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Analysis of Multi-period Investment under Regulation in the German Power Grid

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To my grandmother Christel Pallas

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List of Abbreviations

AReg	Anreizregulierung - Incentive Regulation
ARegV	Verordnung über die Anreizregulierung der Energieversorgungsnetze (Anreizregulierungsverordnung) - Incentive Regulation Rule
BDEW	Bundesverband der Energie- und Wasserwirtschaft e.V. - Federal Association for the Energy and Water Industry
BMWi	Bundesministerium für Wirtschaft und Technologie - Federal Ministry of Economics and Technology
BNetzA	Bundesnetzagentur - Federal Network Agency
CAPM	Capital Asset Pricing Model
EEG	Gesetz für den Vorrang Erneuerbarer Energien - Act on Granting Priority to Renewable Energy Sources
EEX	European Energy Exchange
EnLAG	Energieleitungsausbaugesetz - Law on the Extension of the Electricity Grid
EnWG	Gesetz über die Elektrizitäts- und Gasversorgung (Energiewirtschaftsgesetz) - Law on the Energy Industry
FCC	Federal Communications Commission
IRR	Internal Rate of Return
LRIC	Long-Run Incremental Costs
NEP	Netzentwicklungsplan - Grid Development Plan
NPV	Net Present Value
Ofgem	Office of the Gas and Electricity Markets
OLS	Ordinary Least Square

RBCA	Relative Benefit Cost Allocation
RPC	Relative Practical Capacity
RRC	Relative Replacement Cost
StromNEV	Verordnung über die Entgelte für den Zugang zu Elektrizitätsversorgungsnetzen (Stromnetzentgeltverordnung) - Electricity Price Rule
SMC	Short-Run Marginal Cost

1 Introduction

1.1 Motivation

The electricity industry in Germany faces huge challenges. Due to the scarcity of fossil energy sources and the public resistance to nuclear energy, renewable energy sources have expanded widely in the recent years and will continue to grow. Targets concerning the share of renewable energy sources have been formally stated by national governments and the European Union. In Germany, the Federal government, as recently as June, 2011, has passed laws following the repercussions of the nuclear catastrophe in Fukushima, Japan, in March, 2011. These laws mandate that 35 % of electricity must be generated with renewable energy by the year 2020.

The increasing importance of renewable energy necessitates the expansion of the existing electricity transmission grid.[1] Boldt et al. (2012) predict that the expansion of renewable energy sources, in particular off-shore wind energy, will lead to a mismatch of generation and consumption of electricity. It is estimated that by 2030, 63 % of all electricity requirement will be produced in northern Germany, whereas 62 % is expected to be consumed in southern Germany. The transmission grids will only be capable of transmitting electricity from the North to the South if extensive investments are made.

Insufficient investment in the electricity transmission grid can have severe consequences. While power blackouts in Germany have not yet been attributed to deficient grid investment, underinvestment in electricity transmission grids was considered the source of blackouts in the U.S., U.K., Italy and Scandinavia in 2001 and 2003.[2]

However, while future investment in the grid[3] is tremendously important in the context of the current challenges, investment decisions in the power grid differ significantly from

[1]This fact is acknowledged widely by public press as well as academic literature, see for instance Monopolkommission (2009), Stratmann (2012b) Brunekreeft and Meyer (2011) or Nykamp et al. (2012).
[2]See for instance Bialek (2004), von Hirschhausen et al. (2004), Joskow (2006a), Pollitt (2007) or Egert (2009).
[3]Throughout this thesis, the notions "grid", "electricity grid" and "power grid" are used as synonyms.

investment decisions in free markets. The power grid is a natural monopoly and hence the price for transmission and distribution is regulated. All investment decisions are therefore influenced by the actual regulatory policy.[4]

In Germany since 2009, a certain version of incentive regulation, the *Anreizregulierung* (AReg) has been in effect. The German AReg, as well as other general forms of incentive regulation, has been found to negatively affect investment.[5] In fact, it is doubtful whether the design of the AReg allows for an achievement of the pressing investment needs resulting from the energy turnaround in Germany. If this is true, then the German power grid will reach its full capacity soon. As a consequence, the energy turnaround cannot be achieved within the set time frame.

The purpose of this thesis is to conceptually analyze the influence of regulation on investment for the German AReg, and additionally to investigate it in a formal model. The specific research questions to be answered are formulated in more detail in the following section.

1.2 Research Questions and Contribution

The research questions to be answered in this thesis are as follows:

(1) How does the German incentive regulation (AReg) affect investment in the power grid?

(2) What effect does the actual price determination have on the affected company's investment decision when overlapping investments over multiple periods are considered in a cost-based price-cap regulation environment? What is the optimal price from the regulator's perspective?

The chosen methodological approach to answering the research questions is partly conceptual and partly analytical. The primary question concerning the influence of the German AReg will be discussed in a conceptual framework, whereas the questions concerning the price determination will be answered in a formal analytical model. The reasons for this choice are illustrated below.

[4]See for instance Laffont and Tirole (1993), Guthrie (2006), Friedl (2007), Cambini and Rondi (2010) or Rogerson (2011).

[5]The existing literature is reviewed extensively in chapter 3.

In the context of renewable energy expansion and the resulting necessity of grid investment, it has been recognized in public press as well as in academic literature[6] that there is a relationship between the AReg and the affected companies' investment behavior. In general, it is doubtful whether the AReg sets incentives for efficient grid investment. The conjecture that the AReg may hamper grid investment deserves an academic investigation.

However, neither an empirical study nor a formal model qualify as suitable options to investigate this conjecture. On the one hand, as the AReg was implemented only in 2009, the existing data are very scarce and hence insufficient for an empirical investigation of the relationship between AReg and grid investment. On the other hand, as the current design of the AReg is very complex,[7] a formal model accounting for all elements would most likely be insolvable and unable to show any specific effects. Consequently, a conceptual analysis of the very specific design of the German AReg and its effects on grid investment is the most appropriate methodological approach. This analysis contributes to the existing literature with a holistic analysis of this topic.

The use of a formal model to answer the second set of research questions can be reasoned as follows. The determining factors of a company's investment decision under the influence of regulation can best be analyzed with a formal model. This is because in such a model, on the one hand certain effects that are of particular interest for the research question can be isolated. Additionally, a formal model ignores disruptive factors that exist in the real world. For instance, as per the model employed in this research, the isolated effect of note is the influence of overlapping multi-period investment. In order to observe this effect, a formal model is the most appropriate methodological approach.

As for the contribution of this model to the field, there is no doubt that the influence of cost-based regulation on a company's investment behavior has already been analyzed widely and in great depth in existing research.[8] There is a large body of empirical, theoretical, conceptual as well as formal analytical research on this topic. Still, this thesis' model contributes another perspective to the existing analytical literature. This thesis is distinguished from prior research on grounds of the specific model setup employed. Figure 1.1 illustrates the model setup schematically.

Instead of analyzing isolated investments over single or multiple periods, the present model focuses on overlapping investments. This means that from one period to another,

[6] See section 2.3.4 for references.
[7] See section 2.3.2 for the actual design.
[8] For an overview see for instance Abel (1990), Kridel et al. (1996), Vogelsang (2002), Armstrong and Sappington (2007) or Cambini and Jiang (2009).

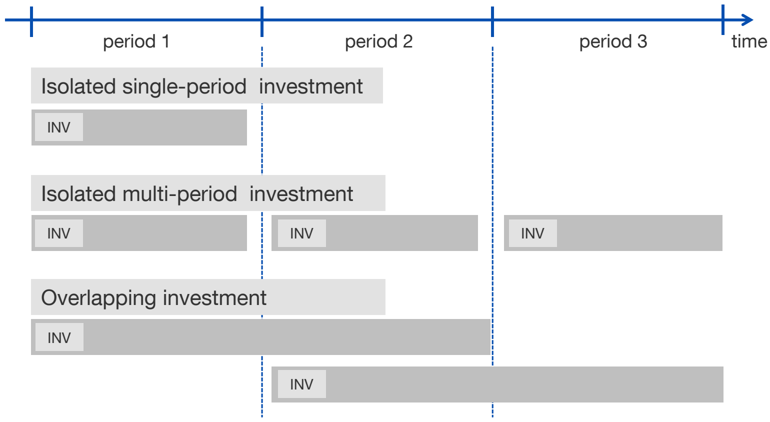


Figure 1.1: Distinction between isolated and overlapping investments.

productive capacity adds up[9] and hence, the company's fixed asset base increases. A change in the fixed asset base has consequences for the regulated price: important cost types, such as depreciation and interest on invested capital, depend entirely on the asset base. These costs are again the basis for the regulated prices in cost-based regulation. Consequently, increased capacity results in a different regulated price. This fact leads to significantly different model outcomes than in similar related analyses. Moreover, setting up the model as described can serve as a stylized model for the German AReg.

In summary, there are two dimensions of this thesis. The first is the question of how the German AReg affects grid investment, which will be investigated conceptually. The second dimension is the analysis of the aspect that several investments overlap, which is presented in a formal model.

1.3 Structure of Thesis

This thesis is structured as follows. Chapter 2 describes the background for regulation and investment in the German electricity grid. The electricity industry is briefly characterized, and the massive need for investment in the grid is elaborated. A description and classification of the German incentive regulation follows, together with a substantiated discussion on its known effects on investment.

Chapter 3 comprises an extensive review of literature on regulation and investment.

[9]In the context of this thesis, capacity is equal to the maximum number of units of a product or service the company offers. For the power grid, this can be the length of transmission lines.

First, empirical studies are reviewed, which show the relevance of the topic. Second, theoretical and conceptual research is discussed analyzing the relation between various forms of regulation and investment, with a focus on incentive regulation. Third, formal analytical models are illustrated from which the research question to be answered in the developed model is finally derived. Fourth, the literature review is enhanced by a discussion of important selected issues in the context of regulation and investment.

The subsequent chapter 4 illustrates the formal model. As mentioned before, the model focuses on overlapping investments under cost-based price-cap regulation. The model exhibits that accounting for overlapping investments results in a different optimal price than the optimum determined in earlier literature. Two extensions of the basic model are developed, in which earlier assumptions are relaxed.

Chapter 5 provides the final conclusion of the thesis. To this end, the results are summarized and their contribution to the existing literature is demonstrated. The thesis ends with thoughts and recommendations for an extension of the analysis and future research.

2 Background for Regulation and Investment in the German Power Grid

The purpose of this chapter is to illustrate the general background for the analysis. As the focus is on the regulation of the power grid, state of the electricity industry is first described in order to create a common understanding of the product, the industry and its players. Second, the massive necessity for investments in the power grid is demonstrated, which emphasizes the need to set efficient investment incentives. However, investment in the power grid differs significantly from investment decisions in an unregulated industry as the cash inflows depend on regulated prices. Therefore, in a third part the AReg, the currently effective regulation of the power grid in Germany, is described, and existing findings on the relationship between the AReg and investment are discussed.

2.1 Description of the German Electricity Industry and its Grid

2.1.1 General Description of the Electricity Industry

In this section, the electricity industry as a whole and the product "electricity" are characterized briefly. An more extensive illustration and analysis of the electricity industry can be found in Hammer (2011).

Distinctive features of the product electricity

Electricity is a crucial part of modern society. Both society and economy are strongly dependent on a reliable and secure electricity supply.[10] A major claim in the German law on the energy industry (*Gesetz über die Elektrizitäts- und Gasversorgung* or short *Energiewirtschaftsgesetz - EnWG*), section 1, is that a secure, non-expensive, customer-friendly, efficient and environmentally friendly supply with electricity must be guaranteed to the general public.

Distinctive features of the product "electricity" can be found in many books and articles. The illustration here mainly follows Jamasb and Pollitt (2007). Electricity is homogeneous, grid-bound, largely non-substitutable, and largely non-storable. It can be classified as homogeneous since there are no objective quality differences that would be a requirement for classification as a heterogeneous product. This is apart from subjective quality features like *Ökostrom* (ecological electricity), which is produced only with renewable energy sources.

A grid is necessary to transmit and to distribute electricity, and every market participant needs access to the network. Although electricity is grid-bound there is no need for generation and consumption to be geographically close together, because transmission over long distances does not result in major loss. Hence, there is no physical barrier, for instance, to producing electricity in the north of Germany and consuming it in the south.

Since electricity plays an important role in private, public and economic life, it is indispensable to industrialized countries like Germany. There is no real substitute for electricity, which is a very distinct feature. In contrast to electricity, other secondary energy sources are at least partially substitutable: for instance, instead of natural gas, gasoline or fuel oil can be used. The non-substitutability is also reflected in the very inelastic demand for electricity: demand will not change significantly for an increase of the electricity price.

In general, electricity is non-storable at a large scale.[11] This results in the fact that demand and supply must always match, which is a huge challenge for the system. However,

[10] On November 15, 2012 at around 7 a.m., Munich faced a power blackout of about 30 minutes. Although it was possible to fix the blackout quickly in most parts of the city, the blackout caused massive and major distortions, especially for traffic and public transport. In particular people commuting to work and students commuting to school were affected, since underground trains could not run for a certain time, and traffic lights stopped working.

[11] In recent years, new electricity storage possibilities have been developed like large powerful batteries or hydrogen storage options. For an overview see e.g. VDE Association for Electrical, Electronic & Information Technologies (2008).

a supply backlog or gap can be balanced via the European Energy Exchange (EEX).[12]

Recent developments and status quo in the electricity industry

In the past, electricity providers were large, vertically integrated companies, which combined all parts of the value chain: generation, trade, transport and sales. The complete value chain in the electricity industry is shown in Figure 2.1.

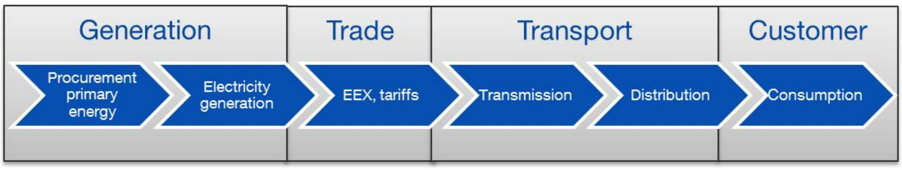


Figure 2.1: Value chain in the electricity industry.[13]

These large, vertically integrated companies were often closely controlled by the government. Since the mid-1980s, a global trend could be observed towards a liberalization of network industries, among them the electricity industry.[14] In Germany, the 1998 amendment to the EnWG (law on the energy industry) allowed for a liberalization of the industry.

In Germany, four large energy companies developed: EnBW, E.ON, RWE and Vattenfall.[15] In order to counteract their tremendous market power, the EU decided that unbundling of these companies was necessary. This requirement was passed as a formal directive in 1996.[16] It states that the large vertically integrated companies were legally required to be split up into parts responsible for generation, transmission (high voltage network) and distribution (medium and low voltage network). In order to comply with the unbundling requirement, the companies first founded legally independent subsidiaries only for their transmission networks. Later, when the EU further mandated not just legal unbundling, but also separate ownership, these subsidiaries were sold to independent

[12]Similar to the stock exchange, the EEX is an organized futures, options and spot market for electricity. According to its website, 267 participants from 22 countries operate on the EEX.
[13]Source: Own illustration.
[14]The development started mainly in the United Kingdom. For a historical perspective, see for instance Vogelsang (2002) or Crew and Kleindorfer (2002).
[15]For some more details on the market participants see section 2.1.2.
[16]Directive 96/92/EC of the European Parliament and of the Council of 19 December 1996 concerning common rules for the internal market in electricity.

transmission grid operators. However, while being independent, the regions in which the grid companies operate coincide with the regions in which the large power supply companies operate. Whereas electricity generation is considered largely competitive, the network still remains a local monopoly.

The most recent development in the industry is the so-called *Energiewende* (energy turnaround), which strongly affects all market participants, in particular the four big players. Since the 1970s, there has been some public opposition to nuclear energy plants. In the year 2000, the German government decided a stepwise phase-out of all German nuclear power plants.[17] In contrast to this, in 2010 the German government under Angela Merkel enacted a life-span extension of certain nuclear reactors. This decision was withdrawn shortly after under the growing public opposition against nuclear power plants after the earthquake disaster in Fukushima (Japan) in March, 2011.

In 2010, nuclear power plants still provided 28.4 % of the consumed electricity in Germany.[18] Due to the scarcity of fossil energy and rising concerns about carbon dioxide emissions, this gap cannot be bridged with coal or gas plants in the long run. A massive increase in renewable energies is necessary. To this end, large investments are crucial, both in energy generation and in transmission and distribution capacities. The implications of the energy turnaround for investment in the industry and particularly in the network are illustrated in section 2.2.

Characteristics of investment in the power grid

The electricity industry mostly involves large power plants as well as thousands of kilometers of transmission and distribution networks. For instance, according to the *Netzentwicklungsplan 2012* (Grid Development Plan), the German distribution network is about 35,000 km long (ca. 21,700 miles).[19] Hence, in terms of generation as well as in terms of transmission and distribution, the industry is highly capital intensive and most of the assets are sunk upon investment. The characteristics of network investment have been analyzed by many authors, see for instance Pindyck (1991), Pindyck (2007) or Friedl (2007).

At the same time, assets have a long useful life of over 20 years. Hence, any investment is long-term oriented by its nature and the decision cannot be made lightly. Whereas in the

[17] The relevant treaty between the German government under chancellor Gerhard Schröder and the affected energy companies is known as *Atomkonsens* (nuclear consensus).
[18] Statistics on such numbers can be found through the provider Statista GmbH.
[19] See Übertragungsbetreiber (2012), p. 10. The NEP is explained in more detail in section 2.2.1.

past, long-term planning was fairly easy for the electricity companies, they face a changed environment today. This is due to regulatory and political changes such as the energy turnaround or the introduction of incentive regulation, as well as new technologies such as storage options or smart grids.

2.1.2 Market Participants in the Power Grid

In order to provide the reader with an understanding of the market structure and its players, the market participants are illustrated briefly in this section.

The four transmission network operators in Germany are 50Hertz, Amprion, TenneT TSO and Transnet BW.

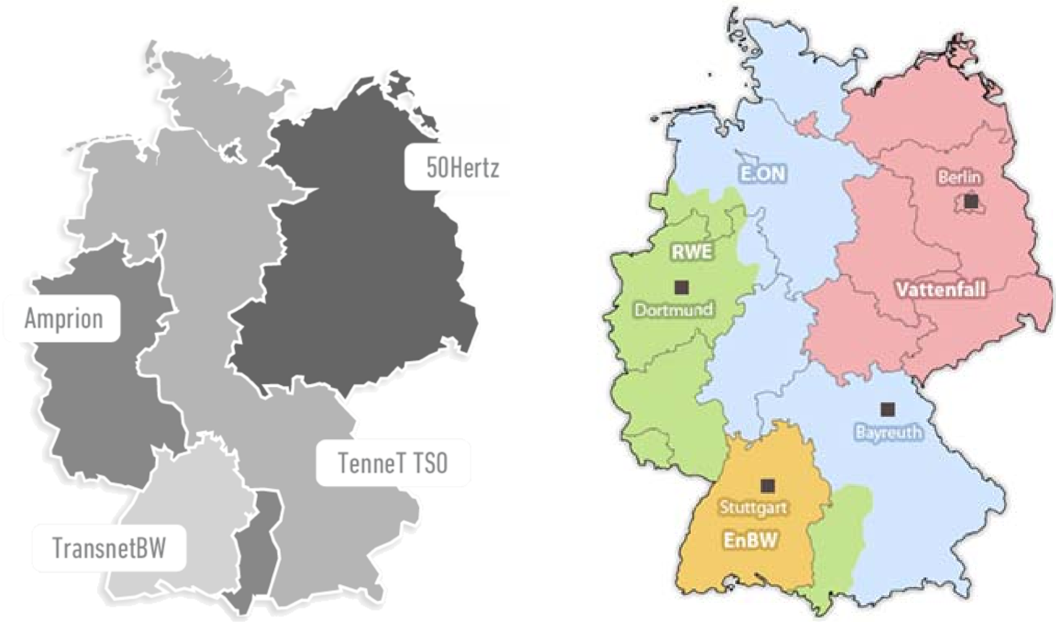
- 50Hertz Transmissions is the former transmission network of Vattenfall Europe and was sold to the Belgian grid operator Elia and an Australian infrastructure fund in 2010. 50Hertz operates mainly in Eastern Germany.
- Amprion belonged to RWE until 2011 when it was sold to a consortium of investors. It mainly covers the west of Germany, in particular the German states of Nordrhein-Westfalen, Rheinland-Pfalz, Saarland, plus the Bavarian administrative district Schwaben.
- The largest transmission grid operator is TenneT TSO which belongs to the Dutch network operator TenneT. It covers the part of Germany in which E.ON operates, and the transmission grid belonged to E.ON until 2009.
- TransnetBW was denoted EnBW Transportnetze AG until March 2012. In contrast to the other transmission grid operators, which are not subsidiaries of the power supply companies any more, TransnetBW fully belongs to the parent company EnBW.

Figure 2.2 depicts the German regions in which the four companies operate, compared to the four big generation companies. Evolved over time, the areas are superposable.

Individually, the four transmission grid companies operate as local monopolists.[20] Their operations are completely independent from the others and they do not have to fear mar-

[20] Despite the local monopoly that is formed by each of the transmission grid operators, the German incentive regulation accounts for the fact that there are four independent players in the market. This is done by planning to introduce yardstick competition in the third regulatory period. In order not to anticipate anything, any further details are left out at this point. For all details regarding the German incentive regulation, refer to the section 2.3.2.

ket entry or competition in their respective regions. The reason for this is that in each of their geographically separated areas, it is not economically reasonable to duplicate the grid. This is a specific feature of large grids, and it appears in many network industries like railway, natural gas, telecommunications, and in particular the power grid. The importance of this feature in terms of investment has been stressed by many authors, see for instance Knieps (2005), Brennan (2009) or Friedl (2011).



(a) Transmission. (b) Generation.

Figure 2.2: Area of operation for transmission and generation companies.[21]

In summary, two important features of the power grid can be observed: first, because of the local monopoly that is formed by each transmission grid operator, there is the possibility to extract monopoly rents. In order to prevent customers from excessive monopoly rents and because of the impossibility to duplicate the transmission grid, governmental intervention in the form of regulation is necessary.

Second, investments in the grid are highly capital intensive and sunk right after investment. In addition to this, assets have a very long useful live of several decades. Hence, investment decisions in the electricity industry are never made lightly and are always entertained with a lot of caution. The following section demonstrates the reasons why massive investment in the grid is currently required.

[21]Source: (a) Übertragungsbetreiber (2012), (b) wirkungsvoll GmbH (o.J.) (2012).

2.2 Necessity of Investment in the Power Grid

The need for massive investment in the expansion of the German power grid has been mentioned briefly in section 2.1.1. This necessity for grid investment, its origins, its reasons and its magnitude will be illustrated in more detail in this section. Furthermore, a short descriptive contemplation of recent investments is included.

2.2.1 Goals of German Government and Implications

The German energy turnaround is the fundamental reason for the current massive investment needs which the economy is facing. As the energy turnaround has only been mentioned briefly in section 2.1.1, it is elaborated here in more detail.

In Germany, in the 1970s and 1980s, electricity was mainly produced by large coal-fired or nuclear power plants. Due to the increasing scarcity of fossil energy sources and the public resistance to nuclear power, the share of these energy sources for electricity generation is going to be reduced in the coming years. In the short run, it is inevitable (yet undesired) to compensate for the decreasing share of nuclear power with coal-fired plants, but in the long run renewable energies are sought as the most important resource.

The manifested goal of the German government is to massively foster the increase of electricity production using renewable energy sources. The government's actual goals and its concepts for a future energy supply can be found in the *Energiekonzept für eine umweltschonende, zuverlässige und bezahlbare Energieversorgung* as of September 28, 2010 (energy strategy for an environmentally friendly, reliable and affordable energy supply). It states that the share of total electricity production with renewable energies should be 35 % of the gross electricity consumption by the year 2020. In the year 2011 the share of renewable energy sources for gross electricity production was already 19.90 %.[22]

Particularly because of the German North-South divide of energy consumption and production, the intended increase in renewable energy generation results in a massive need for investment in the transmission grid. According to Stratmann (2012a), the transmission grid operators criticize the lack of support from the government, in particular concerning reliable and stable policies. Yet it is inevitable that investments in the grid are made, in order to avoid a collapse of the German power grid triggered by insufficient investment. This has for instance been pointed out by Handelsblatt (2012).

[22] Source: Statista, Statistisches Bundesamt.

Based on the *Energiekonzept*, the German government defined a *10-Punkte-Sofortprogramm* (ten item immediate action program), which facilitates the derivation of immediate actions towards the realization of abstract long-term goals. The government recognizes the importance of a powerful electricity grid and includes two items which explicitly address challenges in the network.

The introduction of a *Netzplattform* (network platform) concerns the communication between government, ministry, Federal states and industry. The government commits to an ongoing dialogue with the most important players in the network context, in particular with the grid operators and the German federal states. The *Bundesministerium für Wirtschaft und Technologie - BMWi* (Federal Ministry of Economics and Technology) is responsible for establishing a platform for continuing communication among the players.

The *Deutschlandweite Netzausbauplanung* (network expansion planning throughout Germany) addresses the governmental framework for the expansion of the electricity grid. The government assures the establishment of rules for a coherent expansion throughout Germany. For this purpose, a ten year binding expansion plan must be set up that is agreed upon by all network operators, and which can therefore serve as a basis for the expansion.

This item of the energy strategy was passed as a formal law with the 2011 amendment of the EnWG. The transmission network operators meet this requirement by establishing a framework for the grid expansion each year. This is the so-called *Netzentwicklungsplan - NEP* (Grid Development Plan).

The NEP contains all measures which are necessary to guarantee a secure and stable grid operation for the next ten years. It accounts for the integration of renewable energy sources and the resulting changes in the European electricity market. Furthermore, it provides an estimate of the necessary investment volumes for all these measures. The forecast investment volumes of the NEP as well as the results of other studies are illustrated in the following section.

