimate of the decoupling impact on the volatility of the risk premium.

These specifications provide separate empirical estimates of the impacts of decoupling on conditional public utility common stock returns and conditional volatility. As event studies, these and all financial market-based event studies face the question of when the event impacted asset prices. Asset prices can reflect forthcoming events before they are implemented. One example that is relevant for this investigation is when decoupling implementation was announced in a utility's regulatory decision. We find that using the date of implementation is a conservative approach to estimating the impact as it is most likely the latest date that a decoupling impact would be detected in a common stock price and much of the impact may already have been priced in the asset. However, if a utility's revenues have been decoupled from sales to the extent that revenues are not affected by the business cycle, then the utility's common stock as a hedging asset would be detected in a zero or negative alpha. Also, if a sufficiently long pre-decoupling time period for observing returns and volatility is obtained, the change in the post-period should be detected as all of the post-decoupling period returns and volatilities are in a different business risk regime.

4. Data

We perform the empirical work on US utilities only. As discussed in the Introduction, decoupling has not been adopted in the EU. EU investor-owned utilities and their regulators have widely adopted price cap regulation, an alternative form of regulation to rate-base-rate-of-return regulation to promote expense and investment efficiency, but not necessarily to encourage utility expenditure on consumer end-use energy and water efficiency. The group of US public utility common stocks includes all electric and gas combination companies that have 95% or more of their revenues decoupled and water utility common stocks that have all of their revenues decoupled before 2014. Data for the common stock rates of return are the total monthly rates of return on the common stock of the public utilities from the Center for Research in Security Prices database (CRSP) of the University of Chicago. Data for each public utility common stock include differing pre- and post-decoupling dates and therefore differing rate of rate and beta samples. The pre-decoupling data for each common stock include all available past monthly returns data in the CRSP before decoupling for that common stock. Post-decoupling rate of returns data for all common stocks end at December 2014 for consistency in the post-decoupling ending period for all utility common stocks. We calculated historical monthly common stock equity risk premiums monthly common stock returns less the monthly yields on long-term U.S. Treasury Bonds for the selected publicly traded water utilities using common stock returns data from the CRSP database and Morningstar (2015) SBBI® 2015 Market Results for Stocks, Bonds, Bill and Inflation 1926–2015 and the Federal Reserve Statistical Release H.15 for long-term Treasury bond yields. The CAPM beta data include all short-term betas available for each public utility common stock that has been decoupled in the CRSP database and ends at 2014. They are available on an annual basis. The CAPM short-term beta[11] is a one-year estimate of beta that approximately involves regressing daily rates of return on the public utility common stock on a market index as shown footnote 10. The standard beta available from financial firm databases such as Value Line Investment Survey or CRSP is a 5-year beta based on regressing monthly or weekly common stock rates of return for the past 5 years on a market index. We find that the longer-term beta would be less sensitive to regime changes in risk such as decoupling. We restrict the sample of pre- and post-decoupling betas for each common stock so that the number of beta observations are the same before and after decoupling.

Since the number of data observations has different times series of ranges for each public utility common stock and decoupling occurred on different dates for most utilities, we have developed Table 1 to show each public utility common stock's data date range, that is, the dates and number of risk premium (rate of return minus risk-free rate) observations used to estimate the GCAPM and the total number of betas used for the pre- and post beta comparison. Table 1 also has the date of decoupling for each public utility.

5. Results and discussion

Table 2 presents the public utility common stocks in the study and the empirical results of the GCAPM estimates. The risk-premium-to-volatility slopes ("alpha") are shown along with the decoupling slope in the risk-premium and volatility equations for each electric, electric and gas combination, and water utility common stocks. The decoupling slope in the risk-premium equation will be negative (positive) if the risk premium should decline (rise) and decoupling creates a reduction (increase) in business risk. None of these slope estimates are statistically significant. The decoupling slope in the volatility equation should be negative (positive) if decoupling caused a reduction (increase) in the volatility of the profit of the utilities. Two of the slopes are negative and significant at $p = 0.10$, yet the magnitudes of the slopes are very small.

All of the alphas, except for one of the energy utilities are positive and significant, yet none in the water utility group are significant. These results indicate that the energy utility common stocks are not business cycle hedging assets and that their profits are synchronized with the business cycle. The results for the water group may indicate that they are business cycle hedging assets as none are statistically significant. The zero value for alpha implies that there is no relation between the business cycle as represented by expected changes in consumption and the return on water utility common stocks. Water utility profits are not correlated with the business cycle even in the absence of decoupling. Also, water use attrition is occurring across the US as households (water consumption per household is declining) due to the use of water-efficient appliances (such as low-flow faucets, showerheads and efficient toilets) and the change per capita water use habits to conserve water.