2.2.2 Prognosis of Necessary Investment Volumes and Findings on Recent Investments

Expansion of renewable energy sources and of the power grid

According to the transmission grid operators themselves, the NEP provides methods and data as well as derived measures for the optimization, reinforcement and expansion of the power grid up to the years 2022 and 2032, respectively. The plan refrains from suggesting precise routes of the electric lines, but instead analyzes the need for electricity transmission between two nodes. It should be noted that the water-side connection of off-shore wind parks is not accounted for in the NEP.[23]

The NEP defines three different scenarios which differ in the maximum amount of energy generation in the range between 186 and 232 GW as well as in the energy mix.[24] All scenarios consider a massive increase of renewable energies, but the share of renewable energy sources in net capacity ranges between 55.93 % and 62.58 % for the three main scenarios. The different share in renewable energy sources inevitably leads to more or less use of conventional (in particular fossil) energy sources. Nuclear energy is used in none of the three scenarios.

The scenario denoted "B2022" is considered by the *Bundesnetzagentur -BNetzA*[25] (Federal Network Agency) to be the most likely one to be adopted. Since it is used as the basic scenario in many further analyses, only the values of this scenario are referred to in this thesis. The net capacities for the different energy sources can be found in Table 3, p. 36 of the NEP. Table 2.1 is a replication of this Table 3.

With 59.3 % of the installed net capacity, the share of renewable energy sources in 2022 is expected to be significantly higher than in the reference scenario 2010 with 35.6 %. As anticipated, the complete omission of nuclear energy results in a moderate increase in natural gas and in an tremendous increase in wind power as well as photovoltaic. On-shore wind capacity will have to be increased by more than 75 %, off-shore wind has more than centupled, and photovoltaic has tripled.

The energy sources that will have increased most strongly - on-shore and off-shore wind power as well as photovoltaic - represent small scale decentralized generation as opposed to large scale centralized power plants like nuclear or coal-fired plants, which were prevalent earlier. A natural consequence of this decentralization is the urgent need for a massive expansion and reinforcement of the transmission grid as well as the distribution grid.

The NEP provides estimates for the necessary investment volumes. The analysis distinguishes between necessary investment in the existing grid (denoted "starting grid") and

[23]As a consequence, the numbers in the NEP concerning the necessary investment volumes can be understood as lower bounds for the actual investment needs.

[24]In the context of electrical power, the so-called energy mix is the composition of primary energy sources that are used to produce the total amount of electricity within a year.

[25]The BNetzA is the regulatory authority in Germany. Throughout this thesis, the BNetzA is referred to with "it", whereas the more general term "the regulator" is referred to with "he". This is used as a convention and does not exclude female regulators.

	Net capacity [GW]		
	2010 (Reference)	2022 (Scenario B)	Relative change
Nuclear	20.3	0.0	-100.0 %
Lignite	20.2	18.5	-8.4 %
Black coal	25.0	25.1	+0.4 %
Natural gas	24.0	31.3	+30.4 %
Pump Storage	6.3	9.0	+42.9 %
Oil	3.0	2.9	-3.3 %
Other conv.	3.0	2.3	-23.3 %
SUM CONVENTIONAL	101.8	89.1	-12.5 %
Share	64.4 %	40.7 %	
Water	4.4	4.7	+6.8 %
Wind (on-shore)	27.1	47.5	+75.3 %
Wind (off-shore)	0.1	13.0	+12,900.0 %
Photovoltaic	18.0	54.0	+200.0 %
Biomass	5.0	8.4	+68.0 %
Other ren.	1.7	2.2	+29.4 %
SUM RENEWABLE	56.3	129.8	+130.6 %
Share	35.6 %	59.3 %	
SUM TOTAL CAPACITY	158.1	218.9	

Table 2.1: Projected energy mix in 2022 according to scenario B2022 of power grid development plan.

investment for expansion. The total investment volume[26] is estimated to be 20 billion €, of which 5 billion € is for the starting grid.[27]

It is obvious that this huge investment sum would not be spent all at once. In fact, the NEP provides a very precise timeline showing when and which part of grid expansion would be executed.[28] The relevant table consists of more than 50 different projects which refer to the grid between two nodes, represented by two cities. The table provides the nature of the project (e.g. reinforcement of existing routes, construction of new routes), the length of the route and the aspired year of commissioning. The range of these years is between 2014 and 2022. This shows that the expansion of the power grid requires continuous, ongoing investment. Furthermore, the investment outlays will occur through all three regulatory periods of the German incentive regulation. This proves that when analyzing investment incentives under regulation, the model setup must account for ongoing

[26]Throughout the NEP, the notion *Investitionskosten* (investment costs) is used. Strictly speaking investment costs are capital costs resulting from a specific investment, hence depreciation plus interest on invested capital over the entire lifetime of the asset. However, it is most likely that the provided estimates in the NEP refer to the total sum of investment outlays.

[27]The other two analyzed scenarios result in total investment volumes of 19 billion € and 23 billion €.

[28]See Übertragungsbetreiber (2012), Table 16, p. 130.

investment over multiple periods.

Development of grid investment

A fact that further points out the importance of setting the right incentives for investment in the power grid is the development of investment over the last couple of years. In 2010, the *Bundesverband der Energie- und Wasserwirtschaft e.V. - BDEW* (Federal Association for the Energy and Water Industry) has published a study on investment in the electricity industry. They analyze the investments of the German electricity providers in total from 1998 to 2011[29] distinguished between generation and grid.

Figure 2.3 shows the total development. Since 2002 total investment, i.e. the sum of generation, grid and others, has grown constantly up to 2010. A decrease of about 9 % is expected from 2010 to 2011.

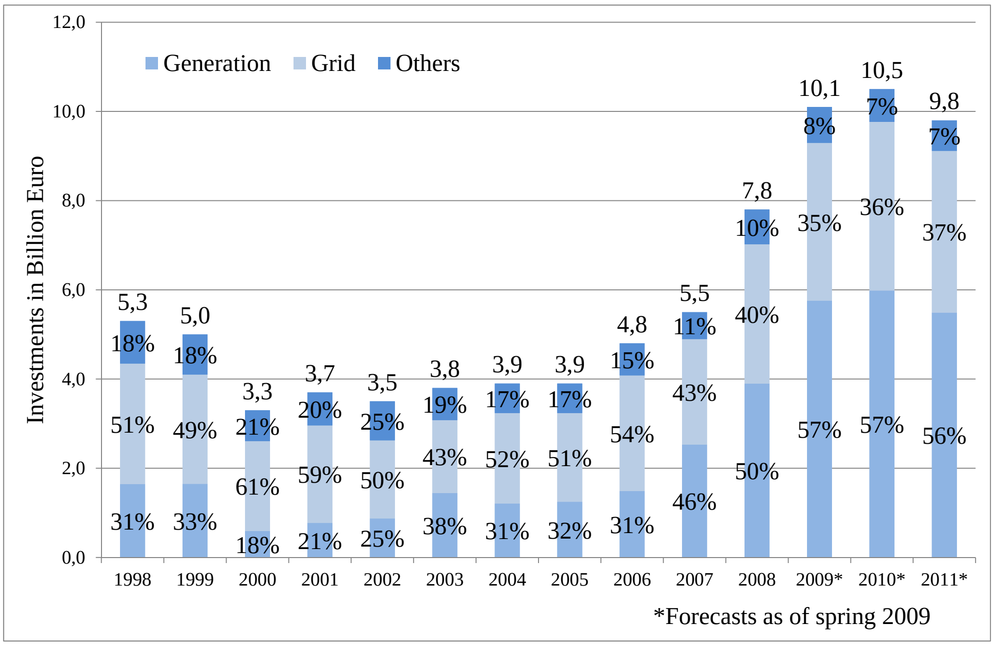


Figure 2.3: Investments of German electricity providers.[30]

[29] By the time of the analysis, the 2009, 2010 and 2011 figures were based on forecasts.
[30] Source: BDEW (Bundesverband der Energie- und Wasserwirtschaft e.V.) (2010).

In absolute terms, investment in the grid has increased constantly since 2004, but its importance relative to investment in power generation capacity has decreased. For instance, whereas grid investment made up 54 % of total investment in 2006, the projected grid investment volume in 2010 is only 36 % of total investment.

The absolute numbers for grid investment for the years 2007 to 2011 can be found in Table 2.2 [31].

	2005	2006	2007	2008	2009	2010	2011
Grid investment (in mio. EURO)	2,010	2,570	2,380	3,090	3,570	3,810	3,630
Change in relation to preceding year	-0.5 %	27.9 %	-7.8 %	+30.4 %	+15.5 %	+ 6.7 %	-4.7 %

Table 2.2: Development of grid investment in Germany (BDEW).

According to this study, investment in the grid has grown between 2008 and 2010. However, two undesirable developments can be observed: first, growth slowed down from 30.4 % to only 6.7 %, and second, grid investment even decreased from 2010 to 2011. This development is alarming, because during the last few years the expansion of renewable energies has increased, which should have been accompanied by an analogous expansion of the grid. For instance, in contrast to the decrease of grid investments from 2010 to 2011, the share of renewable energies for gross electricity consumption has increased from 17.1 % to 20.3 %.[32]

The deviating development of generation investment and grid investment has also been recognized by other studies. According to Stratmann (2012b), the expansion of the power grid lags behind the expansion of renewable energy. This is also an result of the so-called *dena-Netzstudien* I and II (dena grid surveys). Furthermore, these studies demonstrate that the need for grid investment has grown faster than expected originally: whereas the first dena-Netzstudie estimated a need of 850 additional kilometers of transmission grid, the second dena-Netzstudie estimates that the transmission grid lacks 3,500 km (ca. 2,174 miles) in length.[33] According to these studies, this shortfall is equivalent to necessary investment outlays of about six billion €.

This development must be analyzed taking the German incentive regulation into account. As it will be described in more detail in section 2.3.2, the first regulation period

[31] The numbers are taken from BDEW (Bundesverband der Energie- und Wasserwirtschaft e.V.) (2010).
[32] See Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit (2012).
[33] See Deutsche Energie-Agentur GmbH (2005) and Deutsche Energie-Agentur GmbH (2010) for details.

of the AReg is from 2009 to 2014, and the second will be from 2014 to 2019. The two photoyears,[34] in which the costs are determined and which are therefore relevant for the revenue cap are 2006 and 2011, respectively. Taking a closer look at the figures in Table 2.2, on the one hand this could be an explanation for relatively high grid investment in 2006. However, the decrease in investment in 2011 is rather surprising. High costs in the photoyear would result in a high revenue cap, which is desirable from the company's perspective. Hence, it would suggest itself to artificially increase the costs in this particular year. High investment in physical assets in 2011 is one way how this can be achieved. By investing in the photoyear, the largest possible sum of depreciation and interest is included in the 2011 costs, based on which the revenue cap in the second regulatory period is determined.

However, it must be noted that this discussion is under the assumption that capital expenditures translate into depreciation and interest costs in the very same year that the investment is made. This must not be the case. Investments made in 2011 may cause higher depreciation charges only in 2012. This again would explain the relatively high figures in 2010 compared to 2011.

Since an actual timing of investment cannot be observed clearly, it seems likely that for investment projects the photoyears are not relevant, because of the investment budgets.[35] An approved investment budget increases the revenue cap at any time, independently of the photoyears. Note that this discussion anticipates several topics - in particular regulation periods and investment budgets - that will be elaborated in section 2.3.2.

Another important source for studies concerning the investment behavior of grid operators is the BNetzA. Every year, the agency runs a survey among the grid operators and requests them to disclose their recent and planned investments in the grid. The results are published in the *Monitoringbericht* (monitoring report).[36] In the 2011 report, the actual figures for 2007 to 2010 were included, as well as forecasts for 2011. The figures are distinguished between investment in the transmission and the distribution grid. The results are shown in Table 2.3.

It is striking that the BNetzA figures differ substantially from the BDEW figures in Table 2.2. For better readability, Table 2.4 repeats the figures.

[34] In the so-called photoyear the cost review takes place. All costs incurred in the photoyear are the basis for the revenue cap for the following regulation period. More on the photoyear can be found in section 2.3.2.

[35] The so-called investment budgets are one element of the AReg that is designed to foster grid investment. More on the investment budgets and their effects can be found in section 2.3.2.

[36] See Bundesnetzagentur (2011a).

	2007	2008	2009	2010	2011
Transmission grid					
Expansion inv.	398	595	408	504	530
Replacement inv.	105	146	114	116	136
SUM	503	741	522	620	666
Percentage change		+47.3 %	-29.6 %	+18.8 %	+7.4 %
Distribution grid					
Expansion inv.	1,179	1,260	1,258	1,558	1,510
Replacement inv.	94	1,133	1,277	1,631	1,521
SUM	1,273	2,393	2,535	3,189	3,031
Percentage change		+88.0 %	+5.9 %	+25.8 %	-5.0 %
SUM transmission and distribution	1,776	3,134	3,057	3,809	3,697
Percentage change		+76.5 %	-2.5 %	+24.6 %	-2.9 %

Table 2.3: Development of grid investment (BNetzA).

	2008	2009	2010	2011
Total grid investment BDEW	3,090	3,570	3,810	3,630
Percentage change	+30.4 %	+15.5 %	+ 6.7 %	-4.7 %
Total grid investment BNetzA	3,134	3,057	3,809	3,697
Percentage change	+76.5 %	-2.5 %	+24.6 %	-2.9 %

Table 2.4: Comparison of BDEW and BNetzA figures.

In 2008, the two figures differ by 44 million €. The largest difference can be found in 2009: the BDEW study finds more than 500 million € higher investments than the monitoring report of BNetzA. The 2010 figures almost exactly coincide, however the 2011 figures deviate by 67 million €.

The deviating results of both studies are most likely due to the fact that the BDEW uses forecasts for 2009, 2010 and 2011, but the BNetzA included realized figures for 2009 and 2010. Only 2011 also remains a forecast in the monitoring report of the BNetzA. Hence, for 2009, the BNetzA results are more substantiated than the BDEW results. Moreover, both discussed studies do not explicitly state to what extent their figures include investments based on investment budget. This differentiation would be important, as investment budgets are independent from the revenue cap.

The existence of different figures for investment in the recent years does not negate the earlier discussion that grid investment has not kept up with generation investment and particularly investment in renewable energy sources. In contrast to the BDEW study, the monitoring report of the BNetzA does indeed find an increase in total grid investment of almost 25 % from 2009 to 2010. However, in line with the BDEW study, it does project a decrease one year later. As discussed earlier, this indicates that although the share of renewable energies for electricity generation has increased between 2010 and 2011, grid investment did not keep up with this development.

In summary, this section demonstrates that while large investment in the electricity transmission grid is necessary, the development of investment over the last few years appears to be insufficient. This insight again shows the importance of setting the right investment incentives when designing a regulatory policy. The following section describes the actual regulation of the power grid in Germany and shows its influence on investment.

2.3 Regulation of the Power Grid in Germany

The previous section has illustrated the massive need for investment in the electricity transmission and distribution grid. However, since the grid represents a natural monopoly, it is subject to a governmental price regulation. Consequently, all investment decisions are directly or indirectly influenced by this regulation.

The purpose of this section is to describe and characterize the regulation of the power grid in Germany. To this end, the regulatory environment is illustrated first. Then the actual design of the German incentive regulation is described and classified in detail. The section closes with a review of research that assesses the influence of the German incentive regulation on investment.

2.3.1 Illustration of the Regulatory Environment in Germany

As mentioned in section 2.1.1, despite the unbundling requirement, which led to competition in generation, trade and sales of electricity, the power grid still remains a monopoly. In order to protect customers from excessive monopoly rents, governmental regulation is necessary. In Germany, the already mentioned EU Directive of 1996 was turned into national law by the 1998 version of the EnWG, which was again amended in 2005.

The regulatory authority in Germany is the *Bundesnetzagentur* (Federal Network Agency) in Bonn, which formally belongs to the BMWi. The function of the BNetzA is to guarantee that the EnWG as well as the EU legislation are adhered to.[37] It furthers the liberalization and deregulation of the electricity market, assures non-discriminatory network access and efficient access prices. The BNetzA is in charge of determining the regulated prices for the affected grid operators.

On the industry side, the companies that are affected by the BNetzA are exactly the transmission and distribution grid operators. As illustrated above, there are only four large transmission grid operators. As for the distribution grid, there are many more: the 2011 monitoring report of the BNetzA includes 869 distribution grid operators. A large part of these companies is fairly small: 91 % of them have less than 100,000 customers each.[38]

Until 2009, an ex post cost-plus regulatory regime was implemented. This means that the grid operator determines prices itself and discloses its costs to the regulator. The BNetzA must revise these costs and hence check if the charged prices were reasonable. Whether disclosed costs are considered appropriate depends on a comparison with other companies of the same structural class.[39] If not, the company was subject to a fine.

Cost-plus regulation has some shortcomings in particular in terms of incentives for cost reductions[40]. In fact, it does not provide any incentives for cost reductions and efficiency improvements, because all costs are reimbursed, as long as they are adequate compared to the peer group. Hence, under this regulatory regime any investment in efficiency improving or just new technologies is not properly stimulated. This disadvantage of any simple cost-plus regulation has been recognized and discussed broadly in regulation literature, see among others Averch and Johnson (1962), Braeutigam (1981), Beesley and Littlechild (1989), Vogelsang (2010) or Kretschmer et al. (2011).

Realizing these shortcomings, in 2007 the introduction of incentive regulation was decided. As Jamasb and Pollitt (2007) state, "the aim of (...) incentive regulation of networks (...) is to provide utilities with incentives to improve their operating and investment ef-

[37] Besides electricity, the BNetzA is responsible for natural gas, telecommunications, mail and railway as well.
[38] See Bundesnetzagentur (2011a), p. 87.
[39] Structural class means a comparison with companies which operate under comparable circumstances, e.g. densely or sparsely populated areas or geographical profile of the region.
[40] A broad discussion of the incentive features of different regulatory policies can be found in the literature review in chapter 3.

ficiency and to ensure that consumers benefit from the gains." For this purpose, the *Anreizregulierungsverordnung - ARegV*[41] (incentive regulation rule) was added to the EnWG, which is effective since October 29, 2007. Section 2.3.2 assesses the German incentive regulation in detail.

2.3.2 Design of the German Incentive Regulation and its Effects

This section describes the current German incentive regulation, the *Anreizregulierung*. The legal basics, theoretical foundations, and components of the AReg are described. Furthermore, selected specific features and their effects are discussed.

Legal basics

The legal basis for the German incentive regulation is the already mentioned EnWG in the version of July 13, 2005. Two main objectives of the law are the following: to guarantee first, a safe, well-priced, consumer-friendly, efficient and environmentally sustainable grid-bound energy supply,[42] and second, a long-term oriented, effective and reliable operation of power grids.[43] Another section was added later that explicitly allows the formulation of an incentive regulation within the boundaries of the EnWG.[44] This was accomplished with the AReg.

Based on a grid operator's costs, the AReg sets a revenue cap for the total revenues. These revenues are translated into prices which are determined using the *Stromnetzentgeltverordnung - StromNEV*[45] (electricity price rule). The StromNEV has already been effective since July 25, 2005, i.e. even before the ARegV.

The AReg splits the years 2009 to 2025 into three regulation periods of five years each. The first regulation period started on January 01, 2009, the second will start five years later, the third another five years later, respectively. The revenue cap for the first regulation period 2009-2013 is determined by using the so-called photoyear 2006. All costs incurred in the photoyear are the basis for the revenue cap in the first regulation period. Analogously, 2011 was the photoyear for the revenue cap for the second regulation period (starting

[41] Officially *Verordnung über die Anreizregulierung der Energieversorgungsnetze*.
[42] Section 1(1), EnWG.
[43] Section 1(2), EnWG.
[44] Section 21a(1), EnWG.
[45] Officially *Verordnung über die Entgelte für den Zugang zu Elektrizitätsversorgungsnetzen*.

January 01, 2014) and 2016 will be the third photoyear. The effects of the time lag between photoyears and regulations periods will be analyzed later in this section.

Features of AReg

The main element of the German incentive regulation is the determination of a cost-based revenue cap for each regulation period, specified in ARegV section 4(1). As described earlier this revenue cap translates into prices via the StromNEV.

Section 6(1) ARegV defines that the revenues need to be determined based on costs. Section 21a(4) EnWG requires that costs must be split into influenceable and non-influenceable costs. The reason is that an increase in efficiency is only required for influenceable costs.[46]

The grid operator's profit and loss statement is used as the basis for determining the relevant costs. All incurred costs, including depreciation and cost of capital, are considered. However, the StromNEV specifies some limitations.

First, equity can only account up to 40 % of total capital.[47] Any equity above this is treated as an interest-bearing liability.[48] Second, the cost of equity - which is crucial for the grid operator's return - is determined by the BNetzA. In the first regulation period, it is 9.29 % for new assets and 7.56 % for old assets.[49] The BNetzA uses the Capital Asset Pricing Model (CAPM) for the determination of the cost of capital. It assumes a risk-free interest rate of 4.23 %, which is the average monthly return for a German governmental bond over the past ten years. For liabilities, the actual interest rates are used, as long as they are standard in the market. They are capped to 4.23 %. The interest rate is an important influencing factor and can influence costs largely. However, the assessment of the interest rate is not an essential part of this thesis and will not be discussed in further detail.

Third, straight-line depreciation must be implemented.[50] For the determination of the relevant book value of the asset, the rule also differs between new assets (activated Jan. 01, 2006 and later) and old assets (activated before Jan. 01, 2006). New assets are valued

[46] More details on this efficiency requirement are provided later in this section.
[47] Section 6(2), StromNEV.
[48] Section 7(1), StromNEV.
[49] Beschluss der Bundesnetzagentur vom 7. Juli 2008 zur Festlegung der Eigenkapitalzinssätze nach der Anreizregulierungsverordnung.
[50] Section 6(2), StromNEV.

at historic costs independently of their financing. For existing assets the leverage must be considered. The part financed by equity is valued at its actual replacement costs, the leveraged part is valued at historic costs. This procedure is in line with the principle of *Nettosubstanzerhaltung* (net preservation of substance).[51]

The employed depreciation method as well as the used cost basis (i.e. replacement costs or historic costs) can also have tremendous impact on investment decisions. These issues will be discussed in depth in later sections of this thesis.[52]

Outlook for third regulation period

The actual design of the regulation in the third period has not been fixed yet. Originally it was discussed to introduce a pure yardstick competition instead of the revenue cap regulation. Yardstick competition means that the efficiency requirements for one particular firm are dependent on the efficiency of a comparable firm.[53] With the introduction of yardstick competition, the BNetzA would account for the oligopoly of grid operators that exists in Germany if the country is considered as a whole. However, in the first two regulatory periods, the operators are treated as pure monopolists: the efficiency performance of the other transmission grid operators does not affect the price determination for one particular company.

By the introduction of yardstick regulation in the third regulatory period, the BNetzA intends to further foster competition among the network operators while trying to reduce the complexity regarding the information needs from the regulator's perspective. However, several features of the intended regulation design were strongly criticized, such that the BNetzA left the actual design open for after 2019.

Theoretical classification

In contrast to a traditional cost-based regulation, where the costs are the direct basis for the regulated price or the allowed revenue/ return, an incentive regulation scheme temporarily unties the allowed revenues from the actual costs.[54] Within a regulation period, there

[51]For some theoretical background on this principle see for instance Bork et al. (1995), Küpper (2008b) or Küpper and Pedell (2010).
[52]See section 3.4.3.
[53]Some more theoretical background on yardstick competition is provided in section 3.2.
[54]More theoretical background on different forms of regulation is provided in section 3.2.

are only two adjustments: first, inflation is considered by using the retail price index (RPI), and second there is a component X which represents a required increase in efficiency.[55] The German incentive regulation is one example for this so-called $RPI - X$ regulation scheme.[56] This regulation scheme is intended to set incentives for cost reduction: every improvement in efficiency greater than the expected X-factor contributes to a larger profit.

Revenue-cap regulation also results in a reduction of risk for the company: in contrast to a price-cap regulation, a revenue-cap regulation design allows the company to compensate for deviations in projected sales. Prices can be changed for different products, as long as the revenues remain constant. For instance, this fact can foster the introduction of new products, because cross-subsidization is possible. However, it should be considered that implicitly, this feature means that risk is passed on to the customers. Furthermore, the possibility of cross-subsidization can also be criticized, as Brennan (1989) illustrates.

Now that is has been illustrated that the AReg is of $RPI - X$ type, in the following, the explicit formula for the AReg and its different components are described in detail.

Specification of the German incentive regulation formula and its components

In order to understand the effects and dynamics of the German incentive regulation, a closer look at the actual design is necessary. For this purpose, the formula of the AReg is illustrated with all of its components. Furthermore, the intended and also observable effects of the single components are discussed.

Attachment 1 of Section 7 ARegV specifies the formula for determining the revenue cap EO_t in year t:

$$\begin{aligned} EO_t &= KA_{dnb,t} + (KA_{vnb,0} + (1 - V_t) \cdot KA_{b,0}) \cdot \left(\frac{VPI_t}{VPI_0} - PF_t \right) \cdot EF_t \\ &\quad + Q_t + (VK_t - VK_0) + S_t. \end{aligned}$$

with

[55] An explicit determination of an X-factor can be found in Beesley and Littlechild (1989). They illustrate its calculation for Manchester Airport and British Telecom and discuss the resulting incentives. The determination of this factor is very complex and needs to be treated with caution, which is also stressed by other authors like Joskow (2008).

[56] See among others Brunekreeft and Borrmann (2011) and Beesley and Littlechild (1989).

$KA_{dnb,t}$	permanently non-influenceable costs in year t
$KA_{vnb,0}$	temporarily non-influenceable costs in year 0 (photoyear)
$KA_{b,0}$	influenceable costs in year 0
V_t	individual distribution factor for a decrease of inefficiency in t
VPI_t	retail price index in t
VPI_0	retail price index in 0
PF_t	general sectoral productivity factor in t
EF_t	individual enlargement factor in t
Q_t	bonus or reduction for quality in t
VK_t	volatile cost part in t
VK_0	volatile cost part in 0
S_t	$1/5$ of the balance of the previous regulation period

Briefly speaking, the formula includes three elements: first, some parts are passed on directly into the revenue cap. Those are, for instance, the permanently non-influenceable costs $KA_{dnb,t}$ and the quality element Q_t. Second, other parts are only passed through adjusted by some factors. As for an example, the influenceable costs $KA_{b,0}$ are adjusted by efficiency and productivity factors as well as the retail price index. Third, there are elements such as the last three summands which serve as adjustment factors over different regulatory periods.

In the following the different parts of the formula and their meaning for investment are discussed in more detail.

Influenceable and non-influenceable costs. In the formula, the explicit distinction between influenceable and non-influenceable costs becomes obvious. Section 11 ARegV determines permanently and temporarily non-influenceable costs and defines influenceable costs as everything else.

Generally speaking, permanently non-influenceable costs are those costs which result from an efficient operation of the grid, meaning its operation under competition. Referring to section 11(2) ARegV, the main permanently non-influenceable costs are:

- **Legal purchase and remuneration obligations.** This is firstly, a legally guaranteed compensation for electricity fed into the grid generated by renewable energy.[57] Secondly, this can be a compensation for grid operators who are legally required to

[57] This guaranteed compensation is legally defined in the *Gesetz für den Vorrang Erneuerbarer Energien - EEG* (Act on Granting Priority to Renewable Energy Sources).

connect off-shore wind parks to the grid, or any similar requirement due to the *Energieleitungsausbaugesetz - EnLAG* (Law on the Extension of the Electricity Grid).

- **Licence fees**. These are fees for the use of public road transport infrastructure or rent for municipality owned land, if facilities need to be built on this land.

- **Compensation fees for upstream grid levels.** This means that one grid operator pays compensation to another grid operator because he necessarily needs to use the other's upstream grid level. These fees cannot be influenced by the downstream grid operator. This fact expresses the general tenor of the AReg: it considers the costs that one specific grid operator is able to influence or not, not the whole group of grid operators. This has also been stressed by the Bundesnetzagentur (2006).

- **Costs caused by investment.** If the regulator approved a grid operator's investment plans, the cost-effective part of this investment is classified as non-influenceable costs as well.[58]

- **Others.** Section 11(7-14) ARegV specifies other permanently non-influenceable costs like lump-sum investment premiums, additional costs caused by underground cabling or employees benefits. It can be noticed that the regulator also included costs which are not directly connected to the operation of the grid. For instance, costs for employee training or employee childcare do count as non-influenceable costs. Apparently, the regulator aims to encourage these activities and to prevent grid operators from reducing costs there.

Temporarily non-influenceable costs are costs that are considered efficient for the present regulation period. These can be costs which result from structural differences among different regions of Germany, for example. The temporarily non-influenceable costs only get adjusted for inflation and progress in productivity.

As mentioned above, costs resulting from approved investment plans are considered permanently non-influenceable costs. For the grid operators, these are mainly capital costs consisting of depreciation charges and interest costs. Hence, the capital costs resulting from investment, which constitute the biggest cost part,[59] are directly passed on into the revenue cap. Considering the price determination by the StromNEV, the capital costs are also a direct part of the resulting price. This fact supports the assumption of the model in section 4.1.2 that the regulated price is determined by the capital costs.

[58] The design and effects of investment budgets are discussed later in this section.
[59] This has been argued in many relevant literature, see for instance Küpper (2008b).

Individual distribution factor. This factor reflects one of the main goals of incentive regulation, namely the increase in efficiency. The goal of the distribution factor V_t is to encourage a decrease in efficiency in a certain period. A distribution factor of 100 % (V_t=1) is given to the most efficient company in a reference group. One hundred percent efficiency results in the fact, that no influenceable costs $KA_{b,0}$ are included in the revenue cap.

Retail price index and general sectoral productivity factor. The factor $\left(\frac{VPI_t}{VPI_0} - PF_t\right)$ partly represents the classical $RPI - X$ regulation scheme. Inflation is expressed by the relation between the current retail price index VPI_t and the retail price index in the base year VPI_0. The sectoral productivity factor PF_t is subtracted to account for the difference between the development of the sector/ industry and the entire economy. PF_t can be considered part of the X-element in addition to the individual distribution factor V_t. Section 9(2) ARegV determines PF_t to be 1.25 % for the first regulation period and 1.5 % for the second period.

Hence, the required efficiency increase X is represented both by the distribution factor V_t and by the sectoral productivity factor PF_t. It is obvious that the larger the efficiency factor X is, the smaller the part of the costs that are included in the revenue cap will be. Consequently, it becomes more difficult for the affected company to generate profit, and it can make sense for the company to attempt to avoid additional costs.

However, it is also straightforward to see from the formula that the permanently non-influenceable costs are not affected by the X-factor. Since costs resulting from approved investments are considered non-influenceable, the requirement of raising efficiency should not negatively affect the company's investment behavior.

Individual enlargement factor. The purpose of this factor is to gain flexibility to be responsive to exogenous changes. This means that if output changes due to factors which the company is not responsible for, e.g. due to more connection points or higher yearly peak-loads, the allowed costs must be changed adequately.[60]

This factor can positively influence investment incentives, especially for expansion investment. However, it should be emphasized that only distribution grid operators are affected by this factor, not transmissions grid operators. For them, the investment budgets as described later in this section are intended to encourage expansion investment.

Quality element. The introduction of the quality element intends to make sure that costs are not reduced at the expense of quality. Quality criteria are for instance the reliability

[60] See also Bundesnetzagentur (2006).

of the network, hence length and frequency of blackouts, which should be measured by certain indicators. Again whether the revenues cap increases of decreases depends on the company's quality performance in relation to a certain benchmark.

Volatile cost parts. The AReg formula includes a factor considering volatile cost parts in order to compensate for cost parts which are unsteady. For example, this can be energy which the grid operator itself consumes. Capital costs are explicitly excluded in this part of the formula.

Regulation account. The affected companies are required to forecast the expected demand in order to charge correct fees. In order to compensate for uncertainties in this forecast and in order to be able to be responsive to deviations in quantity, a regulation account is introduced. If the company generates higher revenues than its revenue cap allows, the difference is put on this account. Interest is paid on this amount and one fifth of the balance is transferred to the next period.

Summarizing, the different elements of the incentive regulation formula are intended to promote increases in efficiency and to avoid any reductions in quality.

Investment budgets

When designing the AReg, the regulator was aware of the importance of stimulating investment in the grid, in particular in the transmission grid. Therefore, the feature of *Investitionsbudgets* (investment budgets) was included in the AReg.[61] A broad description of investment budgets in the context of the German AReg can be found for instance in Ufer et al. (2010). This section provides just a brief illustration.

The importance of investment budgets becomes obvious if the actual figures of filed investment budget applications are considered. According to the BNetzA,[62] between 2007 and 2009 9 billion € were applied for. For the transmission grid operators, investments approved via investment budgets account for a range of 50 % up to 75 % of total investment.

As for the actual process, in the original version of the ARegV, if an expansion or restructuring project was planned, a transmission grid operator was supposed to file an application for an investment budget. If the application was approved, the amount of the budget was added to the revenue cap. However, the approval was only granted on real-

[61]See section 23 of ARegV.
[62]See Kurth (2008).

ized costs instead of planned costs. Of course for large scale investment projects, costs are only realized significantly after the investment outlay.

This issue was accounted for with a compensation: the revenues were not only increased by the amount of the investment budget, but by a higher amount such that the compensation is net present value (NPV) consistent. However, this left another important issue unresolved. Since the revenue adjustment only happened later than the investment outlay, a gap in profit and liquidity resulted.

Since this gap in profit and liquidity negatively affected investment incentives, the B-NetzA changed their policy.[63] From March 2012 on, investment budgets get approved based on planned costs instead of on realized costs.

Effects of time lag

Earlier in this section the determination of the regulation period and the photoyears is described. The effects of the time lag between the photoyear and the affected regulation period remains to be discussed. Whereas the time lag for the investment budgets was accounted for by a change of the ARegV, there is another time lag issue independent from the investment budgets, which remains unresolved.

As mentioned earlier, the photoyear in which costs are determined is always three years before the affected regulatory period. This fact leads to a serious time lag in costs recognition. Costs incurred in the photoyear itself add to the revenue cap in the next period, i.e. three years later. However, further costs incurred in the years between the photoyear and the start of the next regulation period (currently, those are the years 2012 and 2013) will not add to the revenue cap in the second regulation period (2014-2019), but they will only be recognized for the third regulation period starting in 2019. Hence there is a maximum time lag of seven years (2012 until 2019) between the incurred costs and their effect on the revenue cap. Nykamp et al. (2012) illustrate the situation in Figure 2.4. Naturally, the grid operators are less willing to generate additional costs due to the longer period until these costs are recognized in the revenue cap.

This section and the preceding one show that there are some shortcomings of the current regulatory regime in Germany that have only partly been resolved to date. These issues are addressed in more detail in section 2.3.4.

[63]See Bundesministerium für Wirtschaft und Technologie (2012).
[64]Source: Nykamp et al. (2012).

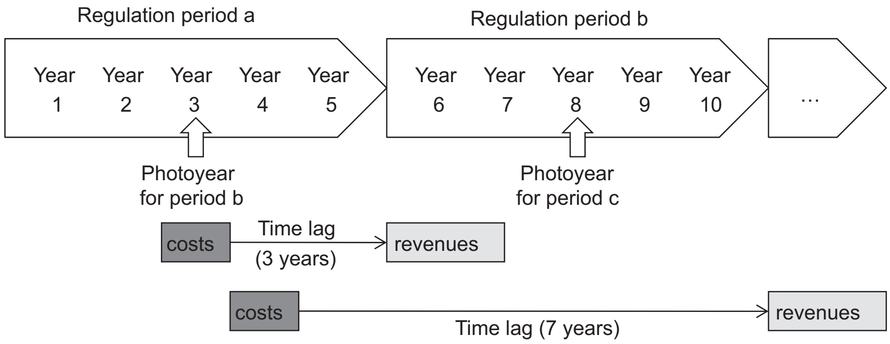


Figure 2.4: Time lag in incentive regulation.[64]

2.3.3 Classification of the German Incentive Regulation

Kretschmer et al. (2011) develop and discuss principles of regulation which address risk and investment incentives. With their analysis, they provide a valuable framework which can be used to assess the quality of a regulatory framework. In this section, their approach will be used to analyze the AReg in different dimensions. This is carried out in order to illustrate its theoretical foundation.

Kretschmer et al. (2011) structure these principles in three categories: competition, welfare and company-specific issues. For these three main categories, they identify the following detailed requirements:

(1) Competition principles

- Orientation towards market and competition
- Transmission to competitive structures and reduction of subsidies
- Possibility of non-discrimatory market access
- Fair competition and no discrimination

(2) Welfare principles

- Efficiency
- Setting of investment incentives and encouragement of progress and innovation

(3) Company-specific principles

- Market orientation
- Unbundling of business units and accounting systems
- Cross-subsidy prevention

- Transparency and possibility for monitoring
- Commensurability

Each category stands for a specific requirement for a regulatory framework. The idea behind the three main categories, and whether the requirements are fulfilled by the AReg, is illustrated in the following.

The competition principles intend to make sure that regulatory markets are as similar as possible to free markets. This is reflected in the claim for non-discriminatory market access. Moreover, regulation should encourage a more competitive environment. Companies should be able to operate independently and make enough profits such that subsidies become redundant.

The German incentive regulation fulfills this requirement to a large extent. Since the power grid will remain a natural monopoly,[65] competition can only be introduced up to a certain level. The projected introduction of yardstick competition shows that the importance of competition is recognized by the regulator.

Concerning the welfare principles, Kretschmer et al. (2011) argue that in order to maximize welfare, efficiency needs to be worked on continuously. Since efficiency is not static and progress needs to be pursued constantly, it is crucial to set incentives for cost reduction, investment and an increase in quality. These claims for efficiency, cost reduction and investment are central elements of the AReg. It will, however, take some time until it is possible to judge whether these goals have been achieved.

The company-specific principles result directly from competition and welfare principles. First, a basic and essential requirement is that an appropriate return for investing must be guaranteed to investors, which is well known from investment theory. The most important instrument here is to use the correct rate of return which includes an appropriate risk premium for investing. Second, market orientation results in the requirement that important market features must be taken into account, e.g. when determining depreciation. Among others, these features include the development of prices and technologies. Market orientation can also mean that under some circumstances, not only costs should be the basis for pricing, but other factors too. Unbundling of business units and accounting systems is very important as soon as a company provides both products or services that are subject to regulation and others that are not. The accounting system must be able to provide the necessary data for price determination and enable a clear distinction between both business

[65] It has been argued in section 2.1.2 that a duplication of the network does economically not make sense.

units' data. For effective regulation, it is furthermore necessary that no cross-subsidies occur between business units operating in free markets and regulated business units. Otherwise, there would only be a distorted picture of the company's success. The claim for transparency reflects that a regulatory authority must be able to monitor and review processes and data used for pricing, whereas accounting for commensurability means that regulatory interventions must be as mild as possible.

Almost all of these requirements are reflected in the design of the German incentive regulation. First, by using costs as the basis for allowed revenues, and by only requesting efficiency improving for influenceable costs, it recognizes the necessity of an adequate return. Second, market orientation is given, which can be seen in the AReg formula. Third, the unbundling requirement has been realized to the fullest extent (also see section 2.1.2). This also prevents any cross-subsidies. Transparency is fostered for instance through the monitoring reports (see section 2.2.2). Whether commensurability is fulfilled is hard to judge from an outside perspective.

With all these principles, Kretschmer et al. (2011) provide a comprehensive framework to assess a certain regulatory policy. Generally speaking, the AReg fulfills the developed principles to a major extent. However, for many of the principles, the actual outcome can only be observed ex post. For example, if the affected companies have indeed become more efficient or whether enough investment can be stimulated can only be judged in the future. Hence, it is particularly important to develop theories and analytical models which assess these tremendously important aspects.

2.3.4 Influence of the German Incentive Regulation on Investment

As illustrated in section 2.2 there is a massive need for new investment in the power grid and there is some doubt in public opinion as well as in academic literature if the current design of the AReg encourages sufficient and efficient investment. In this section, the existing findings on the influence of the AReg on investment are illustrated.

Right after the introduction of the AReg, its incentive features for new investment got strongly criticized. According to Flauger and Stratmann (2010), Wulf Bernotat, the former CEO of E.ON stated in the beginning of 2010 that the current practice of the BNetzA prevents rather than fosters investment. According to him, the AReg's focus is solely on cost reduction. This is not a negative feature by itself, but the current massive modernization expansion needs a regulatory policy focusing on investment incentives.

According to the Bundesministerium für Wirtschaft und Technologie (2011), Federal Minister of Economic Affairs, Dr. Philipp Rösler acknowledges that regulation has to provide a stimulating environment for investment in the power grids. Therefore the change in the ARegV in spring 2012 concerning investment budgets was crucial for encouraging investment.

Although the AReg was only introduced in 2009 and hence is fairly new, there is already a considerable amount of academic literature analyzing the relation between the AReg and investment. Brunekreeft and Meyer (2011) discuss different aspects of the German incentive regulation. Generally speaking, they argue that the incentive regulation does not set any incentives for an improvement of the grid quality. In their analysis, they explicitly address the investment budgets. Although the German incentive regulation includes this element which is intentionally designed to stimulate investment, one particular weakness lies in the approval process in its original version: investment budgets were approved based on realized costs, not based on planned costs. The consequence was that it took some years until the costs were added to the revenue cap.

The affected company bore two major disadvantages because of this gap. First, the company's return was decreased caused by lost interest. Second, the company faced a loss in cash flow or profit. Brunekreeft and Meyer (2011) state that if investment needs are increasing over a longer period of time, cash flow and profit are not covered persistently. However, as already mentioned in section 2.3.2, this particular shortcoming of investment budgets has recently been revised, and with the current approval process based on planned costs, the profit and liquidity gap no longer occurs.

Brunekreeft and Meyer (2011) provide several further suggestions for modification of the AReg in order to foster investment. First, they argue for markups in allowed returns. These markups - which are also called top-ups or adders - can be granted for all investments or only for selected investments. Second, a reduction in risk to which the companies are exposed must be achieved. This risk exists mainly because of the possibility to declare certain investments unnecessary ex post and thus not include them in the revenue cap. This possibility should be waived. However, note that as a consequence, the ex ante review would have to be more diligent, which is more complex and costly for the regulator. Third, it should be guaranteed that efficiency requirements for capital costs resulting from investments do not provide wrong incentives. This can be achieved by treating capital costs differently than operating costs. Since these aspects are not a prior concern of this thesis, they are not discussed in any further detail.

Another article that focuses on the effects of the German incentive regulation is Nykamp et al. (2012). The authors' main concern is investment in new technologies which is necessary to successfully integrate renewable energy generation. Nykamp et al. (2012) conclude that under current standard incentive regulation, the grid operators gain profitability by avoiding investment and by not implementing smart solutions.[66] They argue that this is particularly serious because of the strong increase in decentralized renewable energy generation during the last years.

Based on an economic calculation, they conclude that with the 'standard' incentive regulation, the implementation of these smart solutions is not sufficiently encouraged. According to their analysis, a grid operator has more incentives to make conventional reinforcement investments. As already recognized by other authors and overcome to a large extent by the most recent change in the ARegV, they also criticize the time lag (see section 2.3.2 for more detail), which is one cause for the wrong investment incentives.

In contrast to Brunekreeft and Meyer (2011) and Nykamp et al. (2012), which analyze the effects of the German AReg on investment, the theoretical discussion of Müller et al. (2011) focuses on the incentives for *innovation* set by incentive regulation. They distinguish between short-term process innovation and long-term product innovation. They conceptually analyze that incentive regulation only fosters process innovation in order to reduce operational expenditures (OPEX) in the short-run. A short-term reduction of OPEX leads to a higher profit for the grid operator in the regulation period, since revenues remain constant, but costs decrease. They conclude that it is yet unclear what incentives are set for long-term product innovation and associated capital expenditures (CAPEX). They suggest that this issue needs to be addressed in more detail in future research. While the relationship between innovations and regulation is a tremendously important topic, in particular considering innovations like smart grids, it is nevertheless not discussed in further detail here.[67]

Elsenbast (2008) is another contribution which economically evaluates the German A-Reg and its different elements. He discusses the benchmarking feature of the AReg, which he believes is difficult to accomplish. Thus, realistic efficiency requirements are hard to determine. At the same time, it is difficult to measure improvements in efficiency. Jamasb and Pollitt (2007) argue in the same direction, but even more critically. According to them, efficiency analyses should not be part of an incentive regulation scheme because of their inherent ambiguity.

[66] They define 'smart solutions' as measures which allow for the integration of renewable energy sources, which avoid peak loads or conventional grid expansion. These solutions result in a more efficient use of grid assets.

[67] For interested readers, contributions concerning this topic are Bailey (1974), Bauknecht et al. (2007), Bauknecht (2011), Bauknecht (2011), Brunekreeft and Bauknecht (2009) or Rodi (2009).

Furthermore, according to Elsenbast (2008) there are uncertainties from an ex ante perspective for the regulated company. For instance, it is unclear how investment will affect the efficiency requirements and hence the allowed revenues. In general, he perceives investment budgets as beneficial. He stresses the importance of the fact that approved expansion investments become part of the non-influenceable costs[68] which are not subject to any efficiency improvement. This is accomplished in the German AReg.

Ufer et al. (2010) focus again on the investment budgets, which are a crucial element of the German AReg. They analyze the effects of the investment budgets in three different dimensions: infrastructural, financial and administrative. They state that the former two aspects are more important than the latter one, which refers to time and effort caused by administrative and bureaucratic burdens for affected companies as well as for the regulator.

From a financial perspective, it is beneficial for the affected company that investment budgets are incorporated in the cost basis as permanently non-influeceable costs. This has been recognized by other authors as well, for instance Elsenbast (2008). Investment budgets are in general important for fostering efficient infrastructure investment. This is because the efficiency requirements of the basic $RPI - X$ regulation scheme, and hence cost reduction requirements, do not apply to these important capital investments.

Maeding (2009) abstracts the actual AReg to some extent. She sets up a model of an idealized $RPI - X$ regulation in order to determine what features of an incentive regulation scheme influence the internal rate of return (IRR) of an investment project. She finds that the time lag as well as the X-factor and the RPI affect the IRR.

Because of the regulatory time lag it can take up to seven years after the investment outlay until the cash inflows from an investment are received. Furthermore, in between the investment outlay and its recognition in the revenue cap, the company faces opportunity costs. Maeding (2009) states that the "time lag until the adjustment of revenues takes place has (...) by far the greatest negative impact on the IRR."[69] The efficiency requirement is less important but still relevant, since it causes stranded costs as well as further opportunity costs.

In order to validate her theory, Maeding (2009) runs a simulation of a revenue cap regulation, in which the actual parameters of the AReg are captured to the largest extent. However, some of her assumptions, for instance concerning taxes and construction lead

[68]For the definition of influenceable and non-influenceable costs refer to section 2.3.2.
[69]Maeding (2009), p. 2.

times, are very optimistic and influence the simulation results in a positive way. Nevertheless, despite her optimistic assumptions, the resulting IRR is always smaller than the WACC in all her calculations. This means that it is economically unfavorable to invest in any of the considered cases.

In addition to their empirical analysis discussed later in section 3.1.2, Cambini and Rondi (2010) also provide insights on the importance of the X-factor in a $RPI - X$ regulatory regime.[70] According to them, the X-factor can significantly influence the possible return of the grid operator and hence its investment decision. The larger the X-factor, the lower the allowed revenue cap becomes. This will also affect future cash flows which determine if an investment project is beneficial. Thus, uncertainty about the development of the X-factor results in uncertainty about the investment project. In particular, if it is expected that the regulator will increase the X-factor in future regulatory periods - as it can be expected in the German AReg - then this may cause an incentive to delay or even to abdicate investment.

Commissioned by the BDEW, Ballwieser (2008b) assesses the effects of the allowed return on equity that was defined by the BNetzA in July 2008. His conclusion is that the allowed return of 9.29 % does not cover the cost of capital. Hence, rationally and economically there is no incentive for an investor to invest in replacement or expansion of the grid.

In his other contribution to the AReg literature, Ballwieser (2008a) criticizes the upper limit for equity of 40 %. In theory this limit would not be reached because investments in utility assets are highly capital intensive. However, if the realized useful time of the asset is longer than the duration of the long-term liability, then the upper limit for the equity ratio can be reached. As a result, the real WACC can exceed the WACC granted by the BNetzA and costs of capital can no longer be covered.

Considering the entirety of existing articles which analyze the German AReg with all its features, it is striking that the single elements need to be designed and specified very carefully. For example, it makes a significant difference if investment budgets are approved based on planned or realized costs. The actual determination of the $X-$factor is a crucial element, as well as the allowed rate of return. All of this suggests that while the intention of a certain element like investment budgets might have been strictly beneficial, the actual specification must be designed with a lot of caution. Nevertheless, by the recent policy change for the approval of investment budgets the regulator has proven that he is responsive to such findings and is willing to improve the policy.

[70]See section 2.3.2 for some details on the $RPI - X$ scheme.

This section has discussed various contributions which all analyze the actual design of the *Anreizregulierung*, the German version of incentive regulation effective since 2009. In order to fully understand the relationship between incentive regulation and investment, it is necessary to have a look at a broader definition of incentive regulation. This is achieved with an extensive literature review in the following chapter.

3 Literature Review on Regulation and Investment

This section provides an extensive review of existing literature on the influence of regulation on investment, focusing on incentive regulation. It is organized by the method used in the reviewed contributions: in a first step empirical analyses are discussed which demonstrate that the topic has been relevant for worldwide economies for decades. Second, theoretical and analytical contributions are reviewed which lead to the model in the following chapter step by step.

3.1 Empirical Findings

In the following section, the results of different articles are discussed which empirically analyze the effects of different regulatory regimes on the affected companies. It is possible to empirically observe that regulation does indeed influence the behavior of companies. This again motivates the topic of this thesis from a practical perspective.

Concerning regulatory policy, in most articles the distinction is made between newer forms of regulation, which mostly refers to incentive regulation, and traditional cost-plus or rate-of-return regulation. Concerning the very general term “performance”, the articles study effects on different outcomes of the affected companies. Among others, these are prices, network investment, productivity or service quality.

3.1.1 Telecommunications Industry

The greatest part of empirical studies on the influence of regulation on affected companies' behavior was published in the mid to late 1990s and refers to the telecommunications industry in the United States. While this might appear surprising at first, the reason for this accumulation becomes obvious when the circumstances - in particular one specific feature of the regulatory environment in the U.S. at this time - are considered more closely: in the 1980s and 1990s, every U.S. state could constitute its regulatory regime on its own. This situation served as a "natural experiment" for researchers, as Sappington (2002) calls it.

The most comprehensive reviews on many empirical studies can be found in Kridel et al. (1996), Cowan (2002) and Sappington (2002). They all discuss the approaches and results of the main contributions.

As mentioned earlier, the different studies assess how regulation affects different aspects of the companies' performance. This can be the evolution of prices, spread of new technologies or infrastructure investment. The literature review here focuses on investment, but first, other aspects are touched upon as well in order to provide the reader with a broad understanding of the topic.

Mathios and Rogers (1989) analyze the long-distance phone call prices of AT&T, one of the major players in the industry. Since - as mentioned earlier - in the U.S. at that time, every state could determine its own regulation, they examine if the different regulatory regimes lead to different prices. They find that pricing flexibility results in significantly lower prices than rate-of-return regulation. However, their results can be questioned from a methodological perspective, since they only use a simple dummy variable technique to capture price-cap regulation.