Table 3 presents the pre- and post-decoupling changes in the systematic risk as represented by the short-term CAPM beta for all of the public utility common stocks. The betas drop after the implementation of decoupling but none of the changes in beta are statistically significant using a t-statistic at a $p = 0.05$. Additionally, the standard errors of the betas (σ_{pre} and σ_{post}) show no consistent pattern of increasing or decreasing after decoupling.

Our results do not show any statistically significant impacts of decoupling on the cost of common equity and risk. Therefore, we find no evidence to conclude that decoupling affects investor perceived risk or the cost of common equity. While electric and gas public utility common stocks were not found to be business cycle hedges, we do find that water utility common stocks may be business cycle hedges.

Our results are based on the moderate amount of data available to date. Although we would obviously prefer more data than are available at this juncture, there is no time to wait for a larger volume of data. Regulators and utilities have been and are implementing policy now as if decoupling does reduce risk and the costs of capital without any

[11] The CRSP short-term beta is described by CRSP as "a statistical measurement of the relationship between two time series, and has been used to compare security data with benchmark data to measure risk in financial data analysis. CRSP provides annual betas computed using the methods developed by Scholes and Williams (Myron Scholes and Joseph Williams, "Estimating Betas from Nonsynchronous Data," *Journal of Financial Economics*, vol 5, 1977, 309–327). Beta is calculated each year as follows where.

$$\beta_i = \frac{\Sigma(lr_{i,t} * M3_t) - \left(\frac{1}{n_i}\right) * (\Sigma lr_{i,t}) * (\Sigma M3_t)}{\Sigma(lM_t * M3_t) - \left(\frac{1}{n_i}\right) * (\Sigma lM_t) * (\Sigma M3_t)}$$

Table 1
Data description for risk premiums and betas.

Electric, Elec. & Gas Comb. Utility	Effective Decoupling Date	Beginning of Measurement Period Returns Data	Total # of Months Return Data	Total Number of Pre- and Post- Annual Beta Observations
Consolidated Edison	10/2007	07/30/02	126	10
Pacific Gas & Electric	01/1983	01/31/53	720	60
Edison International	01/1983	01/31/53	720	60
CH Energy Group	07/2009	01/31/06	84	6
CMS Energy Corp.	05/2010	9/30/07	64	6
Hawaii Electric	12/2010	11/30/08	50	5
Portland General Electric	12/2010	11/30/08	50	6
Idaho Power	03/2007	05/30/01	140	12
Water Utility				
American States Water	1/2002	6/2002	153	12
California Water	1/2009	10/2001	162	12
Connecticut Water	7/2008	10/2002	150	10
Artesian Resources	11/2008	6/1996	226	12

Table 2
GCAPM estimation results.[a]

Electric, Elec. & Gas Comb. Utility	α_i	α_D	β_D
Consolidated Edison	1.460***	0.004	−0.000
Pacific Gas & Electric	1.781***	0.001	−0.001
Edison International	1.379***	0.003	0.000
CH Energy Group	2.094***	0.004	−0.000
CMS Energy Corp.	1.440***	0.011	−0.000
Hawaii Electric	1.607***	0.004	−0.000*
Portland General Electric	0.461	0.010	−0.000
Idaho Power	1.939***	0.003	−0.000
Water Utility	α_i	α_D	β_D
American States Water	0.596	0.011	0.000
California Water	0.525	0.004	−0.000
Connecticut Water	−1.008	0.009	0.000
Artesian Resources	3.006	−0.004	−0.002*

[a] The GCAPM was estimated with the GARCH-M method. The estimated models are.

$$R_{i,t+1} - R_{f,t} = \alpha_{i,t}\sigma^2_{i,t+1} + \alpha_{i,D}D_{i,t} + \varepsilon_{i,t+1}$$

$$\sigma^2_{i,t+1} = \beta_0 + \beta_1\sigma^2_{i,t} + \beta_2\varepsilon^2_{i,t} + \eta_{i,t+1},$$

And $R_{i,t+1} - R_{f,t} = \alpha_{i,t}\sigma^2_{i,t+1} + \varepsilon_{i,t+1}$

$$\sigma^2_{i,t+1} = \beta_0 + \beta_1\sigma^2_{i,t} + \beta_2\varepsilon^2_{i,t} + \beta_{i,D}D_{i,t} + \eta_{i,t+1}.$$

Table 3
Changes in systematic risk from decoupling. [a]