Resende (2000) also analyzes local telephony in the United States, but he uses a different methodological approach. By combining data envelopment analysis and economic techniques, he is able to show that incentive regulation can lead to more productive efficiency than rate-of-return regulation.

The relationship between systematic risk and different regulatory regimes is in the focus of Alexander et al. (1996). In contrast to most other articles, they do not limit their data to the U.S. or the U.K., but consider a large number of countries, also in the rest of Europe and the Pacific region. Asset betas are calculated for each company for the years 1990 to 1994. It is assessed if there is a relation between certain regulatory regimes and the betas. By definition, incentive regulation is associated with higher risk than rate-of-return regulation, and Alexander et al. (1996) are able to prove this empirically: they find that in their sample, systematic risk is higher for incentive regulation than for rate-of-return regulation. The intuition behind this is that in a pure form of incentive regulation (e.g. price-cap regulation), the economic cycle - and consequently changes in costs or demand -

are not accounted for. This results in an increase in market risk for investing companies.

A holistic analysis on how incentive versus rate-of-return regulation affects various outcomes is provided by Ai and Sappington (2002). In particular, they determine the impact of regulation on network modernization, investment, revenue, cost, profit, service quality, local service rates, and telephone penetration. For this purpose, they analyze U.S. state incentive regulation between 1990 and 1996. In particular, they distinguish between three different types of incentive regulation (price-cap regulation, rate case moratoria, and earning sharing) and rate-of-return regulation. For network modernization they find a clear advantage of incentive regulation.

Furthermore, they find that price-cap regulation results in higher earnings than rate-of-return regulation. However, this result does not appear to be particularly surprising because price-cap regulation is designed to allow for higher profits when companies are able to reduce their costs. Ai and Sappington (2002) state that it is more unexpected that they could not find any significant differences in cost per access line among the considered types of regulation. This is surprising because - stated in a simplified way - one would expect that costs are reduced in a price cap regulatory regime in order to gain higher earnings. Moreover, cost reduction is not a prior objective in rate-of-return regulation because of the guaranteed return.

Another important finding in Ai's and Sappington's analysis is that they could not provide evidence for a systematic decline in service quality. This finding is in contrast to prejudices about incentive regulation and in contrast to a few observations that the incentive for cost savings is at the expense of service quality. They explain this finding by the fact that regulators are aware of this risk and consequently have introduced close quality monitoring or financial penalties for a decrease in quality.

Other studies reviewed by Kridel et al. (1996) reveal some common results, which are mostly in line with Ai and Sappington (2002). First, there are many positive effects of incentive regulation: Kridel et al. (1996) state that "productivity, infrastructure investment, profit levels, telephone penetration, and new service offerings have increased under incentive regulation."[71] Second, there is no evidence that service quality has decreased due to incentive regulation. Third, although expected, it cannot be shown that incentive regulation leads to cost reduction. For the purpose of this thesis, the main contributions particularly for infrastructure investment are depicted.

In the opinion of Kridel et al. (1996) the "most comprehensive study (...) of the rela-

[71] Kridel et al. (1996), p. 269.

tionship between incentive regulation and investment in telecommunications infrastructure"[72] is provided by Greenstein et al. (1995). With a methodologically sound analysis for the years 1986 to 1991, they are able to show that incentive regulation can foster future infrastructure investment. They argue in favor of the use of price caps instead of earnings sharing,[73] because price caps are more effective in incentivizing infrastructure investment.

Taylor et al. (1992) is another important empirical study on the effects of incentive regulation on network modernization. The authors' focus is again the U.S. telecommunications industry and they use a dataset from 1980 to 1994 to show that incentive regulation can foster the deployment of new technologies. For instance, by this time the diffusion of ISDN was in progress and the authors find evidence that by implementing incentive regulation instead of rate-of-return regulation the adoption of ISDN is accelerated by about five months.

The relatively consistent findings in Greenstein et al. (1995) and Taylor et al. (1992) are contrary to the results in Tardiff and Taylor (1993). Tardiff and Taylor use an updated dataset as well as a different operationalization of incentive regulation. This new measure of incentive regulation focuses on profit incentives and not any longer on more "soft" incentive regulation features like pricing flexibility. In order to distinguish their analysis from the earlier article, Tardiff and Taylor (1993) criticize that any regulatory reform was considered a form of incentive regulation by Taylor et al. (1992). Obviously, this is an extremely broad definition of incentive regulation and does not capture a more specific design of regulatory policy.

Under these circumstances, the authors do not find any statistically significant relation between the development of infrastructure and incentive regulation.[74] The different results in these two studies illustrate that only the actual definition of incentive regulation can lead to very different results. This fact shows that in empirical studies the specific definition of variables can have a tremendous effect and that conclusions cannot be drawn lightly.

Another literature review on empirical studies is provided by Sappington (2002) with his contribution to the "Handbook of Telecommunications Economics". For the topic of

[72] Kridel et al. (1996), p. 293.

[73] Earnings sharing is a form of incentive regulation which was popular in the regulation of U.S. telecommunications in the 1990s. The idea is to admit some flexibility in earnings to the affected companies, under the condition that they have to share extra earnings with their customers.

[74] Considering the mentioned pricing flexibility, a possible explanation can be found in the so-called *competition effect pitfall*. This means that observed benefits are credited to lighter regulation, but in fact they result from increased competition. In this case, the formerly involved pricing flexibility can result from competition.

network investment and network modernization, he also reviews the studies of Greenstein et al. (1995), Taylor et al. (1992), Tardiff and Taylor (1993) and Ai and Sappington (2002), and he interprets their results for the largest part similarly to Cowan (2002) and Kridel et al. (1996).

In terms of network modernization, Sappington provides an important observation for a drawback in Greenstein et al. (1995) and Ai and Sappington (2002). Neither one of the articles accounts for the fact that some parts of investments are not made voluntarily, because incentive plans often mandate network modernization investments. It is likely that investment was strongly affected by this investment requirement, because in the early years of incentive regulation, large increases in network modernization were observed.

Summarizing, the largest part of the reviewed studies on the relation between incentive regulation and the behavior of affected companies in the telecommunications industry do find that incentive regulation has positive effects. These effects concern infrastructure investment as well as the spread of new technologies or price levels. However, as the comparison of Tardiff and Taylor (1993) and Taylor et al. (1992) shows, knowing how "incentive regulation" is in fact defined and operationalized is crucial for the outcomes of an analysis. Furthermore, the specific design and rules of a policy must be accounted for, such as mandatory infrastructure investment.

Furthermore, none of the reviewed results focus in any kind of way on the actual determination of regulated prices within an incentive regulation policy, which is a crucial part of the model in this thesis. However, it is fairly obvious why this issue has been neglected in empirical studies to date: it is difficult to capture the influence of actual price determination (e.g. used depreciation method, timing of cost review, used interest rate) statistically. The reason is that in a regulatory regime, these procedures are defined ex ante and do not change over a certain period. Hence, in order to empirically observe the influence of one of these factors, an event study about a change in regulatory policy, which only affects this particular factor, would be necessary.

3.1.2 Electricity Industry

In contrast to the telecommunications industry, where many empirical studies can be found, the empirical literature on how regulation affects investment in the electricity grid is scarce. This has among others been acknowledged by Cambini and Rondi (2010) and Joskow (2006b). Joskow states that "the empirical research on the performance of incentive regulation in the telecommunications sector is much more extensive than is the research on electricity and gas networks."[75]

Reasons that can explain this phenomena are detailed here. First, in contrast to the electricity industry, regulation changed much earlier for telecommunications. There was a tremendous change in the telecommunications industry in the 1980s and 1990s, mostly due to the liberalization of the market. This made it possible to empirically study the effects of this change in the consecutive years. Furthermore, the "natural experiment" mentioned earlier - the fact that regulation was different from state to state in the U.S. - provided a fertile environment for these studies.

In the electricity industry, however, the change in regulation is relatively young. Particularly for the German incentive regulation, empirical investigation has been impossible to date, because the AReg was only introduced in 2009, and more time is required to observe effects. As Jamasb and Pollitt (2007) state, "the effects of incentive-based regulation can best be assessed in the long run, as the firms need time to adjust to their new operating environment, and the sector regulators must gain experience."[76] Consequently, the few empirical studies focusing on the electricity industry do not - for the large part - consider the German regulatory regime, but other countries instead. Nevertheless, the findings in these studies do provide some insights and a vision for the general consequences of electricity grid regulation. These results will be discussed in the following.

Generally speaking, the reviewed studies are ambiguous and difficult to compare with each other. This is because first, they all assess different countries, which differ largely in their regulatory regimes. Additionally, fairly different questions are addressed with different approaches. The range of topics discussed is broad: whereas one study focuses on the influence of expected profits on investment behavior, another study assesses how important an independent regulator is in combination with incentive regulation. The existing contributions nevertheless provide valuable insights and hence will be illustrated in the following.

Experiences from Finland

Kinnunen (2006) analyzes investment incentives provided by the Finnish regulation between 1997 and 2001. For investment, she distinguishes between new physical assets (length of grid lines) and monetary investments (sum of investment outlays). Moreover, she studies the development of investment after liberalization. Briefly summarized, Kin-

[75] Joskow (2006b), p. 54.
[76] Jamasb and Pollitt (2007), p. 6163.

nunen (2006) did not find any dramatic changes in the investment volumes, but one can note that the volumes are highly variable depending on the year. She runs regressions in order to answer the question whether and to what extent investment is affected by expectations for sales, profits, return on equity, or return on invested capital.

For the Finnish regulatory regime, the ex post regulation was effective until 2005. Its distinctiveness was the ex post assessment, which provides the affected companies with more freedom, a policy that is in contrast to "classic" ex ante price-cap regulation. The regime was a mixture of cost-based rate-of-return and incentive regulation. The goal was to find a price which would incorporate efficient operating costs as well as an adequate return on capital. The "adequate" rate of return was set ex post by the regulator with regard to the risk to which the company was exposed. However, this rate was not considered adequate by the affected companies. In particular, they argued that this rate was too low to incentivize investment. Furthermore, the uncertainty resulting from the ex post approval of the rate of return was a major influencing factor on investment incentives.

Regarding the empirical results, Kinnunen (2006) first considers physical assets, particularly the length of lines. She finds that the ratio of distributed electricity and line lengths at high voltage level decreases. This finding can be interpreted ambiguously: it could indicate a more efficient use of the distribution grid capacity, i.e. a reduction of excess capacity. However, this can only be considered good news if enough capacity is provided from a social welfare or macroeconomic perspective. If this is not the case, then this decrease indicates that Finland will not be able to meet the demand for electricity distribution in the future, and that as a result, investment in the grid is critically important.

In terms of monetary investment in the grid, Kinnunen (2006) illustrates that the amount of investment and the energy consumption develop in different directions. Energy consumption increases, whereas no increase in investment can be observed. Yet, she argues that a possible explanation can be that investment has "become cheaper", such that the absolute values for investment do not change, but the same amount of money can result in more physical investment.

In order to provide a statistically sound analysis of the relation between factors that are considered to have an influence on investment behavior and the *actual* investment behavior of the affected companies, she runs an ordinary least squares (OLS) regression analysis for the years 1997 to 2001. The factors which she includes into the analysis as explanatory variables are value of sales and profit, return on equity, and return on invested capital. She states that "the level of the value of sales (...) had the by far the highest explanatory power."[77] The value of profit was also an important influencing factor.

In contrast to sales and profits, return on equity and return on invested capital seem to play a less important role. The results are statistically significant in some years, but not in all. Her interpretation of these findings is that future expectations on predicted sales and profits play a major role for investment decisions.

Kinnunen (2006) concludes that although her results show a statistically significant relationship between the explanatory variables and investment behavior, many influencing factors are not captured in the model. For instance, long-term perspectives must be analyzed in more detail. Moreover, uncertainty about the regulatory regime can have a tremendous impact on investment and can result in negative investment incentives, but this should be modeled more explicitly. In summary, in her opinion, it cannot be stated that the regulatory regime has played a significant role in discouraging investment.

Experiences from the United Kingdom

Another study which examines the experiences with incentive regulation in the electricity network sector is Jamasb and Pollitt (2007). They focus on the electricity distribution network in the United Kingdom.[78] They discuss the historical development of regulation and status quo in the U.K., analyze incentive regulation from a theoretical perspective and examine its effects. Lastly, they provide recommendations for further developments of the regulatory policy.

The authors find that in the U.K., the incentive regulation scheme was successful in the reduction of costs, prices and energy losses. Furthermore, they do not find any decrease in the quality of service, which is in line with the results of Ai and Sappington (2002) and others for the telecommunications industry.

In order to foster efficient investment, in 2005 to 2010 a distribution price control review was implemented which included a sliding scale system for capital investments. A capital budgeting scheme was introduced that induces the companies to correctly reveal their actual investment costs. This scheme was of a "menu of contracts" type, which is for instance suggested in Laffont and Tirole (1993) or Baron (1989).

[77] Kinnunen (2006), p. 860.

[78] Whereas Jamasb and Pollitt (2007) mostly talk about distribution networks, their analysis also affects the transmission grid. One particularity of the U.K. system is that twelve regional electricity companies fully own the National Grid Company, which is responsible for transmission. Each of these regional electricity companies owns and operates its own distribution grid.

As for the empirical assessment whether efficient investment was stimulated, Jamasb and Pollitt (2007) analyze data from the Office of the Gas and Electricity Markets (Ofgem), which is the regulatory authority in the United Kingdom. They find that capital expenditures in the U.K. electricity distribution network have increased since the beginning of the 1980s. This was when the liberalization of the energy market started. However, it should be noted that a short-term increase in expenditures does not necessarily lead to efficiency improvement. The development of capital investment in the U.K. electricity distribution network is shown in Figure 3.1.

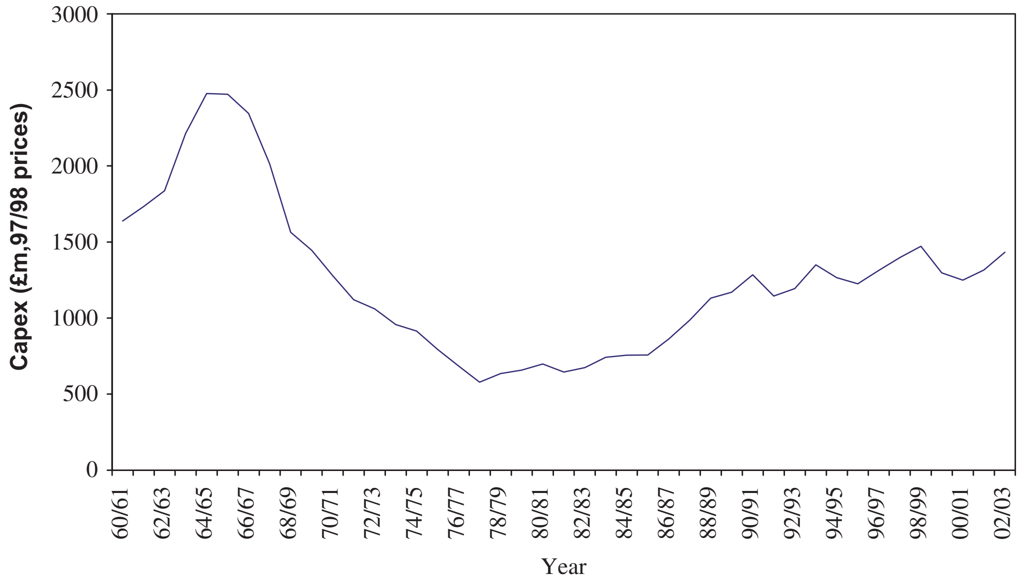


Figure 3.1: Capital investment in the U.K. electricity distribution network, 1960-2003.[79]

As Jamasb and Pollitt (2007) themselves do criticize their analysis because of the lack in long-term assessment, no general conclusions can be drawn from the observed increase in capital expenditures. This again shows that it is difficult to precisely isolate the effects of regulation on important issues such as long-term efficient investment. However, Jamasb and Pollitt (2007) state that there are many valuable "lessons learned" from the U.K. experience of incentive regulation which other countries can build upon.

Experiences from Norway

The effects of the Norwegian electricity market reform in 1990 is the main focus of Bye and Hope (2005). They analyze different outcomes like changes in prices, investment in power

[79]Source: Jamasb and Pollitt (2007).

plants and also investment in network capacity. In Norway, the transmission companies were first subject to a rate-of-return regulation which was changed to a revenue-cap policy in 1997.

Regarding network investment, they find a significant reduction in network capacity investment after the reform in 1990. This is illustrated in Figure 3.2. They see two reasons for this development: first, in the 1980s, there was a massive increase in electricity demand which resulted in a large need for capacity investment in the distribution network. These investment projects were mostly finished by 1990, so by then, the existing capacity was sufficient and no new investment was necessary. But this fact was not the only reason for the significant decrease in network investment. Second, Bye and Hope (2005) state that the new regulatory policy reduced the profitability of new investment.

The change of regulatory policies has parallels to the regulatory reform in Germany: a cost-based regime was given up for revenue-cap regulation, a much more incentive-based policy. As Bye and Hope (2005) could find a negative influence on the profitability of new investments, this effect may be observable in Germany in some years as well.

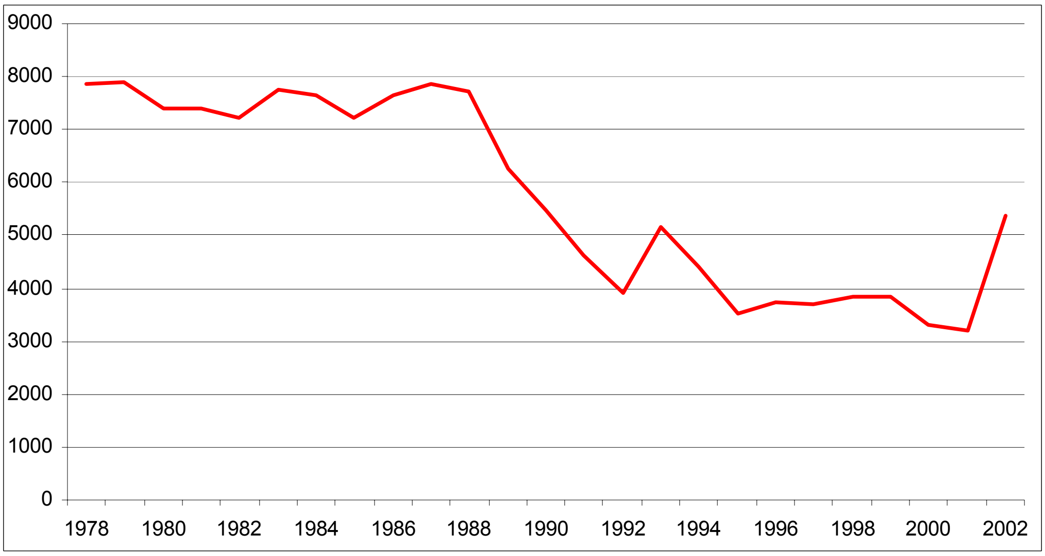


Figure 3.2: Investment in network capacity in Norway, 1978-2002.[80]

Experiences from selected other countries

Egert (2009) provides a theoretical as well as empirical analysis of incentive regulation with

[80]Source: Bye and Hope (2005).

regard to infrastructure investment. His sample consists of selected OECD countries, and he analyzes different regulated sectors. His focus is on the independency of the regulatory authority.

In the empirical part of his article he argues that if implemented without any connection, neither an independent regulator nor incentive price regulation itself can promote new infrastructure investment. It is crucial that both are implemented jointly. If this is fulfilled, then a significant increase in investment can be observed. Moreover, Egert (2009) is able to show the importance of low entry barriers for fostering investment.[81]

In more detail, before starting his own analysis, he reviews earlier empirical findings. He does not limit those to the electricity industry, but also considers other important network industries. For railway, the dominant example in the literature is the liberalization of the U.K. railway system in the 1990s. Although significant declines in service quality are the dominant public impression, and although these declines are blamed to massive underinvestment, there is no empirical evidence for a systematic underinvestment.[82] For telecommunications, he reviews the same articles as Cowan (2002) or Kridel et al. (1996), which for the most part find a positive correlation between incentive regulation and investment, particularly for fostering new technologies. However, contrary to the earlier analyses he includes one newer article with more differentiated results into his review. Based on a cross sectional dataset for 2001, Floyd and Gabel (2003) find that investment in certain kinds of new technologies is encouraged more strongly by rate-of-return regulation than by incentive regulation.

For his own empirical analysis, Egert (2009) collects data on the regulatory regimes in selected OECD countries via a questionnaire and data on investment in different sectors from the OECD STAN database. He runs cross sectional regressions for different sectors under different regulatory regimes. Sectoral investment is the dependent variable. He states that his analysis is not longitudinal, but only provides a snapshot for the time around the end of 2007 to beginning of 2008.

It must be noted that Egert (2009) does not limit his analysis to the electricity industry, but he assesses various sectors: electricity, gas and water supply, road, rail, water and air transportation are subject of his analysis. This is because his intention is not to analyze the development of investment for one particular sector over a certain period of time, but to assess the relation between the general setup of a regulatory regime and investment behavior.

[81] This result confirms earlier work of Alesina et al. (2005).
[82] See among others Affuso and Newberry (2000), Clark et al. (2001) or Pollitt (2000).

As for the results of the OLS regressions, he finds that "lagged investment, barriers to entry and the interaction term including regulatory independence and incentive regulation are significantly correlated with contemporaneous investment."[83] As briefly mentioned above, this analysis also reveals that the combination of an independent regulator and incentive regulation is crucial to foster investment. This can serve as a proof that finding the right regulatory policy mix is particularly important. Furthermore, by using a Bayesian averaging of classical estimates approach, Egert can support the claim of some earlier literature that keeping entry barriers low is necessary for encouraging investment.

Cambini and Rondi (2010) provide another empirical analysis of investment under regulation. They assess whether incentive regulation or rate-of-return regulation set better incentives for investment. Using a sample of EU energy utilities from 1997 to 2007, they are able to show that incentive regulation is superior in this matter. Their analysis further shows the importance of the X-factor for fostering investment, which has already been illustrated in section 2.3.4.

In contrast to the majority of other articles that focus on developed countries, Vagliasindi (2004) assesses infrastructure investment in transition economies.[84] Using OLS regressions and case studies, she investigates whether investment in infrastructure has led to better quality and reliability of services. Vagliasindi is able to show that "increased investment, tariff increases and the establishment of an independent regulator are all significantly associated to the reduction of power and telecom outages."[85] While she does not investigate a specific regulatory regime, her results are in line with Egert (2009), who also argues for the importance of an independent regulator.

Summarizing, the review of existing empirical analyses on the relation between incentive regulation and investment in the electricity grid does not reveal a distinct result. It can be suspected that in a real, practical regulatory regime, there are many influencing factors that are difficult to capture in an empirical analysis. These important influencing factors can range from mandatory investment in the past over uncertainty about a granted return, to the independence of the regulatory agency. However, based on empirical analyses, it seems likely that incentive regulation by itself has not systematically changed investment behavior of affected companies.

Whereas the discussion of the empirical literature on regulation and investment proves

[83] Egert (2009), p. 17.
[84] She focuses on countries in South East Europe. Her sample includes among others Azerbaijan, Albania, Georgia, Romania and the Ukraine.
[85] Vagliasindi (2004), p. 303.

the relevance of the topic, it also appears that an empirical investigation might not be the most adequate instrument to analyze this relationship. Certain effects can be isolated in a better and more obvious way by theoretical and analytical assessments. This conjecture is supported by the fact that in the existing literature there are many more analytical than empirical analyses of the relationship between regulation and investment. The following sections review these theoretical and analytical analyses.

3.2 Theoretical and Conceptual Discussions

Theoretical literature on the relationship between regulation and investment is vast. Vogelsang (2010) even states that this relationship "appears to be an evergreen problem", which emphasizes that there is still room for further research. The purpose of this section is to provide an overview of existing theoretical and conceptual discussions on this relationship. Formal models are omitted first but revisited and discussed extensively in the following section 3.3. Other recent and extensive literature reviews can be found in Guthrie (2006), Cambini and Jiang (2009) or Vogelsang (2010).

In contrast to section 2.3.4, which discusses existing literature concerning the actual German *Anreizregulierung* and its features, this section provides a survey of theoretical and conceptual discussions on more general forms of incentive regulation. The successive section 3.3 views more specific analytical approaches which are of particular importance for the model developed in chapter 4.

Numerous forms of regulation exist. As the detailed description of these different forms is not the purpose of this thesis, refer to Knieps (2005) or Train (1991) for an extensive and broad illustration.

As an introduction to the theoretical discussion on regulation and investment, it is important to understand how the reimbursement of costs and the provision of incentives are treated by the different forms of regulation. Kretschmer et al. (2011) classify different forms according to the extent that prices are based upon the company's incurred costs. This is schematically illustrated in Figure 3.3.

The authors identify two reference points: starting at complete reimbursement of all costs, the cost orientation decreases continuously over cost-plus regulation, rate-of-return regulation, revenue-cap and price-cap regulation until a company's revenues are completely independent from its costs in perfect yardstick competition. While cost orientation decreases continuously, incentives and risk increase at the same time. According to Kretschmer et al. (2011) in the upper reference point of complete cost reimbursement, there is no risk for the company and no incentive for efficiency or cost reduction, since the regulator simply includes all costs into the regulated price. This effect is also known as the *gold-plating effect*.[86] The lower reference point is closest to a competitive setting in which risk is completely born by the companies.

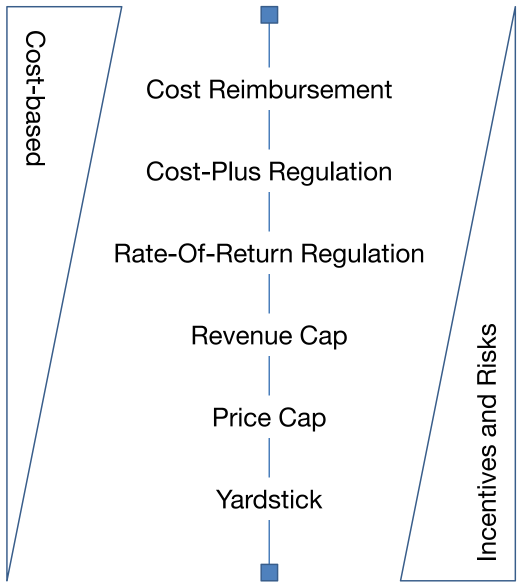


Figure 3.3: Cost orientation and incentives for different forms of regulation.[87]

Generally speaking, the regulatory systems in the upper half of the figure can be denoted *cost-based* systems whereas the lower half represents *incentive based* systems. In the following review of articles, the focus is put on incentive based regulatory systems, and the other forms of regulation are touched upon shortly.

Stated briefly, the main criticism of rate-of-return regulation is that it can induce excessive investment and does not set incentives for either efficiency improvements or low consumer prices. This has been recognized early by Averch and Johnson (1962).[88] In contrast to this, in the opinion of Vogelsang (2010), incentive regulation provides incentives for efficiency improvements and low consumer prices.

The identified weaknesses of rate-of-return regulation concerning efficiency improvements and cost reduction led to the development of incentive regulation policies. One

[86]See for instance Ajodhia et al. (2004).
[87]Source: own illustration based on Kretschmer et al. (2011).
[88]The article of Averch and Johnson (1962) is discussed in more detail in section 3.3.1.

specification of incentive regulation is price-cap regulation, which is also the dominant form of incentive regulation in the literature. In a price-cap regulation scheme, a maximum price for the relevant product or service is set by the regulator.[89]

Historically, Stephen Littlechild (1983) was the first to propose price-cap regulation in the course of the privatization of British Telecom in the U.K. in the early 1980s. Based on this report, Littlechild published an article jointly with Michael Beesley on the regulation of privatized monopolies in the U.K. (Beesley and Littlechild (1989)). In their article, they explicitly address the differences between price-cap regulation, which is present in the United Kingdom, and rate-of-return regulation, which can mainly be found in the United States. They identify criteria to determine under which circumstances a certain regulation method is more advantageous. Furthermore, they analyze which regulation scheme encourages competition.

Their result is that price-cap regulation is beneficial in industries where technology is changing slowly. Consequently, they recommend the use of price-cap regulation in telecommunications, gas supply, and electricity supply and rate-of-return regulation in gas and electricity transmissions grids.

Later, it was recognized that the cost reduction effect of "pure" forms of incentive regulation like price-cap regulation can lead to a decrease in quality and hence a decrease in liability of the assets. Hence, the focus was put on better incentive mechanisms which guarantee efficient investment and no loss in quality. Most attention was put on long-term effects of regulation on investment. The article of von Hirschhausen et al. (2004) focuses on these long-run effects of regulation on infrastructure. The authors see a particular necessity to account for these long-run effects in the design of regulatory policies. Other articles that stress this importance include Brunekreeft (2004), Burns and Riechmann (2004), Keller and Wild (2004) or Vagliasindi (2004). The authors argue that long-term effects must be of particular concern in the design of regulatory policies. In their opinion, underinvestment in the electricity grid is jointly responsible for power black-outs.

Joskow (2006b) provides a vast and substantial review of incentive regulation in electricity networks. He discusses the theoretical background of incentive regulation regimes as well as the practical implementation of such systems. He uses the U.K. as an example and emphasizes the link between theory and practice.

[89] For general discussions on the differences between rate-of-return regulation and price-cap regulation, see among others Acton and Vogelsang (1989), Cabral and Riordan (1989), Braeutigam and Panzar (1993), Liston (1993), Sappington (1994), Sappington (2002), Joskow (2006a) or Armstrong and Sappington (2007).

In his analysis, Joskow points out that there is a gap between idealized theoretical models of incentive regulation and their practical implementation. He states that "incentive regulation in practice is considerably more complicated than incentive regulation in theory."[90] This statement is followed by ten observations concerning the relation between theory and practice. For instance, in order to overcome adverse selection and moral hazard problems[91] he suggests that a menu of cost-contingent incentive contracts should be offered to the firm.

Generally speaking, his basic conclusion is that incentive mechanisms largely depend on the actual design of a regulatory regime with all its facets. Hence, although theoretical and analytical analyses can provide insights into the underlying dynamics and functionality of a certain policy, many real life issues are difficult to capture.

Similar to his 2006 contribution, Joskow (2008) discusses theory and application of incentive regulation in the context of electricity networks. As for the application, he again uses the U.K. as his primary example for price-cap regulation. He illustrates various issues that appear when an incentive regulation scheme is implemented in practice: service quality, determination of efficiency requirements (X-factor) or the performance of the company. His analysis is in line with other articles addressing the weaknesses of incentive regulation for long-term infrastructure investment.

Burns and Riechmann (2004) discuss how different regulatory instruments can affect investment behavior. They identify four important issues that should be accounted for in order to induce efficient investment. First, they stress the importance of service quality which must be measured by output instead of input. Second, they suggest the use of comparative efficiency analysis for evaluating output, as long as - third - all costs (in particular capital costs) are involved in this analysis. Last, they emphasize the importance of the regulator's commitment.[92]

Another very important author in the field of regulation and investment is Ingo Vogelsang, who has published many articles on this subject.[93] In his 2002 article, he provides a broad review on incentive regulation in different dimensions. He characterizes the regime and illustrates different specifications. Starting with classic specifications like price caps or yardstick regulation, he further illustrates approaches like rate moratoria, profit sharing, banded rate-of-return regulation or menu of contracts regulation. He discusses the

[90] Joskow (2006b), p. 51.
[91] See Laffont and Tirole (1993) or Armstrong and Sappington (2007) for information asymmetry issues.
[92] This issue is discussed in depth in section 3.4.1.
[93] See among others Vogelsang (1988), Vogelsang (2001), Vogelsang (2002), Vogelsang (2003), Vogelsang (2006) and Vogelsang (2010).

implications of these different forms of incentive regulation for capital investment decisions. Moreover, he illustrates the effects of incentive regulation on cost reduction, service quality and allocative efficiency and distinguishes between a monopoly and a competitive setting.

Furthermore, Vogelsang illustrates the experiences with, as well as the development and implications of incentive regulation over the 20 preceding years. He finds that, although price-cap regulation may have good incentive features from a theoretical perspective, it largely depends on the actual implementation of the regime by the actual regulator as to whether the desired effects can be realized. In his opinion, it is questionable if recent optimal regulation literature is highly relevant for practical purposes. His 2010 article is skeptical concerning the impact of incentive regulation. He states that due to the impossibility of full commitment from the regulator, "the compatibility of incentive regulation and efficient investment is (...) in doubt."[94]

Summarizing the illustrated conceptual analyses of incentive regulation, it can be stated that whereas particular effects can be isolated in analytical models, the actual implementation of a incentive regulation policy requires a lot of consideration and detailed accounting for real life circumstances. The focus on long-term effects which include the preservation of quality is an important issue.

Coming back to the lower reference point of Kretschmer's et al. (2011) classification (see Figure 3.3), the version of incentive regulation which emphasizes cost reductions most strongly is yardstick competition. One of the most comprehensive analyses of yardstick competition can be found in Shleifer (1985). In this article, the basic theory and mechanisms of yardstick competition are illustrated vastly.

The underlying idea of yardstick competition is to artificially build a competitive environment. This is achieved by making the performance requirements for one firm dependent on comparable firms. Various dimensions can be addressed by the term "performance": this may be the level of costs, efficiency or even quality. It is hence important that the firms are in fact comparable[95] and operate in the same market environment.

The main advantage of yardstick competition is that the regulator can incentivize desired behavior, despite his limited knowledge of the operating environment of the firm. This is beneficial, because high information needs hampers the implementation of a regulatory policy.

[94]Vogelsang (2010), p. 1.
[95]In the pure form of yardstick competition, it even is required that the affected firms are *identical*.

However, it must be noted that one crucial requirement is that the firms face no uncertainty. Otherwise, they would be exposed to a very high amount of risk. Nevertheless, Armstrong and Sappington (2007) state that "it is generally optimal to condition each firm's reward on the performance of other firms, thereby incorporating yardstick competition to some degree."[96] Shleifer (1985) concludes that "yardstick competition is likely to outperform cost-of-service regulation."[97]

One important shortcoming of the system is the possibility to manipulate a yardstick scheme if all affected companies are collusive. The regulator must actively work against this. Moreover, as Armstrong and Sappington (2007) illustrate, yardstick competition might discourage innovation, in particular in the presence of spillover effects[98] or limited regulator's commitment.

Dalen (1998) provides another analysis of investment incentives set by yardstick competition. His model involves uncertainty about the regulatory policy; the regulator is unable to commit to a certain policy before the firms invest.

In his analysis, he distinguishes between industry-specific investment and firm-specific investment. The former refers to investment from which the entire industry benefits (spillover). This is mainly research and development, or innovation in general. The latter denotes investment which leads to a firm-specific advantage relative to the other companies in the industry. Dalen (1998) is able to show that while yardstick competition reduces industry-specific investment, it increases firm-specific investment. Dalen states that this finding is new in a sense that in earlier models "the effect of yardstick competition is shown to be unambiguously positive for the regulator."[99]

Intuitively speaking, this result is not very surprising. In a yardstick competition setting, benefits for one firm result from being more efficient than its peer group. However, industry-specific investment is beneficial for the entire industry, but does not lead to an advantage for the investing firm in comparison to the peer group. Hence, as Dalen states, industry-specific investment does not change the relative position of the firm.

Although it is not unexpected, this finding yet is particularly severe considering present challenges in the electricity grid. For instance, in order to be able to deal with the integration of renewable energies, technological innovation is crucial. These can include smart

[96] Armstrong and Sappington (2007), p. 76.
[97] Shleifer (1985), p. 326.
[98] This issue is the main subject in Dalen (1998), who also finds that yardstick competition does not encourage industry-specific investment.
[99] Dalen (1998), p. 106.

grids, or any other new technology to manage load balance. Obviously, such innovation is industry-specific and not firm-specific. Thus, following Dalen's results, yardstick competition is not the appropriate way to incentivize such important innovations.

In summary, there is a tremendous amount of theoretical and conceptual literature which analyzes the effects of incentive regulation, ranging from rate-of-return regulation over price-cap regulation to yardstick competition. As for the effects, the articles focus on efficiency improvements, cost reduction, service quality, infrastructure investment and others. While incentive regulation is mostly found to set the right incentives for efficiency improvements and cost reductions, distortions in infrastructure investment and service quality are found frequently.

This means that on the one hand, these issues need to be precisely accounted for in the actual design of a regulatory policy.[100] On the other hand, many aspects of the relation between incentive regulation and infrastructure investment still need to be assessed in more detail in analytical models.

3.3 Formal Analytical Models

The purpose of this section is to review existing analytical models on regulation and investment which are of particular importance for the model developed in chapter 4. To this end, in a first step more general single-period models are reviewed, in a second step multi-period models are turned to. Based on this discussion the research gap evolves and is addressed in detail in the following model.

3.3.1 Single-period Models

In this section, rate-of-return regulation is touched upon briefly, but the focus is on incentive regulation in different specifications. The idea of rate-of-return regulation is to concede an adequate return on invested capital to a company. Some of the first authors to analyze investment incentives resulting from rate-of-return regulation in a formal model are Averch and Johnson (1962). Under their restrictive model assumptions[101] they find

[100] This has been realized in the actual design of the German AReg by explicitly including a quality element and investment budgets in the policy.

[101] Averch and Johnson (1962) assume the company to have just one product, that there are only capital and labor as factors of production, which are substitutable, and that factor costs are independent of output and cannot be influenced.

that there is an incentive to replace labor by capital. Economically, this is an undesired effect, which has become known as the *Averch-Johnson effect*. One restriction of the model in Averch and Johnson (1962) is that the rate of return cannot exceed the monopolistic rate. This assumption was modified by Bawa and Sibley (1980) who allow for a higher rate of return.

The literature on rate-of-return regulation was subsequently extended by the analysis of other factors. According to Vogelsang (2010), these factors were the integration of a regulatory lag[102], the discussion on the adequate determination of the rate base[103], and the application of the so-called used-and-useful criteria.[104]

A holistic analytical assessment of price-cap regulation can be found in Brennan (1989). He analyzes the theoretical underpinnings and properties of price-caps in a setting of a multiproduct regulated firm. In particular, he discusses what he believes should be the basis for setting regulated prices, and he perceives using costs critically. In his view, there are several disadvantages of directly attaching prices to costs like production inefficiency or quality issues.

In order to overcome several problems of price caps, he suggests the introduction of a "regulatory lag": this is a period without any price changes, such that companies have the possibility to increase their profits by reducing costs. In fact, even though it is not mentioned directly, this in fact implicates revenue-cap regulation instead of price-cap regulation.

When talking about the effects of incentive regulation on investment, it must be distinguished between the exact type of investment. This is crucial, because whereas incentive regulation is generally known to set efficient incentives for cost-reducing investment, in its pure form it only poorly encourages infrastructure investment. This fact is acknowledged widely in the literature. Armstrong and Sappington (2006) and Guthrie (2006) illustrate that it depends on the type of investment - investment in cost reduction or in infrastructure - for how regulatory policies affect investment decisions. Cambini and Rondi (2010) state that "price cap mechanisms may weaken the incentive to invest in new infrastruc-

[102] Regulatory lag refers to a period of time in which regulatory policy does not get changed, see e.g. Baumol and Klevorick (1970), Bailey and Coleman (1971), Joskow and MacAvoy (1975).

[103] Here, the central question was whether to use replacement costs or historic costs, see e.g. Evans and Guthrie (2005), Evans and Guthrie (2006), Guthrie (2006). For a discussion of this topic in the context of this thesis see section 3.4.3.

[104] This criteria means an asset can only be included in the rate base if it is used and useful. Supporters of its use are Gilbert and Newbery (1994) and Newberry (2000) while Egert (2009) expresses some criticism. Baumol and Sidak (2002) analyzes the criteria in case of low demand or excess capacity.

ture."[105] All forms of investment have been analyzed in formal models, which will be discussed in the following.

Impact on cost-reducing investment

There is a stream of literature that focuses on the effects of incentive regulation for cost reduction. Achieving cost reduction by detaching prices from costs is one of the main goals of incentive regulation. Cabral and Riordan (1989) provide a formal analysis of this topic. They find that price-cap regulation encourages the company's investment incentives for cost reduction compared to rate-of-return regulation. However, they advise against price caps that are too low, which can destroy investment incentives completely.

Cabral's and Riordan's analysis is subject to fairly tight restrictions: they assume full commitment of the regulator as well as an infinite time horizon. Biglaiser and Riordan (2000) extend the analysis. They find that investment incentives depend on the length of the commitment. However, they still argue for price-cap regulation instead of rate-of-return regulation if timely capital replacement investments should be incentivized.[106]

Later, aspects of uncertainty are incorporated in these models.[107] For instance, Roques and Savva (2009) investigate the actual level of the price cap. They find that a tight price cap can destroy investment incentives, whereas a relatively high price cap has desirable effects. Similar results can be found in Rammerstorfer and Nagel (2009). Other articles which deal with uncertainty issues are Panteghini and Scarpa (2003) and Moretto et al. (2008). According to Guthrie (2006) issues of uncertainty and irreversibility are crucial for the effects of incentive regulation on investment and more research is needed on these topics.

Impact on infrastructure investment

If incentive regulation is considered in a simplified way, its effectiveness for inducing infrastructure investment can be doubted. According to Armstrong and Sappington (2006), in the purest version of incentive regulation, which simply aims at cost reduction, infrastructure investment would not be induced, since they cause additional capital costs. As rate-of-return regulation "rewards" a high asset base, it is more suitable for infrastructure

[105] Cambini and Rondi (2010), p. 4.
[106] Their article is discussed in more detail later in this section.
[107] A more detailed discussion of the influence of uncertainty can be found later in this chapter.

investment. However, of course these dynamics are well-known and mostly countervailed by the specific design of incentive regulation schemes.

Biglaiser and Riordan (2000) compare the effectiveness of rate-of-return regulation versus price-cap regulation for replacement investment. They find that the former does not provide incentives for replacement investment. Price-cap regulation is superior in this matter, as companies can achieve additional profits by costs reductions, which can result from early capital replacement investment.

Furthermore, they address the question of how the length of the regulatory period affects investment behavior in a price-cap regulatory regime. They find that if the regulatory period is too short, then price-cap regulation loses its advantages compared to rate-of-return regulation. On the other hand, if a regulatory period is long, then the company replaces capacity mostly at the beginning of the period, and there are no incentives for investment near the end of the period.

Long-run effects are also in the focus of Matsukawa (2008). His goal is to determine the long-run effects on investment and social welfare resulting from revenue-cap regulation for a electricity transmission monopolist. In his article, the monopolist's goal is to maximize expected profits subject to a cap on his expected average revenues. Using a static model with stochastic demand, Matsukawa (2008) can show that revenue regulation leads to a lower access fee, sets incentives for investment in the transmission grid, and increases consumer surplus.

Summarizing, the discussed formal models in general draw the same conclusions as the theoretical analyses illustrated in section 3.2. It is easy to show that incentive regulation and in particular price-cap regulation encourages cost reduction and improvement in efficiency. However, setting the right incentives for infrastructure investment and the maintenance of service quality is difficult to achieve.

3.3.2 Multi-period Models

The model developed in this thesis focuses on the aspect that infrastructure investment lasts over multiple periods. Consequently, in order to illustrate the research gap in detail, related multi-period models are discussed in this section. Before actually coming to models on regulation, models in a wider context will be addressed.

An important basis for the analysis of regulation and investment has been built by the literature analyzing investment incentive issues in the context of divisional managers. The basic setting of this literature is that investment decisions are not made by the owner of a company but by a divisional manager. The authority for these decisions is granted to the manager because he is better informed about the investment project. The information asymmetry between owner and manager represents a classical principal-agent setting.[108]

It is intuitive that the owner/ manager setting has many analogies with the regulator/ regulated company setting. In both cases the investment decision is delegated to a better informed agent (manager or regulated company). This investment decision affects the principal's objectives which is in general a maximization of the market value of the firm for the owner and maximization of social welfare for the regulator. Although the agent's investment decision is very important for the principal, it can only be influenced indirectly, and the principal needs certain means to incentivize the agent to make the right decision.

Pioneering work in this field has been done by Solomons (1965). The literature has mostly been extended starting in the 1990s. Fundamental contributions are Rogerson (1997) and Reichelstein (1997)[109] who develop a specific cost allocation rule, which is called the *relative benefit cost allocation rule* (RBCA). This rule assigns a cost share consisting of depreciation and interest costs to each period such that this share represents the expected future cash flows in this period relative to the discounted total sum of all future cash flows. Rogerson (1997) as well as Reichelstein (1997) argue for the use of this cost allocation rule and illustrate that, if residual income is calculated using this rule, and the manager's compensation is tied to residual income, then the manager always chooses the efficient investment level. Reichelstein (1997) shows that if the owner's and the manager's time preferences diverge, then this is the unique cost allocation rule which leads to goal congruence.[110]

The basic idea of the relative benefit cost allocation rule has been developed further ever since, mainly by William Rogerson, Stefan Reichelstein, Sunil Dutta and Madhav Rajan.[111] Rogerson (2008) develops the *relative replacement cost rule* (RRC), which in contrast to the RBCA rule does not require demand as an input. Whereas the model in Rogerson (2008)

[108]The principal-agent theory is an important theory for behavioral interdependencies within a firm. Literature on this theory is vast, see for instance Jensen and Meckling (1976), Macho-Stadler and Pérez-Castrillo (1997), Salanié (1997), Schweizer (1999), Jost (2004) or Küpper (2008a).

[109]There are many more important contributions in this field, but they are not discussed in further detail. See among others Baldenius and Ziv (2003), Friedl (2005), Friedl (2006), Bareket and Mohnen (2007) or Pfeiffer and Schneider (2007).

[110]*Goal congruence* is a term describing corresponding objectives of owner and manager. According to Reichelstein (1997), goal congruence means that the manager has an incentive to accept all projects with a positive NPV, and only those projects.

[111]See Dutta and Reichelstein (2002), Rogerson (2008), Rajan and Reichelstein (2009), Dutta and Reichelstein (2010), Rogerson (2011) and Nezlobin et al. (2012).

refers to a general managerial context, Rogerson (2011) specifically analyzes a regulatory setting using the relative replacement cost rule.[112]

Rajan and Reichelstein (2009) use another version of the rule which does not require expected future cash flows as an input, but only the expected pattern of the asset's future productivity. Not using expected future cash flows is considered a simplification and better applicable for practical purposes. They denote this rule *relative practical capacity rule* (RPC). In this article, Rajan and Reichelstein further illustrate that the different allocation rules are different in general, and do only coincide in certain cases, in particular if the NPV of all investments is zero. Dutta and Reichelstein (2010) apply the earlier finding to decentralized capacity management and internal pricing. Again, they use the RPC rule, but they also explicitly refer to Rogerson (2008), and state that the relative practical capacity rule is conceptually similar to Rogerson's relative benefit cost allocation rule.

There are several other articles that build on these contributions and further investigate certain aspects. One of them is Biglaiser and Riordan (2000). Their focus is the analysis of price regulation under consideration of technological progress in the capital equipment. They argue that it is crucial to account for technological progress in models on regulation because it was possible to observe price declines affecting companies' investment behavior, in particular in the telecommunications industry in the 1990s. In their model, technological progress leads to a reduction both in capital costs and operating costs.

Several other authors refer to Biglaiser's and Riordan's article. Rogerson (2011) states that Biglaiser and Riordan (2000) achieve the same results as in his contribution with exponential depreciation. Rajan and Reichelstein (2009) also address the difference concerning the depreciation method and describe Biglaiser's and Riordan's model as an analysis of the dynamics of product prices in settings where the regulator does not implement the relative practical capacity depreciation rule.

Nezlobin et al. (2012) assess the dynamics of the rate-of-return regulation process in the long run. They use the findings in Rogerson (2011) as a starting point to analyze the dynamic and asymptotic properties and explicitly allow for depreciation methods other than Rogerson's relative replacement cost rule. The deviation of efficient prices from long-run marginal costs resulting from other depreciation rules than the RRC rule is determined. For the actual asymptotic pricing process, Nezlobin et al. (2012) are able to show that in the course of the rate-of-return regulation process, the resulting product prices can only converge to one very specific equilibrium price. Furthermore, they address issues of stability in the price building process and identify requirements for the process to converge.

[112] This article is discussed in more detail later in this section.

Since straight-line depreciation is prevalent in practice, they analyze its properties in more detail. Compared to the RRC rule, straight-line depreciation is more accelerated,[113] and such an accelerated depreciation method causes the equilibrium price to be lower than the firm's long-run marginal cost.

Rogerson (2011) is another very important contribution to the cost-based regulation literature. Using the relative replacement cost rule, he develops a specific formula for determining efficient prices for a regulated company. The prices are efficient in the sense that they represent the long run marginal cost of production, and the firm breaks even at these prices. Since Rogerson's formal model of a regulated firm making sunk investments shows several important parallels to the model developed in this thesis, it is reviewed in more detail in this section.

In his model, Rogerson (2011) considers a firm with no initial assets and an infinite investment sequence. The firm produces output $q_t \in [0, \infty)$ in period $t,\ t \in \{1, 2, ...\}$ by using its capital stock K_t. The capital stock is assumed to be the only input to produce output. Depreciation is included in his model in a very general way: he introduces a variable s_t that represents the "the share of an asset that survives until at least the t_{th} period of the asset's lifetime."[114] Whereas this variable appears odd at first glance, it is merely a generalization of various depreciation methods. For instance, if $s_t = \beta^{t-1}$ for some $\beta \in (0, 1)$, exponential depreciation is represented.

Furthermore, he defines z_t to be the price of purchasing a new unit of assets in period t. He assumes assets prices to be weakly decreasing over time and to change at a constant rate. This constant change rate is denoted α with $\alpha \in (0, 1]$. With $z_0 \in (0, \infty)$ being the initial asset price, it holds that $z_t = z_0 \cdot \alpha^{t-1}$. α can for example be interpreted as the rate of technological progress. Lower values of α represent faster technological progress - hence price decline for the technology - and vice versa.

Rogerson's approach is to determine *user costs*, denoted by c_t. He defines these user costs to be the "imaginary" cost of renting one unit of asset. Rogerson (2011) is able to show that if these user costs are calculated using the relative replacement cost rule, then equating them with the regulated price is the efficient price choice. In particular, the opti-

[113] A definition of the term "accelerated" in relation to the RRC rule can be found in Rogerson (2011).
[114] Rogerson (2011), p. 6.

mal regulated price p_t^* in period t is $p_t^* = c_t^*$ with:

$$c_t^* = k^* \cdot z_t \tag{3.1}$$

$$k^* = \frac{1}{\sum_{i=1}^{\infty} s_i(\alpha\delta)^i}, \tag{3.2}$$

with δ being the discount factor.

Rogerson (2011) emphasizes one big advantage of his approach: by simply determining the user costs for each period with this fairly simple formula, the "seemingly complex multi-period problem actually collapses into a series of additively separable single period problems."[115] He states that welfare is maximized with this procedure and that the firm has no disadvantage in any kind of way, because it breaks even at these prices.

Rogerson's results are very convincing and elegant. A simple formula that results in the maximization of social welfare while still satisfying the company's need to break even is promising for use in regulatory practice. However, several strong assumptions are crucial for the model, which must not be ignored.

First, the infinite investment sequence with no initial assets is a strong simplification of reality. In particular, the large electricity grid operators which are affected by regulation do in every case have initial assets. The infinite sequence however, does not result in distortion, because as stated before, the originally infinite problem can be solved period by period. The only inputs needed for the price determination in one specific period are z_t, s_t, α and δ as defined above. Also the break-even for the company is assured in every single period for itself.