	Mean β_{PRE}	Mean β_{POST}	σ (β_{PRE})	σ(β_{POST})	t-Statistic
Electric, Elec. & Gas Comb. Utility					
Consolidated Edison	0.608	0.427	0.172	0.064	−1.329
Pacific Gas & Electric	0.522	0.535	0.174	0.373	0.112
Edison International	0.588	0.582	0.199	0.294	−0.051
CH Energy Group	0.680	0.401	0.279	0.326	−0.759
CMS Energy Corp.	0.758	0.559	0.198	0.140	−0.815
Hawaii Electric	0.619	0.570	0.253	0.155	−0.171
Portland General Electric	0.637	0.658	0.069	0.052	−0.151
Idaho Power	0.905	0.728	0.251	0.125	−0.818
Mean	0.670	0.560			
Water Utility					
American States Water	0.975	0.623	0.535	0.279	−1.430
California Water	1.192	0.520	0.544	0.257	−2.735***
Connecticut Water	0.664	0.502	0.235	0.176	−1.232
Artesian Resources	0.075	0.146	0.100	0.161	0.909
Mean	0.434	0.475			

[a] Beta is the annual year-ending beta from the CRSP database. The data timeframe is different for each utility with an equal number of annual pre- and post-decoupling beta data observations for the specific stock in the CSRP database and ends in 2014. Each single beta was estimated with one year of daily rate of return data. See Table 1 and footnote 11. ***, **, * refers to statistical significance at 0.01, 0.05, and 0.10 respectively.

evidence that it does. This paper serves as an early warning signal, albeit with the limited evidence that is available.

6. Conclusion and policy implications

We conclude that decoupling has no statistically measurable impact on the cost of common equity based on our empirical analysis for electric, electric and gas, and water utility common stocks. Some researchers may view this result as a "non-result." This is an important finding as it is consistent with the empirical findings of Vilbert et al. (2016). It is also important for policy globally as decoupling is considered as a potential reducer to risk and the cost of common equity by regulators and public utilities in the US based on intuition, without any empirical evidence.

Moody's (2011) finds a reduction in business risk as measured by the change in the variability of gross profit after decoupling but did not estimate the impact on the cost of common equity. Moody's (2011) did find that electric utilities were somewhat reluctant to adopt decoupling as electric utility executives anticipated that growth in sales would return to the industry after the steep recession that ended with the business cycle trough in June 2009 {NBER (2018)}. Since the US business cycle expansion post-June 2009, electricity sales have remained almost flat, which may have caused the change in sentiment toward decoupling by electric utility executives. Growth in a utility's commodity sales above the level used to design regulated rates would increase the profit and rate of return on common equity. The US investor-owned electric utility industry also expected that the adoption of decoupling would cause state public utility regulators to reduce their allowed rate of return under the notion that it reduces risk. Moody's (2011) was written soon after the recession had ended, but the anticipated growth in sales has not materialized after more than ten years into the US business cycle expansion. A few years after the Moody's (2011) study, the EEI found in a more recent report a change in sentiment {EEI (2015)} that electric utilities favor decoupling and that it has become more widespread across the US.

We conclude that decoupling has no statistically significant impact on investor perceived risk and the cost of common equity. This does not mean necessarily that decoupling has no impact on the perceived risk and the cost of common equity of public utilities. We find that it cannot be isolated and estimated, given the many other factors affecting investor perceived risk. For many electric utilities, some current major risk drivers are flat or declining sales from customer-owned solar projects and energy efficiency resources; the requirement to buy back excess customer generated electric from renewable resources at full retail rates (net metering); increasing requirements in the proportion of a utility's sales that have to be generated from renewable energy, causing larger purchases of renewable energy credits (known as renewable portfolio standards that have been adopted by many states and across Europe); increasingly stringent environmental regulations on coal plants; and the impact of falling and low natural gas prices on the competitiveness of existing coal and nuclear plants.

For water utilities, we find their common stocks to be moderate business cycle hedges (no correlation with the business cycle rather than a strong negatively correlated hedge). Since water utility sales are declining on a per capita basis and unassociated with the business cycle, decoupling may provide financial protection if water revenues decline. To the extent that there is positive growth in the number of water utility customers that offsets the declining per capita consumption, total revenues and sales may not be falling. The impact of decoupling on water utility investment risk and cost of common equity was not able to be detected in this study. This is the first study on decoupling in the water utility industry and an area for future research.