Second, the assumptions on the development of demand and the unit price of an asset are very strong as well. Demand is assumed to be weakly increasing over time. For the electricity industry, this seems possible, however, some current developments like the introduction of smart grids or storage possibilities may result in an actual decrease in demand for electricity and hence for electricity distribution. Similarly, Rogerson (2011) assumes weakly decreasing asset prices. Again, this is convincing considering economies of scale or economies of scope, but either a more advanced technology or higher costs for resources like steel could also result in increasing asset prices.

The insight in Rogerson (1997) and Reichelstein (1997) that inducing efficient invest-

[115] Rogerson (2011), p. 13.

ment decisions requires the use of the relative benefit cost allocation rule[116] is the basis for Friedl (2007).[117] Friedl examines the effects of cost-based price regulation on a regulated company's investment decision, in particular if the relative benefit cost allocation rule is not used. He is able to show that the use of straight-line depreciation for determining capital costs results in underinvestment from a social welfare perspective. The use of annuity depreciation solves this problem. In his article he explicitly addresses the importance of the demand function for the company's investment decision.

The model developed in this thesis uses Friedl's model as a starting point. For this reason, the parts of his analysis that are important for the present model are illustrated in more detail.

In a discrete-time, static setting, Friedl models a regulated company which faces a one-time irreversible investment opportunity. After an investment outlay of $c \cdot x$ the company is able to sell x products or services for T periods. c denotes the investment outlay for one unit of capacity. Variable operating costs are normalized to zero. It is argued that this does not change the model outcome, since in a cost-based regulatory regime, variable operating costs would be passed on directly to the regulated price.

For each point in time t, there is a specific linear inverse demand function of the form $p_t(q_t) = a_t - b_t \cdot q_t$. The variable a_t represents the consumer's maximum willingness to pay, and b_t is the slope of the demand function. Demand is specified by this function, but at the same time limited by the available capacity. Hence, demand is given by:

$$q_t(p_t, x) = \min\left\{\frac{a_t}{b_t} - \frac{1}{b_t} \cdot p_t, x\right\}. \quad (3.3)$$

It is assumed that the company knows its demand, that demand is unknown to the regulator. Hence, demand can influence the company's investment decision, but the regulator cannot use it for pricing.

A cost-based price regulation is modeled, in which the price cap $\overline{p}_t$ is determined based on the company's costs. In the absence of variable operating costs, these costs are exactly the depreciation charge plus interest on invested capital. In particular, Friedl (2007) investigates straight-line depreciation and annuity depreciation.

The regulated company's goal is to maximize the NPV resulting from an investment

[116] In fact, this is also an insight in Rogerson (2011), since the relative benefit rule and the relative replacement cost rule are conceptually very close.
[117] Another closely related article is Crew and Kleindorfer (1992).

project whereas the regulator wants this investment to be chosen in a way that it maximizes social welfare. Friedl (2007) explicitly models the company's and the regulator's optimization problem and solves them analytically.

He illustrates that in a setting in which only the capital costs are included in the regulated price, the maximum possible NPV is zero. In order to avoid a negative NPV, it is crucial that the company chooses the investment such that total capacity exactly meets demand. If the company provided excess capacity, the resulting NPV would be negative.

Considering this requirement, Friedl (2007) determines the optimal capacity choice from the company's and the regulator's perspective. Comparing both levels, it is straightforward to see that - under the additional assumption of constant demand - straight-line depreciation results in underinvestment. However, by the use of annuity depreciation to determine the regulated price, efficient investment can be induced. For non-constant demand, he shows that the relative benefit cost allocation rule as in Rogerson (2011) leads to efficient investment.

Friedl (2007) argues that his analysis contributes to existing research by showing the importance of the assumed demand for the choice of depreciation method. Straight-line depreciation can only be optimal with a very specific development of the maximum willingness to pay, the annuity method is optimal for constant demand, and the relative benefit cost allocation rule induces efficient investment for the case of non-constant demand.[118] Friedl (2007) furthermore stresses that the regulator's ability to commit to a certain policy is crucial for his results.[119]

The insight that is particularly interesting for the model in this thesis is that with constant demand, the annuity method leads to efficient investment behavior. Hence, if such an isolated investment opportunity is considered, implementing the annuity method - which results in increasing depreciation charges over time - is the optimal choice for the regulator. It will be shown that this changes dramatically for multi-period investment.

The fact that is not considered[120] in any existing formal model is how investment over several periods changes the optimality of a certain pricing approach. The model in the following chapter incorporates the analysis of a very specific setup: a regulated monopolist faces two consecutive investment opportunities. The company can invest in productive

[118]It must be noted that there are certain requirements for the use of the relative benefit cost allocation rule: a constant saturation quantity on the one hand and knowledge about the development of the maximum willingness to pay on the other hand. For details see Friedl (2007), p. 341-343.

[119]For a discussion about the influence of the regulator's ability to commit see section 3.4.1.

[120]To the best of the author's knowledge.

capacity at one point in time as well as exactly one period later. Since assets do not depreciate within one period, productive capacity accumulates with the second investment. The regulator fully commits to a certain pricing policy ex ante. Hence, at the time when the investment decision is made, the company knows exactly how the investment will translate into the regulated price and consequently how this affects the NPV of the investment project.

From the regulator's perspective, it is optimal for social welfare if the company invests a specific amount of capacity at both points in time. Following existing literature, such as Rogerson (2011) and Friedl (2007), simply the use of a certain depreciation rule guarantees such efficient investment. It will be shown that in this specific described setting with two overlapping investments and accumulating productive capacity, these otherwise optimal depreciation rules fail.

3.4 Discussion of Selected Issues in the Context of Regulation and Investment

Up to now, the literature review has focused on general approaches concerning regulation and investment. The purpose of this section is to discuss selected issues that are of particular relevance for models in this field. These issues are first, the level of information and of the regulator's commitment. Second, the influence of uncertainty. Third, options in the choice of the cost basis and the impact of this choice for investment and fourth, alternative pricing approaches.

This discussion is important, as these issues are not investigated explicitly in the following formal model, but they are still important influencing factors in the context of regulation and investment. Hence, the purpose of this discussion is to provide the reader with a broad understanding of these issues by reviewing important findings in the literature.

3.4.1 Level of Information and Commitment

To anticipate some characteristics of the model in the following section, it is deterministic and does not involve any uncertainty, for instance in future demand. It assumes that the regulator has full information about the company's capital costs and is able to fully commit ex ante to a certain regulatory policy. There is a stream in the literature vastly analyzing exactly these issues. This section depicts the development of this literature over time and discusses important findings.

One of the earliest analyses of optimal regulation can be found in Hotelling (1938). In fact, Hotelling (1938) is considered the first advocate for marginal cost pricing[121] together with Dupuit (1952). Their finding is that under full information, the highest consumer well-being can be achieved if the affected company charges the marginal costs for its product, and the regulator subsidizes the company by its fixed costs. Hotelling's model is very "puristic" in that it assumes full information and full commitment.

The background for Hotelling's analysis are the reintroduced toll bridges around New York in the 1930's which he calls "inefficient reversions."[122] Schuler (2012) states that pricing such a public good or service raises a "fundamental economic question", namely who pays for the new facility: either its actual users through a systems of tolls or the whole society by a system of taxes. Hotelling (1938) argues for the latter option: he strongly criticizes including fixed costs into pricing and argues that this approach is so inefficient that it can result in cyclical fluctuations and unemployment.

The company should only be allowed to charge marginal costs. According to him, "the optimum of the general welfare corresponds to the sale of everything at marginal cost". As a solution to cover the fixed costs, he suggests that the government subsidizes the fixed costs and charges an additional tax to compensate for this subsidy. He considers taxes on incomes, inheritances, and the site value of land as suitable options.

It has to be noted that the assumptions used in Hotelling's analysis are very strict. He assumes firstly, that the regulator has full information about all relevant factors, like the company's cost or the actual demand. Furthermore, it is also assumed that the regulator can fully commit to a certain regulatory policy and there is no uncertainty about a possible change of the policy in the future. Both are very strong assumptions. Effects of a possible relaxation of these assumptions are analyzed in many other articles which will be introduced later in this section.

Baumol and Bradford (1970) also determine the optimal regulatory policy when the reg-

[121] As for pricing, there are many different approaches on which there is vast literature and which must be distinguished clearly and carefully. For instance, in addition to marginal cost pricing, there is peak-load pricing and Ramsey pricing as advancements and Coasian two-part tariffs as an alternative. However, the focus in this section is on the level of information, commitment and uncertainty. For an extensive analysis of different pricing approaches see Laffont and Tirole (1993). Some more details are provided in section 3.4.4.

[122] Although Hotelling (1938) refers to toll bridges, his results apply as well to all utilities with large fixed costs, for example the electricity industry.

ulator is perfectly informed. In contrast to Hotelling, they argue for a departure from marginal cost pricing. They suggest Ramsey prices, which according to Sidak (2006) represent prices that maximize the sum of consumer and producer surplus, and at the same time fulfill a break even constraint for the firm. While Ramsey pricing was developed much earlier than Baumol's and Bradford's article,[123] Crew and Kleindorfer (2002) state that "Ramsey pricing was given a new lease on life by Baumol and Bradford (1970)."[124]

In their analysis, Baumol and Bradford (1970) identify optimal "second-best" prices. They use the notion "second-best" because in contrast to earlier literature, they introduce an additional constraint in their optimization. They state that "resource allocation is to be optimal under the constraint that governmental revenues suffice to make up for the deficits (surpluses) of the individual firms that constitute the economy"[125]. In order to fulfill this requirement prices must deviate from marginal costs. More precisely, they find that the difference between price and marginal costs needs to be proportional to the difference between marginal revenues and marginal costs. Consequently, the more marginal revenues differ from marginal costs, the larger is the deviation between the price and marginal costs.

In the end, the identified prices maximize welfare while ensuring a profit of at least zero for a monopolist who produces with increasing returns to scale. According to Brennan (1989), the analysis of Baumol and Bradford (1970) shows that conventional cost-of-service regulation can generate these prices, which maximize economic welfare subject to the constraint that revenues from sale of the regulated product cover costs.[126]

Their findings with regard to a departure from marginal cost pricing represent an important contribution to the regulatory pricing literature, but their article also provides insights into the relevance of full information and full commitment. They show that despite the assumption of full information and full commitment, marginal cost pricing may not be sufficient for the firm to break even. It can be inferred that there are further important drivers for the optimality of a certain pricing policy besides the level of information and commitment. In fact, Baumol and Bradford (1970) find that in certain circumstances the suggested simplest form of regulatory pricing - setting prices equal to marginal costs - does not suffice to guarantee non-negative profits for the regulated company, but higher prices are necessary. This is the case despite the assumption of full commitment and full information.

[123] Ramsey pricing is generally accredited to Ramsey (1927) and Boiteux (1949).
[124] Crew and Kleindorfer (2002), p. 10.
[125] Baumol and Bradford (1970), p. 265.
[126] However, Brennan (1989) still sees that cost-of-service regulation is associated with a "predictable errors and distortions", e.g. the Averch-Johnson effect.

Whereas the previous passage discusses articles with full-information and full-commitment models, now the effects of a relaxation of these strong assumptions are assessed. First, findings are illustrated that relax the full-information assumption but still assume full regulatory commitment. This assumption is dismissed in a second step.

The importance of assessing the influence of limited information about certain model features like demand or costs can be easily understood: in most real cases, the regulator is far from being perfectly informed about these factors. A discussion about where the regulator's information comes from in practice and the associated difficulties is provided in Joskow (2006b), who expresses doubt about the effectiveness of existing reporting systems.

Information asymmetry between regulator and regulated company is in the focus of the analysis in Baron and Myerson (1982). In their model, the regulator does not know the company's cost function and therefore has to rely on the company's cost report.[127] Baron and Myerson (1982) develop an optimal policy which is designed to maximize social welfare. At the same time, the policy guarantees a non-negative profit and - which is particularly important for the model setting - does not set any incentive to misreport costs.

Although Baron's and Myerson's article includes uncertainty about one factor - the company's cost - it still can be classified as a full commitment analysis. Baron and Myerson (1982) state that they suggest an *optimal* regulatory policy which indicates their normative approach. A possible deviation from this policy is not part of their model. Their article shows that introducing information asymmetry changes the optimal policy as compared to earlier results: the regulator approves a price which is higher than the marginal costs. Under certain circumstances, this price can even be higher than the unregulated monopoly price, which provides an incentive for the firm to truthfully report its costs.[128] Hence, as Laffont and Tirole (1986) state, the "optimal incentive mechanism in general entails a welfare loss compared with what could be achieved under perfect information."[129]

It must, however, be noted that Baron's and Myerson's article differs quite substantially from the model presented later in this thesis in two major assumptions: Baron and Myerson (1982) assume that the regulator knows the demand function, but there is uncertainty about the company's costs. While the assumption on the demand function is simply denoted "not unnatural", the difficulty of explicitly determining a cost function, even for the

[127] A similar article is Sappington (1982), in which an optimal regulatory policy incentivizing research and development is determined.
[128] For details please refer to Baron and Myerson (1982), p. 922.
[129] Laffont and Tirole (1986), p. 615.

firm itself, drives the second assumption.[130]

Baron and Myerson (1982) are not the only authors who are concerned with limited information. Besanko and Sappington (1987) provide an extensive literature review of results for regulatory policies when the regulator's knowledge is limited.[131] Similar to Baron and Myerson (1982), they focus mainly on mechanism-design models. Despite limited information the regulator can still fully commit to a certain regulatory policy. In their setting, the regulator has limited information about demand and/or the company's costs.

As a baseline case, Besanko and Sappington (1987) consider full information and come to the classic result, as found in Dupuit (1952) and Hotelling (1938), that the price should equal the marginal costs of production. As a further step, they introduce information asymmetry through the regulator's lack of knowledge whether the company's costs are high or low. Analogously to Baron and Myerson (1982), they find that the price needs to be above marginal costs whenever the company faces high costs. As the first extension of their baseline model, they analyze a setting in which the regulator can observe the quantity of capital the firm employs. However, the company's actual production cost realizations and the quantities of non-capital inputs are still not known to the regulator.

Their solution is that the optimal regulatory policy induces the firm to over-capitalize. In other words, the firm substitutes labor with capital. This is the same result as the famous Averch-Johnson effect found by Averch and Johnson (1962). The main difference is that Averch and Johnson (1962) model a rate-of-return regulation, whereas Besanko and Sappington (1987) assume a very simple form of regulation in which the regulator can only set a price and a subsidy.

Still, although the assumptions of the model in this thesis are different from the discussed articles, one important conclusion can be drawn from the review: as soon as a deviation from full information is incorporated into a model, the optimal pricing rule changes substantially. Whereas in early full-information and full-commitment models like Hotelling (1938) pricing at marginal costs results in the maximization of social welfare, a break-even constraint for the company like in Baumol and Bradford (1970) or the introduction of uncertainty about the company's costs and/or demand as in Baron and Myerson (1982) and Besanko and Sappington (1987) results in higher prices than marginal costs. This is associated with a loss of social welfare. A deviation from the deterministic setting

[130] Another supporter of this view is Weitzman (1978). Laffont and Tirole (1986) extend the analysis by introducing a noise into the cost observability and an unobservable effort variable.

[131] Similar literature reviews can be found in Baron and Besanko (1987), Caillaud et al. (1985) and Sappington and Stiglitz (1987).

in this thesis' model will most likely require a change in the regulated prices as well.

As a next step, it seems natural to incorporate an analysis of the regulator's ability to commit to a certain regulatory policy. In reality, there are few cases in which a regulator or government can actually make a binding commitment over a longer time period.[132]

Besanko and Spulber (1992) deviate from the full commitment assumption. They use a sequential-equilibrium model to examine the investment decisions of regulated firms under asymmetric information. They emphasize the importance of the question of whether or not the regulator can commit to a certain pricing policy and argue that investment decisions of regulated companies strongly depend on what behavior they expect from the regulatory authorities. They exclude the possibility for the regulator to make binding commitments and therefore distinguish their model explicitly from mechanism-design models like Baron and Myerson (1982) or Besanko and Sappington (1987).

Besanko and Spulber (1992) show that without regulatory commitment, asymmetric information can lead to less underinvestment. In their model, the regulator only sets rates after observing the firm's investment. They obtain a unique sequential equilibrium, and they can show that their solution has advantages compared to a full-information approach.

In general, the purpose of mechanism-design models is to find the optimal incentive mechanism under idealized circumstances. Thus, they are of more theoretic nature and their practical use is limited. Besanko and Spulber (1992) argue that the actual implementation of such models is problematic because of possible opportunistic behavior of the regulator: for him, it might be beneficial to deviate from a regulatory design after the affected company has made a sunk investment. The firm can anticipate this behavior and therefore the originally intended mechanism does not function any more. Besanko and Spulber (1992) point out that "the predictive power of the mechanism-design framework thus is limited by the extent to which regulators are able to make binding commitments". According to them, it is empirically observable that regulatory designs have often been changed some time after the original design was agreed upon.

The regulator's limited ability to commit has also been addressed in the context of yardstick competition. Dalen (1998) models a setting in which the regulator is unable to commit to the regulatory contract before the firms invest. In the context of his model, he shows that

[132] The German *Energiewende* is an obvious example for policies and laws being changed rapidly due to public pressure. These changes affected electric utility companies to an enormous extend. For more on this see section 2.1 or many newspaper articles, for instance Bauchmüller and Szymanski (2011) or Süddeutsche Zeitung (2011).

firm-specific investment is encouraged at the expense of industry-specific investment.[133]

Although the justification for the importance of limited commitment is plausible, the model in this thesis still uses a different approach: it is designed deterministically, which also concerns commitment. The regulator commits to the pricing policy, and does not deviate from it. Details on this will follow in chapter 4.

3.4.2 Uncertainty

Uncertainty about the future value of an investment project can also have tremendous influence on investment decisions.[134] There is another branch of literature which incorporates real options into models on investment and regulation.[135] In contrast to the limited-information articles discussed earlier, which analyze information asymmetry about demand or costs, the uncertainty models explicitly account for the fact that the future value of investment projects is uncertain. Possible reasons are either long lead times or a future change in regulatory policy.

Contributions to this stream of literature include Teisberg (1993), Teisberg (1994), Grenadier (2002) and Dobbs (2004). Their articles are discussed below and used to draw implications for the model in chapter 4. Further important contributions in this field are Braeutigam and Quirk (1984), Brennan and Schwartz (1982a)[136] and McDonald and Siegel (1986). The general procedure to solving option pricing models is not illustrated here. An extensive analysis of this approach can be found in Pindyck (1991) and Brennan and Schwartz (1985).

One of the first models analyzing price cap regulation with stochastic demand can be found in Dixit (1991). With his option pricing analysis, he provides a basic result, that many following articles refer to.[137]

Dixit's findings are the following: in a competitive industry without regulation, a firm invests in new capacity as soon as increased demand turns the price high enough to make the investment's NPV equal to zero. In Dixit's article this is called an investment trigger price. With a price ceiling this basic idea still holds: demand pressure must be sufficiently

[133]His article is discussed in more detail in section 3.2
[134]See for instance Pindyck (1988), Pindyck (1993) or Dixit and Pindyck (1994).
[135]For an overview on real options see for instance Trigeorgis (1996), Amram and Kulatilaka (1999) or Friedl (2006).
[136]As well as Brennan and Schwartz (1982b) and Brennan and Schwartz (1985).
[137]See e.g. Grenadier (2002) or Roques and Savva (2009).

high to cause a high price which triggers new investment. However, this *regulated* investment trigger price must be higher than the unregulated trigger price. Hence, with price cap regulation, firms invest later than in the unregulated setting.

This fact is explained by the asymmetric distribution of risk associated with future demand: the firm cannot profit from an increase in demand because it cannot charge higher prices than the price cap. At the same time, the firm incurs losses if the demand decreases. Dixit (1991) further argues that, if the price cap is lowered to long-run average costs, then the company will stop investing at all.

There are a couple of assumptions in Dixit's model: he assumes the firms in the industry to be identical and to have long-run constant returns to scale between capital and labor. He considers demand uncertainty, but he does not account for any uncertainty in policy change. This also implies that the price ceiling is known and does not change over time. Hence, his model is of mechanism-design type, meaning that the regulator can fully commit to a certain policy.[138] Furthermore, the possibility of intertemporal substitution or complementarity in demand is not incorporated in the model.

In his conclusion, Dixit suggests several possible extensions of his model. First, the industry should be modeled as a monopoly, which is more adequate in regulated industries. This was accomplished by Dobbs (2004) and further extended to an oligopoly by Roques and Savva (2009). Second, depreciation of capital is important in a regulated context. Depreciation is included also in Dobbs (2004). Last, he points out that further sources of uncertainty should be accounted for in future research. Simultaneous demand and supply uncertainty is analyzed in Chao (1983) and uncertainty about future regulatory policy is the main subject in Besanko and Spulber (1992). However, neither of these two articles uses an option pricing approach.

Elizabeth Teisberg (1993) uses an option pricing approach to analyze investment decisions of a regulated firm. She incorporates lead times of projects and the possibility to delay or abandon an already started project. Her analysis is motivated by the empirical observation that electric utility firms have changed their investment behavior. While earlier, they invested in very large plants, later there was a tendency to built smaller plants with shorter construction lead times. With her model about uncertainty and options, she provides an analytical explanation for this.

[138] Other mechanism-design models are discussed in the previous sections (e.g. Baumol and Bradford (1970) or Besanko and Sappington (1987)), but none of these models demand uncertainty or uses an option pricing approach.

One of her main assumptions is that she does not define regulation in terms of a fixed rate of return that the regulator commits to and the company consequently can rely on. Instead she assumes that the regulatory policy is uncertain prior to the outcome of the firm's investment project.

She distinguishes her analysis from prior literature[139] by explicitly accounting for lead times of investment projects. It is intuitive to incorporate construction lead times into formal analyses, because they lead to a significant uncertainty: electric power utilities are usually large plants, which require a long construction time. It is likely that regulatory policy changes in between the points in time when the investment decision has been made and the project is completed. Hence, the affected companies cannot rely on the return they expected when making an investment decision. Accounting for lead times also results in flexibility to delay or even abandon a project.

Teisberg (1993) shows that uncertainty about future regulatory policy (and consequently future economic conditions) can lead to a lower value of the investment project compared to the value under certainty. This result is remarkable since in other option pricing models which do not consider a regulatory environment, uncertainty usually leads to an even increased value of the investment projects. Black and Scholes (1973) can be mentioned as the first authors establishing this result, or McDonald and Siegel (1986) or Majd and Pindyck (1987) as further relevant contributors in this field.

In particular, Teisberg's analysis provides an explanation for why smaller investment projects and shorter lead time projects are preferred by the regulated companies. In the model, the reason can be found in the "asymmetric distributions of possible profit and loss restrictions."[140] Hence, her argumentation is in line with Dixit (1991). Smaller projects have one main advantage: possible "damage" due to changes in regulatory policy is not as severe as for large projects. Shorter lead times are beneficial because whether or not the plant is going to be useful will not deviate significantly from the expectations at the time of the investment decision.

In her 1994 contribution, Teisberg explicitly addresses sequential investments and argues that the sequential character of investment outlays needs to be accounted for in the option pricing model. She provides an example analysis of a plant that is built over ten stages which each lasts several months. Similar to her 1993 results, it appears that the shorter the lead time, the higher is the value of the investment project.

[139] See Braeutigam and Quirk (1984) or Burness et al. (1980).
[140] Teisberg (1993), p. 600.

It is convincing that accounting for lead times and therefore sequential investment can strongly influence certain model outcomes. However, Teisberg's analysis still differs significantly from many other models on regulation and investment, since it does not explicitly analyze the determination of regulated prices.

Grenadier (2002) provides an option analysis of investment strategies which several authors later use as a basis for further analyses.[141] Grenadier explicitly analyzes how competition influences investment incentives. He argues that this is crucial because in a real life setting, one firm's actions are strongly dependent on the behavior of other market participants. Accounting for this fact will result in a strategic equilibrium. In his model he uses a continuous-time real option approach in a game theoretic setting (Cournot-Nash framework).

In his analysis, several firms can all increase their productive capacity by an incremental unit. Every firm's goal is to find an optimal investment strategy such that its market value is maximized. This investment strategy is determined by exlicitly accounting for the investment choices of the firm's competitors.

Grenadier (2002) finds that his results differ significantly from standard real option models, which find that because of the value of the waiting option, firms invest only when the NPV is a high positive number. Accounting for competition significantly changes this result. It turns out that this "drastically erodes the value of the option to wait and leads to investment at very near the zero net present value threshold". This is due to the fact that the investing firm does not have any exclusive investment rights, and the value of the investment opportunity decreases if competitors invest earlier.

Dobbs (2004) is another contribution to the understanding of a monopolist's intertemporal investments. He considers a setting with three certain characteristics: first, the firm is subject to a price cap regulation. Second, the investments made are largely irreversible. And third, the uncertain stochastic evolution of important variables like demand or technology development requires a real option approach. Dobbs (2004) investigates the level as well as the timing of investment. He distinguishes his model from the analysis in Dixit and Pindyck (1994) by the considered size of an investment. In his analysis, there is no fixed size of an investment, but the firm can freely alter the level of investment.

As a first step, Dobbs (2004) determines so-called relative prices[142] which trigger new investment. In line with earlier literature, he finds that in the case of certainty, this relative

[141] See among others Dobbs (2004) or Roques and Savva (2009).
[142] In this case "relative" refers to a price per unit of installed capacity.

price consists of the sum of the discount rate (reflecting the cost of invested capital), depreciation rate and technical progress rate (reflecting change in capacity costs). Uncertainty increases this price. Under perfect competition this increase is smaller than in a monopoly setting, such that in the end, the perfect competition price lies in between the certainty and the monopoly price.

Dobbs (2004) discusses the relation between a price cap and these relative prices. He shows that the price cap needs to lie in between the certainty and the monopoly price. The best choice in fact is to set the price cap equal to the perfect competition price. However, in all possible cases the price at which new investment is triggered lies above the price cap, and hence quantity rationing occurs.

Since this effect is only due to uncertainty, Dobbs (2004) emphasizes the severe impact of uncertainty: "When subject to a price cap, whether or not the price cap is set at the competitive level, the monopoly firm will have an incentive to under-invest in capacity."[143] This effect is explained with the important influence of demand uncertainty. The firm will rather invest less because of the downside risk that there will be much less demand than expected.[144]

The firm will shed demand until demand is sufficiently strong to trigger new investment. The intuition is that in order for an investment to be beneficial, the imposed price cap theoretically must be binding at all times. Consequently, if there is a period in which the actual price is below the price cap, then this period must be "paid off" with a high demand period, in which the actual price is above the price cap. This situation can be artificially provoked by quantity rationing. Summarizing, in Dobbs (2004) the underinvestment, hence the distortion in the regulated firm's investment level, is solely due to uncertainty about future demand.

Roques and Savva (2009) adhere their analysis closely to Dobbs (2004), and identify a research gap in the fact that Dobbs studied the effects of a price cap for perfect competition and for a monopoly, but not for an oligopoly.

They start their analysis with the same observation as in Dobbs (2004) and Grenadier (2002): in unregulated oligopolistic markets, firms do not invest at a zero NPV price; instead, they wait for the price to increase. Hence, the firms strategically underinvest because by doing so, they can artificially increase demand and thus charge higher prices. The difference in the zero NPV price and the actual investment trigger price is called the

[143] Dobbs (2004), p. 422.
[144] Again this argumentation is in line with Dixit (1991) and Teisberg (1993).

oligopolistic markup.

The introduction of an exogenous price cap does increase the price at which the NPV is zero. However, there is also an opposite effect: at the same time the price cap diminishes the oligopolistic markup. Roques and Savva (2009) argue that it is not obvious which of the two effects is dominant. In other words, it is unclear "whether a price cap speeds up or delays investment."[145]

Taking this argument into account, there must be an optimal price cap which lowers the investment trigger price as much as possible. Roques and Savva (2009) determine this optimal price cap for the oligopolistic setting, and show that it is the same price cap as in a competitive setting. Hence, while it matters whether there is a monopoly or not, it does not matter whether the market is an oligopoly or there is perfect competition.

While the number of the firms in the market does not affect the optimal price cap, it yet is important for its robustness. Roques and Savva (2009) show that the price cap is "more beneficial when the market is highly concentrated and demand is not very volatile."[146]

They also find that it is crucial for investment whether the price cap is relatively high or low. If the price cap is very tight, the affected company will not invest, whereas a relatively high price cap can in fact speed up investment. They mention that their results affirm the claim for higher price caps for electricity prices in the United States.[147]

Stated briefly, similar to Dobbs (2004), one of the basic results in Roques and Savva (2009) is that the existence of uncertainty always leads to underinvestment. This is in contrast to deterministic models, where under certain circumstances efficient investment can be incentivized.

In summary, this section and the precedent one showed that the level of information, uncertainty about variables like demand or costs, or about the regulator's commitment are important influencing factors for the relationship between regulation and investment. It is promising to further investigate these aspects in the context of formal models.

[145] Roques and Savva (2009), p. 508.
[146] Roques and Savva (2009), p. 508.
[147] See e.g. Joskow and Tirole (2007), Grobman and Carey (2001).

3.4.3 Choice of Cost Basis

Another important issue in the context of regulation and investment is the question whether prices should be based on historic costs or replacement costs. The effects of either choosing historic or replacement costs are illustrated in this section.

As the name suggests, in a cost-based regulation system, the determination of a regulated price is based upon the company's costs. In regulated industries such as the electricity grid, it is a well-known fact that variable operating costs are mostly negligible compared to capital costs, which result from large investments in physical assets.[148] Consequently, the costs associated with these assets are the most important part. These costs are depreciation and interest on invested capital.

In order to determine depreciation, there are two alternatives: either, depreciation charges can be calculated based on historic costs, or, they can be determined based on current replacement costs. In general, historic costs and current replacement costs do not coincide, so the two ways can lead to significantly different depreciation charges.

Using historic costs as a basis means that the original book-value of an asset, hence the "price" that actually has been paid for the asset, is relevant for the determination of the depreciation charges. When this is executed consequently, the sum of all depreciation charges over the assets lifetime equals the book value which was originally capitalized. Using replacement costs means that whenever a depreciation charge is determined, the basis for the depreciation charge is the current replacement value of the asset.[149] The theoretical foundations and definitions of both bases are substantially illustrated in Friedl and Küpper (2011).

Comparing both approaches, whether one or the other depreciation charge is higher depends upon the development of the "price" of the asset. Assuming straight-line depreciation, this means the following: if today, the investment outlay for the same asset is higher than in the past, then the depreciation charge based on historic costs is lower than the depreciation charge based on replacement costs. If this investment outlay is lower than in the past, using historic costs results in a higher depreciation charge.

Companies invest in order to generate future cash flows, hence investment is naturally future-oriented. The natural consequence would be to base future prices on forward-

[148]See for instance Küpper (2008b) or Friedl and Küpper (2011).

[149]There are more specifications, for instance the distinction between actual replacement value (*Tagesneuwert*) and used replacement value (*Tagesgebrauchtwert*). For these specifications see Friedl and Küpper (2011).

looking costs or replacement values. This is also in line with the claim that companies need to orient towards competition and the market. However, in many cases determining the actual replacement value of a particular asset is ambiguous. Hence, there is always an arbitrary component in this approach.

The main advantage of using historic costs is that they can be manipulated only with difficulty: past outlays can be verified easily. Therefore, the price determination is very transparent and objective.[150] However, this approach lacks in forward orientation. This is crucial as in general, it is a prior concern of a company to persist in the future. Moreover, it has been argued by Laffont and Tirole (2000) and others, that a negative effect for access price regulation can occur: when capacity costs decrease, it must be prevented that incumbents intentionally invest at high prices. The motive of this is that the incumbents are then able to charge their competitors (access seekers) or customers high prices based on these high historic costs instead of lower current replacement costs.

As there are shortcomings and benefits for both alternatives, is it not per se clear which approach should be used in a regulatory context. The model in chapter 4 does not analyze the impact of the two alternatives analytically. In order to still illustrate the consequences of this choice, this section reviews the most important contributions in the literature concerning historic costs or forward-looking costs which have some impact for regulatory purposes. Whenever possible, parallels to the model in chapter 4 are pointed out.

Originally, historic costs were commonly used as the basis for the regulation of access prices. It has to be noted that the regulation of access pricing applies mostly to telecommunications rather than to the electricity industry. However, the insights regarding the investment incentive effects of both approaches are still valuable and deserve to be illustrated.

According to Guthrie et al. (2006), in 1985 the British telecommunications regulator used historic costs to determine prices for the access to the network of British Telecom. As critique of the use of historic costs became more prevalent, this policy was changed in 1994, when a forward-looking approach was implemented. Instead of using historic costs, the pricing policy was supposed to reflect current replacement costs of assets. This was realized by calculating forward-looking incremental costs.[151]

In the U.S., the 1996 Telecommunications Act dictated that prices need to be based on costs, but without specifying which costs exactly are referred to. Later, according

[150] An extensive discussion of this can be found in Tardiff (2002).
[151] For details for the development in the U.K. see e.g. Melody (2000).

to Salinger (1998) the Federal Communications Commission (FCC) added that forward-looking costs were meant.

Furthermore, a combination of both approaches is possible. This was the case, for instance, in the Dutch telecommunications industry, when local loop unbundling was implemented. In the beginning, access prices were determined based on historic costs, which was later changed to replacement costs.[152] The reason for adopting this procedure was that by this time, existing capacity had already been depreciated to the largest extent. Hence, with the change from historic to replacement costs, access prices initially were low, but increased to replacement costs gradually, such that companies aspiring access faced incentives to create their own asset base.

Guthrie et al. (2006) state that in telecommunications, there is still a trend towards using replacement costs. This observation is supported for instance by one recent order of the BNetzA[153] concerning the remuneration of access lines of *Deutsche Telekom AG*. In this order, they explicitly dictate the use of replacement costs. However, for electricity and natural gas, the use of historic costs for new assets is directed in the StromNEV.[154]

In reality the use of both approaches can be observed, and in existing research, the results concerning their benefits and shortcomings are ambiguous. In the following, selected contributions and their results are illustrated.

One of the first articles focusing on the definition, properties, measurement and use of forward-looking costs is Salinger (1998). His article responds to what he sees as an ambiguous definition of what forward-looking costs actually are, and how prices can be determined using forward-looking costs. According to him, an example for the necessity to provide a clear definition is the 1996 Telecommunications Act in the United States, which mandates a cost-based determination of prices, explicitly referring to forward-looking costs, but without exactly specifying what is understood by this.

Salinger's general definition of forward-looking costs differs significantly from a simple replacement value. He defines the forward-looking costs of a good to be "the current price that makes the expected net present value of current investment equal to 0, subject to the constraint that future prices will be set so that the expected net present value of all future investments will be 0 in any period in which investment is to occur. In periods when no investment occurs, prices are set so that demand equals available capacity."[155]

[152] For details for the development in the Netherlands see e.g. Rood and te Velde (2003).
[153] See Bundesnetzagentur (2011b).
[154] Also see section 2.3.2.
[155] Salinger (1998), p. 150/151.

With its focus on investment, this definition emphasizes the future-orientation of an approach: forward-looking prices make the net present value of investments equal to zero. Note that this definition does not involve any profit for the affected company. The mentioned constraint guarantees consistent pricing in the future. It is necessary, since not one unique, but several different streams of future cash flows result in a zero NPV. Besides this constraint, Salinger uses multiple other assumptions in order to be able to actually determine the forward-looking costs.

Salinger's calculation of forward-looking costs is very thorough. He accounts for many important aspects such as the asset's life, demand uncertainty and growth, competition risk, or technological change. It is obvious that all of these factors are subject to some degree of uncertainty, and that they need to be estimated carefully. He draws one important conclusion from the importance of all these forward-looking factors on the one hand, and the difficulty to appropriately incorporating all of them into a calculation on the other hand: "The forward-looking cost standard does have a positive meaning, but it is a good deal more complicated than is commonly realized."[156]

Summarizing, Salinger argues for the use of forward-looking costs, and he provides a substantiated way of calculating them. But additionally, he also points out the difficulties of their calculation due to the prevalent uncertainty of some important forward-looking factors.

As there is a trend in different industries towards pricing based on forward-looking costs instead of historic costs, Guthrie et al. (2006) investigate the advantages and shortcomings of both approaches. In contrast to earlier assessments of the topic, they explicitly account for uncertainty about future costs. They apply an ex ante model, in which the option value of waiting to invest is determined. By doing so, they find that the historic cost approach is superior to forward-looking cost approaches in terms of efficient investment incentives. Historic costs being beneficial for inducing earlier investment is fairly intuitive: Guthrie et al. (2006) state that historic cost rules "reduce the risk the incumbent faces as a result of its investment."[157]

Based on their results, Guthrie et al. (2006) provide several suggestions for policy makers. First, they stress that policy makers should take historic cost approaches into account because of their advantages with regard to dynamic efficiency. If, however, the policy maker still applies a forward-looking rule, then the initial access price needs to be higher than the access price resulting from a historic cost approach. The reason is again the risk

[156]Salinger (1998), p. 162.
[157]Guthrie et al. (2006), p. 1783.

that the incumbent is facing, when pricing is based on forward-looking costs. The incumbent needs to be compensated for the additional risk, hence the increased price represents a risk premium. If there is no risk premium, the investment will be made much later than desirable from a social welfare perspective.

Finally, they argue that in certain cases a hybrid approach - as was applied in the Netherlands - can be beneficial. For instance, a hybrid approach which uses historic costs first, and forward-looking costs later can foster a new technology. A new technology requires high investment outlays in the beginning that will decrease afterwards. Furthermore, the incurred costs from investing can be very volatile at first, but volatility too will diminish in time. Naturally, firms face large risks in the beginning, when costs are volatile, and when there is uncertainty about whether the technology will become established. Hence, in the beginning, it is crucial to base pricing on incurred historic costs, because otherwise, the company would be hesitant to invest due to high risk and uncertainty. Guthrie et al. (2006) state that later, once the technology is established, "forward-looking prices would be more attractive because they would be trending down with project cost, thereby leading to higher surplus flows."[158] For future research, they suggest that such hybrid approaches need to be analyzed in much more detail.

Although their approach is convincing and provides valuable insights into the use of either cost basis, there are several limitations of their analysis. They simplify the model setting substantially by focusing on a one-time investment, and not accounting for ongoing investment in any kind of way. Ongoing investment is for example considered in Rogerson (2011). Rogerson does not apply an explicit option valuation approach, but he finds that using either historic or forward-looking costs is less important than using the "right" cost allocation rule (the RRC rule in his case) when determining depreciation.

Another extension of the analysis in Guthrie et al. (2006) is provided by Friedl (2011). Friedl determines the exact point in time for which investment is optimal for both the company and the regulator. The explicit determination of this point in time for the regulator is not conducted by Guthrie et al. (2006). They also do not account for different interest rates of company and regulator, and they do not allow for different market structures.

In addition to the development of a specific formula to determine efficient regulated prices,[159] Rogerson (2011) also represents an important contribution to the discussion of

[158] Guthrie et al. (2006), p. 1784.
[159] See section 3.3.2.

the benefits and shortcomings of forward-looking and historic costs.[160] He states that his formula for long run marginal costs of production can be interpreted in both ways: either as a formula for calculating forward-looking costs or as a formula for calculating historic costs. He stresses that this result contradicts "the commonly expressed view that measures of forward looking costs are superior to measures of historic costs in environments with declining asset prices".

An analysis closely related to Rogerson (2011) is Rajan and Reichelstein (2009). The authors find that with the use of a certain cost allocation rule - namely their *relative practical capacity* (RPC) rule[161] - historic unit costs do coincide with marginal costs. If however, different depreciation rules are used, this is no longer the case. Rajan and Reichelstein (2009) investigate the magnitude of the deviation between historic costs and marginal costs for different depreciation rules, in particular for straight-line depreciation. They are able to show that this deviation is not very large "for a reasonable range of parameter specifications".

For their analysis, Rajan and Reichelstein (2009) use a formal model to assess a firm which makes a sequence of overlapping investments in productive capacity. In their model, which allows for growth, the useful life of assets is limited to a finite number of periods, and existing capacity declines over time. Hence, the available total capacity results from new investments plus the "surviving" share of assets that has not declined yet. In fact, the expected future pattern of an asset's productivity is an important variable in their analysis. Using only this pattern of productivity, they provide a formula for the RPC rule.[162] In analogy to Rogerson (2011), Rajan and Reichelstein (2009) state that if the RPC rule is used to determine depreciation, the resulting cost charges represent average historic costs. They conclude that "proper accrual accounting makes it possible for the historical costs to coincide with the forward-looking long-run marginal cost, (...) even though the

[160] As mentioned earlier, the publication date of this article may cause some confusion. Although this article has only been published in 2011, it has been available as a working paper since 2008. Hence, different articles between 2008 and 2001 refer to this article as Rogerson (2008).

[161] See also section 3.3.

[162] Footnote 14 in Dutta and Reichelstein (2010) distinguishes the relative replacement cost rule according to Rogerson (2011) from the relative practical capacity rule according to Rajan and Reichelstein (2009): "The term relative practical capacity rule has been coined in Rajan and Reichelstein (2009), while Rogerson (2008) [Author's note: as explained earlier Rogerson (2011) is meant.] refers to the relative replacement cost rule to reflect that in his model the cost of new investment falls over time. It should be noted that under the relative practical capacity rule the depreciation charges are based only on the anticipated pattern of an asset's productivity over time but not on the relative magnitude of expected future cash inflows resulting from an investment. The link to expected future cash flows is a crucial ingredient in the relative benefit allocation rule proposed by Rogerson (1997) and the economic depreciation rule proposed by Hotelling (1925). As demonstrated in Rajan and Reichelstein (2009), these depreciation rules are generally different, though they coincide in certain special cases, most notably if all investments have zero NPV."

historical cost is principally composed of sunk costs."[163] Hence, like Rogerson (2011), they provide an argument for the use of historic costs, because with the use of the right depreciation rule, historic costs lose their shortcomings in comparison to forward-looking costs by - at the same time - avoiding risks of manipulation and arbitrariness.

A depreciation schedule different from the RPC rule results in a deviation of historic costs from marginal costs. As straight-line depreciation is prevalent in practice, they investigate this depreciation method in more detail. They determine an explicit formula for the percentage error for a deviation of historic costs from marginal costs. This percentage error is dependent on the growth rate, cost of capital, decay factor of the asset and the share of the investment, which is expensed immediately. They find that if these parameters lie in, what they call, a "reasonable range", then straight-line depreciation does not cause a major distortion. For instance, they state that "one would need to have rather high growth rates and/or fairly extreme decay factors in order for the average historical cost to misstate the marginal cost by more than 5 %". Hence, although straight-line depreciation is subject to some critique, and although it does only coincide with the RPC rule for a very specific situation,[164] the deviation of historic costs from marginal costs is not very severe. Rajan and Reichelstein (2009), however, stress explicitly, that the directly expensed share of an asset can cause quickly escalating errors. This observation is serious inasmuch as certain accounting principles dictate the direct expense of investments, for instance investments in intangible assets.

Finally, in terms of a regulation setting, it is argued that by the use of the RPC rule, two goals are met at the same time: first, that prices are set based on marginal costs, and second, that this procedure allows the firm to break even.

Böckem and Schiller (2009) base their analysis on the findings in Rogerson (2011) and Rajan and Reichelstein (2009). They assess cost-based access pricing regarding the resulting investment incentives. In contrast to earlier work like Rogerson (2011) with the assumption of perfect downstream competition, Böckem and Schiller assume *imperfect* downstream competition. They state that their analysis complements the results in Rogerson (2011). Moreover, the chosen setting models reality in the telecommunications sector quite adequately: one network provider (e.g. Deutsche Telekom in Germany) is responsible for investing in industry-wide capacity. Several competitors in the downstream market (e.g. Vodafone) are granted access to the network for a specific rent, which is also determined by the regulator. The importance of setting efficient investment incentives for the network

[163] Rajan and Reichelstein (2009), p. 832.
[164] The capacity resulting from new investment must decline linearly over time and with a specific rate. For a specification of this rate, see Rajan and Reichelstein (2009), p. 839 or Friedl (2007), p. 344.

provider to sufficiently enlarge or maintain the network is obvious.

Böckem and Schiller (2009) find that downstream competition can cause holdup of capacity investment. For pricing, it is crucial to implement the relative replacement cost (RRC) depreciation schedule, which is for instance specified in Rogerson (2011) or Dutta and Reichelstein (2010). If this is not fulfilled, then the network provider can find incentives for "playing manipulative games with the cost-based access price."[165] This finding, which explicitly accounts for imperfect competition in the downstream market, extends two existing fundamental insights. First, Biglaiser and Riordan (2000) as well as Nezlobin et al. (2012) do neglect downstream competition and are able to show that inefficient investment behavior results if the relative replacement cost depreciation rule is not implemented. Second, the result in Rogerson (2011) is extended, demonstrating the same result for perfect downstream competition.

Contrary to earlier results, Böckem and Schiller (2009) argue that pricing at long run incremental costs (LRIC) is not the best choice in a setting with one network provider and imperfect downstream competition. When the price equals long run incremental costs, then the network operator has a disadvantage compared to his competitors. The regulator can eliminate this effect by allowing for a mark-up on the LRIC.

It can be concluded from Böckem's and Schiller's analysis in terms of this thesis that above all, regulatory dynamics are strongly affected by the existence of a downstream market. Particularly important is the question of whether there is perfect or imperfect competition in the downstream market. This influencing factor must not be ignored. Furthermore, Böckem's and Schiller's analysis again confirms the importance of the relative replacement cost rule. The use of the RRC rule provides efficient investment incentives and helps to avoid undesired outcomes.

As one of the most current contributions to the related literature, Friedl and Küpper (2011) provide an extensive assessment of benefits and shortcomings of historic costs and forward-looking costs in regard to the determination of regulated prices. They analyze the theoretical foundations of both concepts in different specifications and provide calculations to support their findings.

They show that the use of either approach can have a large impact on investment incentives. They argue that the use of long-run incremental costs is more beneficial in providing efficient investment incentives than historic costs. According to them, the future orientation of long-run incremental costs is the main driver for this result. However, not only the

[165] Böckem and Schiller (2009), p. 1.

use of long-run incremental costs is important, but also the depreciation method. Friedl and Küpper (2011) argue that annuity depreciation is most promising for investment incentives.[166]

Moreover, they also consider the practical relevance and feasibility of their results by analyzing whether both approaches are compatible with international accounting standards. They find that the use of historic costs is unquestionably suitable, and they also consider the LRIC approaches compatible.

To summarize the review of articles which all assess the benefits and shortcomings of either basing regulated prices on historic costs versus replacement costs, there is no unambiguous, completely compelling result. In fact, it appears that the superiority of one or the other approach largely depends on other influencing factors. Guthrie et al. (2006) point to the importance of uncertainty and the future development of costs. Rogerson (2011) as well as Böckem and Schiller (2009) and Rajan and Reichelstein (2009) stress that the use of the right allocation rule can have more impact than either approach. Even if this allocation rule is not used, Rajan and Reichelstein (2009) find that straight-line depreciation does not cause a major departure of historic costs from marginal costs. Moreover, Böckem and Schiller (2009) show that the existence of perfect or imperfect downstream competition is an important influencing factor. Lastly, Friedl and Küpper (2011) find that the exact specification of replacement costs can make a significant difference.

3.4.4 Alternative Pricing Approaches

Having assessed the two important aspects of the level of information and the choice of the cost basis in the previous sections, this section discusses alternative pricing approaches and their relation with regulation and investment. Although the literature on these topics is vast, the discussion will be brief.

In many analytical models on regulatory pricing, only capacity costs translate into the regulated price.[167] However, it cannot be ignored that many other pricing approaches exist, in particular for pricing the use of capital-intensive utilities, of which the electricity industry is one. This fact calls for a closer investigation of these different pricing procedures and how they affect investment. The focus is put on peak-load pricing as it is applicable

[166] This is in line with the specifications of the model in chapter 4.

[167] See for instance Friedl (2007) or citetRoger2011. The developed model in the following chapter also employs this approach.

to and common in the electricity industry.[168]

The starting point for the discussion is marginal cost pricing which is accredited to Hotelling (1938) and Dupuit (1952).[169] It is a recognized fact that social welfare is maximized if price equals marginal costs. This has for example been acknowledged by Guthrie (2006) and Laffont and Tirole (1993). Guthrie (2006) further explains that regulation is necessary, because an "unregulated monopolist produces at a level where price exceeds marginal cost, therefore supplying quantities of goods and services that are lower than the socially-optimal levels."[170]

However, if an investment is characterized by large sunk costs, marginal cost pricing is not suitable. According to Sidak (2006) large sunk costs imply very low marginal cost for one more unit of the product or the service. As a consequence, the sunk capital costs can not be recovered using these marginal costs. This leads to so-called "second-best" solutions like in Baumol and Bradford (1970), which require that under these circumstances, prices have to be above marginal costs.

As another advancement of marginal cost pricing, peak-load pricing was developed, mainly by Boiteux (1949) and Steiner (1957). According to Laffont and Tirole (1993) peak-load pricing is the solution to the "common capacity problem" which means that marginal costs are different depending on if in a certain period, capacity use is saturated or not.

According to Crew et al. (1995), peak-load pricing denotes pricing of a non-storable commodity with variable demand. Electricity is a suitable field of application: it cannot easily be stored,[171] and its demand changes over the course of a day due to peoples' daily routines. In order to serve the demand during the peak time (the time of the day with the highest demand), a very high amount of installed capacity would be necessary. However, since peak times are only short, most of this capacity would be idle for the rest of the day (off-peak time). This causes significant inefficiencies and peak-load pricing aims at mitigating this effect.[172]

[168] See for instance Bailey (1972) or Schuler (2012).

[169] Marginal cost pricing was further promoted by Lerner (1994), Meade (1944) and Fleming (1944). In contrast to marginal cost pricing Ronald Coase (1946) suggested so-called Coasian two-part tariffs. This pricing approach has some advocates with regard to electricity transmission pricing, but is not in the focus of this analysis. For more information refer for instance to Matsukawa (2008).

[170] Guthrie (2006), p. 942.

[171] However, there are recent developments in the electricity industry which specifically aim at providing a storage possibility. This can be batteries or even power-to-gas technologies like hydrogen. These fairly new storage options significantly influence electricity markets, players and investment. For more information refer to the theses of Jan Michalski and Merlind Weber, Center for Energy Markets, TUM.

[172] It has to be mentioned that in the literature, peak-load pricing mostly refers to pricing electricity itself rather than its transmission. However, the prerequisites for these models are also fulfilled for power transmission.

In a peak-load pricing regime, different prices for different times of the days are implemented. The baseline result in a deterministic setting is that social welfare is maximized if during off-peak times only the operating costs per unit are charged, and during peak times, this price gets increased by the marginal capacity costs.[173] The expectation is that customers will have an incentive to shift their usage to off-peak times if possible and thus, the demand pattern gets smoothed. In off-peak times, they get charged less, namely only the operating costs. In peak times, customers that need to consume the product or service during this times will have to "pay their share" for the cost of capacity necessary to provide the product or service.[174]

As for other analyses of peak-load pricing, Crew et al. (1995) provide a comprehensive survey on its development and a classification of peak-load models. According to them, the baseline deterministic models of Boiteux (1949), Steiner (1957) or Turvey (1968) were extended step by step. One of the first extensions was to include demand uncertainties. Naturally, since demand uncertainties can result in supply shortfalls and supply rationing, literature on outage costs was developed. Crew and Kleindorfer (1976) is an example of an analysis on costs of rationing.