Another explanation for the lack of detection of a change in risk or the cost of common equity from decoupling is that risk may be created with the implementation of decoupling and the net impact may not be clear as an increase or decrease in risk as Vilbert et. al. (2016) and Wharton and Vilbert (2015) concludes. They find that the implementation of decoupling is a new and alternative regulatory regime that may be a new source of regulatory risk for the utility. Finally, as discussed in detail in the Introduction above, volume risk, that is, the fundamental nature of the business and business risk, is not alleviated by changing the reward mechanism, and attempts to do so may increase risk and the cost of common equity. The point is that there are cogent theoretical and practical bases to expect that decoupling increases or decreases risk, so it is problematic to develop an *a priori* hypothesis to test a one-way directional impact of risk and return from decoupling.

Therefore, we do not recommend that public utility regulators in the US or elsewhere reduce or increase authorized common equity cost rates in the presence of decoupling mechanisms based on the assumption of changed or reduced risk. The impact is *de minimis* and not statistically significant amongst all of the other investor perceived risk factors affecting the market prices of public utility common stocks. While an alternative research approach may attempt to isolate the impacts of other individual risk factors on the cost of common equity and risk, making for a long regression equation, we cannot detect a statistically significant signal of decoupling on the cost of common equity or volatility. As a contrast, for example, the risk and cost of common equity impact of owning nuclear power generation assets (versus no nuclear assets) has a measureable impact on investors' returns, risk and cost of common equity without attempting to isolate the myriad of other risk variable impacts. Decoupling as a regulatory policy mechanism to encourage public utilities to provide resources and funding to their consumers to conserve electricity, natural gas, and water (therefore also wastewater flows) has no *measurable* impact on the investment risk and the cost of common equity (either up or down). As a policy prescription, public utility regulators should not adjust the allowed rate of return which affects the public utility's rates as a spillover impact of using decoupling to promote environmental policy.

Finally, the US may be further ahead in adopting rate mechanisms that address energy and water efficiency due to its long-term lag relative to Europe in the efficient use of energy and water and the recent "necessity-is-the-mother-of-invention" US driver of energy and water efficiency. European and regulators globally should proceed slowly in adopting decoupling and assuming that decoupling reduces risk as there is no empirical evidence to date that it does.

An extension of this research could evaluate risk premiums or discounts in bond yields as there are many more investor-owned utilities which have outstanding bonds relative to those that have their own publicly traded common stock due to consolidation in the utility industry in the US. For example, Exelon is the holding company of six utilities whose stocks were publicly traded on the New York Stock Exchange. They are Atlantic City Electric, Baltimore Gas and Electric, Commonwealth Edison, Delmarva Power and Light, Philadelphia Electric and Potomac Edison Power. Another future extension could focus on decoupling when some EU investor-owned utilities and regulators, inevitably, adopt decoupling should it prove to substantially encourage more conservation in the US. An investigation of hedging costs and savings, risk impacts, and effects on profits with and without decoupling may shed more light on the topic. There also needs more research on water/wastewater decoupling as this is the first study known to date on the topic involving cost of capital and risk. Lastly, a social welfare comparison, separating out consumer-surplus and shareholder-value creation and investigating the impacts on conservation from price and revenue caps is another extension of this paper for future research.

Funding sources

The work contained in this research has received partial funding from the Rutgers University School of Business – Camden, Summer Research Program.

Acknowledgements

The authors thank the participants at the 2017 and 2018 Center for Research in Regulated Industries Eastern Conferences for helpful comments. They also thank two anonymous reviewers and an Energy Policy editor for their insightful comments.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.enpol.2019.04.006.where R_i is the conditional total return on the stock, R_f is the risk-free rate of return, $\sigma^2_{i,\ t+1}$ is the next period conditional volatility, D is the dummy variable that equals 1 when decoupling is in place, and α_D and β_D are the slopes on the conditional returns and volatility decoupling dummy variable that represent the impact of decoupling on those variables. Monthly returns data are from the CRSP database and includes all data available from the CRSP database and ends at 12/2014. The monthly risk-free rate of return is the Ibbotson income return on Long-Term US Treasuries. ***, **, * refers to statistical significance at p values of 0.01, 0.05 and 0.10 respectively.where R_i is the conditional total return on the stock, R_f is the risk-free rate of return, $\sigma_{2i,\ t+1}$ is the next period conditional volatility of the risk premium for asset *i*. $\varepsilon_{i,t}$ and $\eta_{i,t+1}$ are the error terms for the mean and volatility equations, D is the dummy variable that equals 1 when decoupling is in place for utility *i*, and α_D and β_D are the slopes on the conditional returns and volatility decoupling dummy variable that represent the impact of decoupling on those variables.

The parameter, α_i, is the risk-premium-to-volatility slope. It is specified from equation (1) as:

$$\alpha_{i,t} = -\frac{vol_t\,[M_{t+1}]}{E_t\,[M_{t+1}]} corr_t\,[M_{t+1},\ R_{i,t+1}]$$

It is positive for assets that are not business cycle hedges as $corr_t$ is negative. A rising (falling) M and rising (falling) expected marginal utility from falling (rising) consumption in a recession is associated with a fall (rise) in returns. The above empirical model specifies a 0 intercept in the risk premium equation as does the GCAPM. The estimation results support the 0 intercept specification (results available upon request).

β_i is the Beta for security i for the year being calculated, $r_{i,t}$ is the return of security i at day t, $lr_{i,t} = \ln(1+r_{i,t})$ is the natural log of the return of security i at time $t+1$ or the continuously compounded return, M_t is the value-weighted market return at time t, $lM_t = \ln(1+M_t)$ is the natural log of the value-weighted market return at time $t+1$ or the continuously compounded return.

$M3_t = lM_t\text{-}1 + lM_t + lM_{t+1}$ is the three-day moving window of the above market return, n_i is the number of non-missing returns for security i during the year, where the summations are over t and include all days on which security i traded, beginning with the first trading day of the year and ending with the last trading day of the year."

(http://www.crsp.com/products/documentation/index-definitions-calculations, accessed March 12, 2019.)

References

Ahern, P., Hanley, F.J., Michelfelder, R.A., 2011. New approach for estimating of cost of common equity capital for public utilities. J. Regul. Econ. 39, 261–278.
Brennan, T., 2010. Optimal energy efficiency policies and regulatory demand-side management tests: how well do they match? Energy Policy 38, 3874–3885.
Brennan, T., 2010a. Decoupling in electric utilities. J. Regul. Econ. 38, 49–69.
Campini, C., Rondi, L., 2010. Incentive regulation and investment: evidence from European energy utilities. J. Regul. Econ. 38, 1–26.
Carter, S., 2001. Breaking the consumption habit: ratemaking for efficient resource decisions. Electr. J. 14, 66–74.
Cavanaugh, R., 2013. Report: "Decoupling" is Transforming the Utility Industry. Natural Resources Defense Council.
Chu, L.Y., Sappington, D.E.M., 2013. Motivating energy suppliers to promote energy conservation. J. Regul. Econ. 49, 227–249.
Edison Electric Institute, 2015. Alternative Regulation for Emerging Utility Challenges: 2015 Update.
Engle, R.F., Lilein, D., Robins, R., 1987. Estimation of time varying risk premia in the term structure: the ARCH-M model. Econometrica 55, 391–407.
Eto, J., Stoft, S., Belden, T., 1997. The theory and practice of decoupling utility revenues from sales. Util. Policy 6, 43–55.
Fama, E., French, K., 2004. The capital asset pricing model: theory and evidence. J. Econ. Perspect. 18, 25–46.
Hillier, D., Draper, P., Faff, R., 2006. Do precious metals shine? An investor's perspective. Financial Anal. J. 62, 98–106.
Khazzoom, J.D., 1980. Economic implications of mandated efficiency in standards for household appliances. Energy J. 1, 21–39.
Khazzoom, J.D., 1987. Energy savings resulting from the adoption of more efficient appliances. Energy J. 8, 85–89.
Michelfelder, R.A., 2015. Empirical analysis of the generalized consumption asset pricing model: estimating the cost of common equity capital. J. Econ. Bus. 80, 37–50.
Michelfelder, R.A., Pilotte, Eugene A., 2011. Treasury bond risk and return, the implications for the hedging of consumption and lessons for asset pricing. J. Econ. Bus. 63, 582–604.
Moody's Investors Service, 2011. Decoupling and 21st Century Ratemaking. Special Comment.
Morningstar SBBI, 2015. Market Results for Stocks, Bonds, Bills, and Inflation 1926 - 2014. Appendix A Tables.
Nadel, S., Herndon, G., 2014. The Future of the Utility Industry and the Role of Energy Efficiency. American Council for an Energy Efficient Economy Report Number U1404.
National Bureau of Economic Research, 2018. NBER.org.
National Resources Defense Council, 2018. www.nrdc.org/resources/gas-and-electric-decoupling.
US Energy Information Administration, 2013. Annual Energy Outlook 2013 Early Release.
Vilbert, M., Wharton, J., Zhang, S., Hall, J., 2016. Effect on the Cost of Capital of Ratemaking that Relaxes the Linkage between Revenue and Kwh Sales, an Updated Empirical Investigation of the Electric Industry. A Brattle Group Report.
Wharton, J., Vilbert, M., 2015. Decoupling and the cost of capital. Electr. J. 28, 19–28.