Of course not only demand uncertainty can be considered, but supply uncertainty as well. This was another subsequent development, and Chao (1983) is one representative of this literature stream.[175] He generalizes earlier analyses by treating uncertainty regarding demand and supply simultaneously. This distinguishes him from, for instance, Crew and Kleindorfer (1976), who only consider demand uncertainty.

By introducing uncertainty into peak-load pricing models, a widely accepted conclusion of former models does not hold any longer. According to Chao (1983) this conclusion is that "the off-peak customers should simply pay the marginal operating cost and the peak period customers should bear all the capacity costs."[176] With demand uncertainty, also the off-peak customers will have to pay a price higher than the marginal operating costs.

A similar analysis to Chao (1983) can be found in Oren et al. (1985). They also determine an optimal pricing policy for a monopolist whose products or services are subject to capacity limitation or peak loading. Their analysis is mainly independent from a regulatory

[173]This has for instance been proved by Crew et al. (1995).

[174]Another pricing approach close to peak-load pricing is Ramsey pricing, accredited to Ramsey (1927). According to Sidak (2006) Ramsey prices are the vector of prices that maximize the sum of consumer and producer surplus, subject to the constraint that the firm breaks even.

[175]There are further developments in the relevant literature like self-rationing, priority service or real-time pricing, but non of these is in the focus of the analysis here.

[176]Chao (1983), p. 179.

setting. However, in the paper's appendix, they explicitly extend the analysis to a situation with regulatory constraints.

They distinguish their analysis from previous results by determining a two-dimensional nonlinear pricing rule, which accounts not only for installed capacity of the service, but also for its usage. They argue that such a distinction is necessary because the provided capacity and the actual usage do not necessarily coincide. Hence they determine individual load duration curves for specific customer groups and base their pricing on these curves.

Elizabeth Bailey (1972) explicitly analyzes the connection between peak-load pricing and regulation. She considers three different forms of regulation, namely rate-of-return, profit per unit and return on total cost. Her finding is that the form of regulation is responsible for which group of customers profits from price reductions.

As a motivation for her analysis she argues that general peak-load pricing principles hold for a welfare-maximizing firm. However, companies naturally intend to maximize their profits. Consequently, it is more straightforward to consider the interactions between a welfare-maximizing regulator (or in general a governmental institution) and a profit-maximizing company which can be influenced by some regulatory policy. Furthermore, she stresses the fact that "many of the industries to which peak-load pricing principles are most applicable (such as the electric utilities or telecommunications) are regulated monopolies."[177]

The results of her analysis are generally in line with basic peak-load findings: she finds that a welfare maximizer will equal prices to marginal operating costs in off-peak periods and will increase the prices by the marginal capital costs in peak periods. Contrarily, an unregulated monopolist will equal marginal *revenues* to marginal operating costs in off-peak periods and will also increase them by marginal capital cost in peak periods.

Her contribution is the analysis of changes in these pricing rules for different forms of regulation: for rate-of-return regulation, only peak-period customers receive a price reduction whereas for profit per unit or return on cost regulation, all customers profit from this reduction.[178]

The review of the cited articles shows that peak-load pricing is a common and reason-

[177] Bailey (1972), p. 662.

[178] Waverman (1975) published a critical discussion of Bailey's article a couple of years later. His critique mainly addressed the production function used by Elizabeth Bailey. He argues that changing some of Bailey's assumptions "leads to the conclusion that rate-of-return regulation benefits off-peak users as well as peak users".

able approach for pricing the use of capital-intensive infrastructure, as it solves problems of classic marginal cost pricing. However, it yet does not have many applications in a regulatory context, and it will not be employed in the following model.

To summarize, the four issues discussed in this section are intended to give the reader a wider understanding of important influencing factors in models on regulation and investment. These factors do not just concern isolated model assumptions like for instance the development of capacity costs,[179] but they rather represent essentially different perspectives. These wider, different perspectives were presented before the formal model in the following chapter, because the model restricts itself to a narrow view on one specific aspect. Any of the discussed issues are promising to be incorporated into model extensions in a second step, but this is beyond the scope of this thesis. The centerpiece of the thesis is the already mentioned analytical model, which is presented in the following chapter.

[179]This is accomplished in section 4.4.2.

4 Model on the Influence of Multi-period Investment on Optimal Regulatory Pricing

This chapter represents the core of this thesis. A formal model is developed which answers the following question: in a cost-based regulation environment and considering investment over multiple periods, what effect does the actual price determination have on the affected company's investment decision? What is the optimal price from the regulator's perspective? Or, in other words, which price determination results in the highest social welfare?

The chapter is organized as follows: in section 4.1 the basic model with its assumptions and objective functions is characterized. Section 4.2 first provides some background on the general pricing procedure and then demonstrates the influence of the specific model setup. The solution of the model can be found in section 4.3. Section 4.4 contains model extensions and relaxes some initial assumptions of the model. A broad discussion about the model results, its limitations and implications for practical purposes can be found in section 4.5.

4.1 Characterization of the Basic Model

4.1.1 Introduction and Relevance

It has been argued widely that cost-based regulation can affect investment negatively. However, the review of existing literature reveals that in analytical models, certain means exist to induce the company to invest efficiently. In a cost-based regulation environment, this mainly means the use of specific depreciation or cost allocation rules to determine the depreciation charge included in the regulated price.

In the existing analytical models the use of this specific depreciation rule always leads to exactly one price for each considered period. In other words, once a certain rule is chosen, there is no further scope of action for the regulator regarding which price to implement exactly.

In the following, a specific model setup is employed: investments overlap, and hence productive capacity accumulates in the second considered period. It will be shown that in this setup, scope of action for the regulator does emerge, because the price of capacity changes. Among the different options for price determination emerging for the regulator, his actual choice can dramatically affect the company's investment decision. This result shows that given a certain initial situation, the regulator needs to be careful and attentive when committing to specific regulated prices in order to set the right incentives for the company.

The model setup is justified both from a practical and a theoretical point of view. As for a practical application, the model setup reflects the situation of the German incentive regulation fairly well: before the AReg became effective in 2009, the regulator committed to a certain pricing procedure for all three future regulation periods.[180] Moreover, the affected companies certainly invest in all periods and increase their productive capacity step by step. From a theoretical perspective, section 4.2.3 will demonstrate that the seemingly highly specific setup in fact applies to many more situations.

In the following the basic model setup and the model assumptions are described succeeded by a short introduction to the price determination procedure.

4.1.2 Model Basics and Assumptions

A discrete-time, deterministic, three-period model is considered in which a regulated monopolist faces two subsequent investment opportunities: he can invest in a specific amount of productive capacity at $t = 0$ and $t = 1$. At time $t = 0$, where no initial assets are assumed, the company needs to decide on both investment opportunities simultaneously.

Assets are assumed to be fully depreciated after two periods, and they cannot be used any further afterwards. In other words, one investment results in productive capacity for two periods: the investment in $t = 0$ provides capacity in periods 1 and 2, the investment in $t = 1$ provides capacity in periods 2 and 3. As a consequence, the two investments overlap in period 2.

[180] In fact it has to be admitted that the third period was left open, but it will be shown in the model that the first two periods are the most relevant.

For both investments, the company decides how many units $x_t,\ t \in \{0,1\}$ of a product or a service it wants to provide to be sold. The necessary investment outlay is $C_t \cdot x_t,\ t \in \{0,1\}$, where C_t denotes the outlay for one unit of capacity. The investment outlay is paid directly at investing: $C_0 \cdot x_0$ is paid at $t = 0$, $C_1 \cdot x_1$ is paid at $t = 1$. Both capacity costs C_0 and C_1 are known at $t = 0$. As a baseline case, it is assumed that capacity costs decrease over time, hence $C_0 > C_1$.[181]

As mentioned earlier, a crucial fact for the rest of the analysis is that this specific setup results in the fact that capacities accumulate to $x_0 + x_1$ in period 2. In other words, if I_t is defined to be the total available productive capacity in period t, then this particular investment sequence results in

$$\begin{aligned} I_1 &= x_0 \\ I_2 &= x_0 + x_1 \\ I_3 &= x_1. \end{aligned}$$

Figure 4.1 shows the described setting.

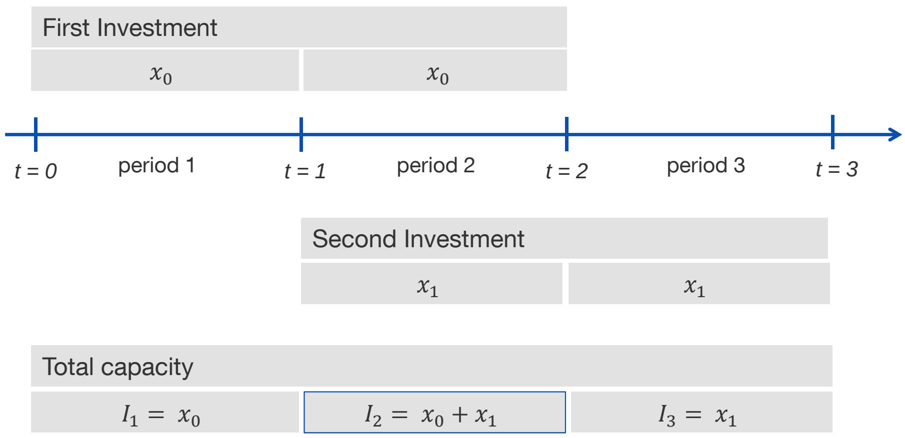


Figure 4.1: Basic model setup for two overlapping investments.

For simplicity reasons, and since it is a common procedure in related models,[182] variable costs are normalized to be zero, and both investments are assumed to be irreversible.

At each point in time t, a specific demand function on the product market exists which indicates the demanded quantity of the product q_t for a given price p_t. Demand is assumed to stay constant over time, and the demand functions are monotonically decreasing in the

[181] This assumption will be relaxed in section 4.4.2.
[182] See for instance Friedl (2007) or Rogerson (2011).

price. Limiting demand to stay constant over time is a strong assumption, but necessary for the basic model setup.[183]

In line with the relevant literature, a linear inverse demand function of the form $p_t(q_t) = a - b \cdot q_t$ is used, where a is the maximal willingness to pay, and b is the slope of the demand function. Note again that a and b stay constant throughout the analysis. The upper limit of available capacity needs to be accounted for. As I_t is the total provided capacity in period t, and p_t is the price in this period, then the sold quantities in each period are:

$$q_t(p_t, I_t) = \min\left\{\frac{a}{b} - \frac{1}{b}p_t, I_t\right\} \tag{4.1}$$

This formulation takes into account that if prices are low, demand is limited by the available capacity and if prices are high, demand linearly decreases according to the demand function.

It is assumed that the company knows the demand function and thus, it can use it for its investment decision. In contrast to this, the regulator has no knowledge about the demand function. Friedl (2007) illustrates the rationale for the assumption in detail: if the regulator knew the demand function, he himself would determine the investment decision that is optimal for the entire economy, and he would enjoin it to the company. However, as the regulator in fact does not know the demand function, he must cede the investment decision to the company, and he must find other ways to influence this decision. Friedl (2007) argues that this is a realistic assumption, as the company has a better knowledge about the relevant market and hence, it knows its customers' willingness to pay.

Furthermore, the model assumes that the company is subject to a cost-based regulation. This means that the regulator is informed about the incurred costs of the company and for each period t, $t \in \{1, 2, 3\}$ he sets a price cap $\overline{p}_t$ equal to the costs. In this setting, since variable operating costs are normalized to be zero, the only incurred costs are depreciation charges and interest on invested capital. It is important to note that the employed depreciation method strongly influences these depreciation charges. The actual determination of the regulated prices is analyzed in detail in section 4.2.1.

The regulator influences the company's investment decision via the allowed regulated prices. The model is deterministic, hence the values of all relevant variables are known to all parties from the beginning of the game on and do not change later. Uncertainty is not

[183]Section 4.5 will discuss this assumption in more detail.

incorporated.[184] The regulator commits to a certain choice of the regulated prices before the company makes its investment decision. Therefore, when deciding upon its provided capacities x_0 and x_1 at $t = 0$ the company knows which regulated prices $\overline{p}_1$, $\overline{p}_2$ and $\overline{p}_3$ it is allowed to charge in the three following periods. The course of the game is illustrated in Figure 4.2.

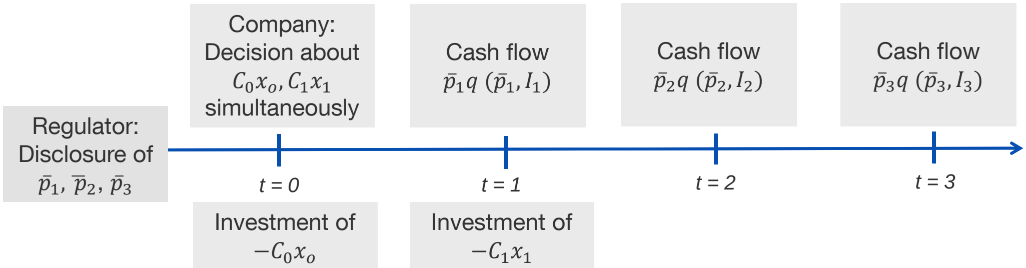


Figure 4.2: Course of investment sequence.

Since the regulated prices are the regulator's most important instrument to influence the company's investment decision, the regulator needs to define these regulated prices in a way that they will induce the company to invest efficiently. It will be illustrated that especially for overlapping investments, the regulator has some scope how to define these prices. In section 4.2.2, this scope and hence different ways for setting these regulated prices are discussed.

4.1.3 Objective Functions of Company and Regulator

It is important to be aware of the fact that the company and the regulator pursue different objectives by investing, hence by choosing the capacities x_0 and x_1.

Burns and Riechmann (2004) provide a comprehensive discussion on the different objectives of producers and consumers. They state that "investment in itself is not an objective for either producers or consumers." Investment is rather a key driver for the surplus either party wants to extract. The goal of producers is to gain an adequate return on their capital and hence maximizing the NPVs of investment projects. Consumers are mainly interested in reasonable prices and good quality of service, of which investment is an important driver. Burns and Riechmann (2004) consider investment a "leading indicator for future levels of service quality". In this model, the regulator acts as the advocate of consumers, in that maximization of social welfare is pursued.

[184]This is another strong assumption, which will be discussed in section 4.5 and in depth in section 3.4.1.

Consequently, in the following model setup, exactly these two different goals between company and regulator are modeled: the maximization of a project's NPV is defined as the company's goal, and the maximization of social welfare as the regulator's goal. First, the company's objective function is explained and discussed, and second, the regulator's objectives.

Company's objective function and capacity constraints

The company's goal is to maximize the net present value of an investment project.[185] Under the assumption that the assets fully depreciate within two periods, it chooses the capacities x_0 and x_1 according to

$$\begin{aligned} &\max_{x_0,x_1} NPV(x_0,x_1) = \\ = \quad &-C_0x_0 - C_1x_1\gamma + \overline{p}_1 \cdot q(\overline{p}_1, x_0) \cdot \gamma + \overline{p}_2 \cdot q(\overline{p}_2, x_0 + x_1) \cdot \gamma^2 + \overline{p}_3 \cdot q(\overline{p}_3, x_1) \cdot \gamma^3. \end{aligned}$$

Note that with r being the company's WACC, $\gamma = 1/(1+r)$ is the company's discount factor. As illustrated in Figure 4.1 the relevant capacity in period 2 is the sum of x_0 and x_1, since the two investments are overlapping.

Using the demand functions results in

$$\begin{aligned} \max_{x_0,x_1} NPV(x_0,x_1) = \quad &-C_0x_0 - C_1x_1\gamma \\ &+\overline{p}_1 \cdot \min\left\{\frac{a}{b} - \frac{1}{b}\cdot\overline{p}_1, x_0\right\} \cdot \gamma \\ &+\overline{p}_2 \cdot \min\left\{\frac{a}{b} - \frac{1}{b}\cdot\overline{p}_2, x_0 + x_1\right\} \cdot \gamma^2 \\ &+\overline{p}_3 \cdot \min\left\{\frac{a}{b} - \frac{1}{b}\cdot\overline{p}_3, x_1\right\} \cdot \gamma^3. \end{aligned}$$

In cost-based regulation, the company avoids to produce any excess capacity. As only capital costs get accounted for in the regulated price, any excess capacity would negatively affect the company's NPV. To this end, the company wants to make sure that the minimum of the demand function and the provided capacity is always equal to the provided capac-

[185] In the majority of existing models, regulated firms are assumed to maximize their market value. However, it must be noted that there are also other possible objectives, among others the maximization of total revenue, output or the realized rate of return. For a discussion on this see Guthrie (2006) or Baumol and Klevorick (1970).

ity. With any higher capacity, the future cash flows would not suffice to compensate for the original investment outlays, because demand is smaller than the provided capacity. Consequently the company's objective function is

$$\max_{x_0,x_1} NPV(x_0,x_1) = -C_0x_0 - C_1x_1\gamma + \overline{p}_1x_0\gamma + \overline{p}_2(x_0+x_1)\gamma^2 + \overline{p}_3x_1\gamma^3 \quad (4.2)$$

$$= (-C_0 + \overline{p}_1\gamma + \overline{p}_2\gamma^2)\cdot x_0 + (-C_1 + \overline{p}_2\gamma + \overline{p}_3\gamma^2)\cdot x_1\gamma \quad (4.3)$$

subject to the following constraints:

$$I_1 = x_0 \leq \frac{a-\overline{p}_1}{b}, \qquad I_2 = x_0 + x_1 \leq \frac{a-\overline{p}_2}{b}, \qquad I_3 = x_1 \leq \frac{a-\overline{p}_3}{b}. \quad (4.4)$$

Obviously, the company's capacity choices are strongly dependent on the regulated prices $\overline{p}_t$ in all three periods: the capacities that the company employs have to fulfill the constraints in equation (4.4). Since the regulated prices influence the upper bounds for the capacities with a minus sign, it is obvious that the higher the regulated price, the lower are the provided capacities. Detached from the formulas, this is also an intuitive insight: for a linear inverse demand function, a higher price results in smaller demand, and for smaller demand, less capacity needs to be provided.

Regulator's objective function and efficient capacities

In this section, the regulator's objective and his efficient capacity choice are analyzed. It must be noted that while the regulator's "efficient capacity choices" are determined, these choices are rather hypothetical. In fact, it is not the regulator who decides upon the capacities, it is the company's decision. Nevertheless, these hypothetical efficient capacity choices must be determined in order to judge whether the regulator would prefer more or less capacity than the company is willing to provide. For the remainder of the model, "the regulator's capacity choice" means this hypothetical capacity choice.

The regulator's goal is to maximize social welfare $SW(x_0, x_1)$. In the context of the model, this means that the sum of consumer and producer surplus in maximized subject to the investment outlays being covered. According to Friedl (2007), from the regulator's perspective, the efficient investment level is characterized by the discounted sum of all integrals (one integral for each period) over the consumer's willingness to pay being larger than all investment outlays. In fact the regulator would like to choose x_0 and x_1 according to

$$
\begin{aligned}
& \max_{x_0,x_1} && SW(x_0,x_1) \\
\Leftrightarrow\ & \max_{x_0,x_1} && \Big\{ -C_0x_0 - C_1x_1\gamma \\
& && + \int_0^{x_0}(a-bq)\,\mathrm{d}q\cdot\gamma + \int_0^{x_0+x_1}(a-bq)\,\mathrm{d}q\cdot\gamma^2 + \int_0^{x_1}(a-bq)\,\mathrm{d}q\cdot\gamma^3 \Big\} \\
\Leftrightarrow\ & \max_{x_0,x_1} && \Big\{ -C_0x_0 - C_1x_1\gamma \\
& && + \left(ax_0 - \frac{b}{2}{x_0}^2\right)\gamma + \left(a(x_0+x_1) - \frac{b}{2}(x_0+x_1)^2\right)\gamma^2 + \left(ax_1 - \frac{b}{2}{x_1}^2\right)\gamma^3 \Big\}
\end{aligned}
$$

In order to solve this maximization problem a two-dimensional optimization is necessary. The first step is to calculate the partial derivatives of $SW(x_0, x_1)$:

$$
\begin{aligned}
SW(x_0,x_1) &= -C_0x_0 - C_1x_1\gamma \\
&+ \left(ax_0 - \frac{b}{2}{x_0}^2\right)\gamma + \left(a(x_0+x_1) - \frac{b}{2}(x_0+x_1)^2\right)\gamma^2 + \left(ax_1 - \frac{b}{2}{x_1}^2\right)\gamma^3 \\
&= x_0\left(-C_0 + a\gamma(1+\gamma)\right) + {x_0}^2\left(-\frac{1}{2}b\gamma(1+\gamma)\right) \\
&\quad + x_1\left(-C_1\gamma + a\gamma^2(1+\gamma)\right) + {x_1}^2\left(-\frac{1}{2}b\gamma^2(1+\gamma)\right) - x_0x_1b\gamma^2 \\
\frac{\partial SW(x_0,x_1)}{\partial x_0} &= -C_0 + a\gamma(1+\gamma) + 2x_0\left(-\frac{1}{2}b\gamma(1+\gamma)\right) - x_1b\gamma^2 \\
\frac{\partial SW(x_0,x_1)}{\partial x_1} &= -C_1\gamma + a\gamma^2(1+\gamma) + 2x_1\left(-\frac{1}{2}b\gamma^2(1+\gamma)\right) - x_0b\gamma^2
\end{aligned}
$$

Setting the partial derivatives of $SW(x_0, x_1)$ equal to zero results in:

$$
\begin{aligned}
x_0^* &= \frac{-C_0(1+\gamma) + C_1\gamma + a\gamma(1+\gamma)}{b\gamma(1+\gamma+\gamma^2)} \\
x_1^* &= \frac{C_0 - C_1(1+\gamma) + a\gamma^2(1+\gamma)}{b\gamma(1+\gamma+\gamma^2)}
\end{aligned}
$$

In order to prove that there is a maximum at (x_0^*, x_1^*) the use of the second derivatives and the Hesse matrix is necessary.

$$H = \begin{pmatrix} \frac{\partial^2 SW(x_0,x_1)}{\partial x_0^2} & \frac{\partial^2 SW(x_0,x_1)}{\partial x_0 \partial x_1} \\ \\ \frac{\partial^2 SW(x_0,x_1)}{\partial x_1 \partial x_0} & \frac{\partial^2 SW(x_0,x_1)}{\partial x_1^2} \end{pmatrix} = \begin{pmatrix} -b\gamma(1+\gamma) & -b\gamma^2 \\ \\ -b\gamma^2 & -b\gamma(1+\gamma) \end{pmatrix}$$

To show that (x_0^*, x_1^*) constitute a maximum, it needs to be shown that H is negative definite. This is equivalent to showing that $-H$ is positive definite. This is true because

$$\begin{aligned} |-H| &= b^2\gamma^2(1+2\gamma) > 0 \\ |b\gamma(1+\gamma)| &= b\gamma(1+\gamma) > 0. \end{aligned}$$

Hence, there is a maximum at (x_0^*, x_1^*).

Summarizing, if the regulator could choose the capacity for the company, the optimal capacity choices from his perspective are:

$$x_0 = \frac{-C_0(1+\gamma) + C_1\gamma + a\gamma(1+\gamma)}{b\gamma(1+\gamma+\gamma^2)} \tag{4.5}$$

$$x_1 = \frac{C_0 - C_1(1+\gamma) + a\gamma^2(1+\gamma)}{b\gamma(1+\gamma+\gamma^2)} \tag{4.6}$$

$$x_0 + x_1 = \frac{-C_0\gamma - C_1 + a\gamma(1+\gamma)^2}{b\gamma(1+\gamma+\gamma^2)}. \tag{4.7}$$

Note that there are conditions on a for x_0 and x_1 to be positive:

$$\begin{aligned} x_0 \geq 0 \quad &\Leftrightarrow \quad a \geq \frac{C_0}{\gamma} - \frac{C_1}{1+\gamma} \\ x_1 \geq 0 \quad &\Leftrightarrow \quad a \geq \frac{-C_0}{\gamma^2(1+\gamma)} + \frac{C_1}{\gamma^2}. \end{aligned}$$

It holds that

$$\begin{aligned} \frac{C_0}{\gamma} - \frac{C_1}{1+\gamma} - \frac{-C_0}{\gamma^2(1+\gamma)} - \frac{C_1}{\gamma^2} &= \frac{(C_0 - C_1)(1+\gamma+\gamma^2)}{\gamma^2(1+\gamma)} \\ &> 0 \ \text{ since } \ C_0 > C_1. \end{aligned}$$

Hence, the highest threshold is the one for x_0:

$$x_0 \geq 0 \Leftrightarrow a \geq \frac{C_0}{\gamma} - \frac{C_1}{1+\gamma}. \tag{4.8}$$

This threshold can be considered a general requirement for the demand. If the maximal willingness to pay a is not higher than this threshold, then investment is not beneficial at all. Hence for the remainder of the analysis, a is supposed to fulfill this requirement.

The following Table 4.1 contains an example which shows the regulator's chosen capacities for selected parameter combinations. The input parameters are the capacity costs C_0 and C_1, as well as the parameters of the demand function, a and b. In particular, four sets of parameter specifications are considered, which are picked completely randomly. These examples will be used throughout the rest of the model in order to illustrate certain findings. Table 4.1 shows the efficient parameter choices for the regulator together with the positivity constraint.

INPUT	C_0	10	10	20	30
	C_1	9	8	10	20
	a	8	8	17	23
	b	0.2	0.2	0.1	0.1
REGULATOR'S CHOICES	x_0^R	5.98	4.15	1.66	3.32
	x_1^R	10.94	14.78	111.51	113.02
	SUM Regulator	16.92	18.93	113.17	116.34
	$x_0 > 0$ for $a >$	6.29	6.81	16.76	22.52

Table 4.1: Example: regulator's capacity choices for selected parameters.

4.2 Background for Cost-based Pricing

The purpose of this section is first, to generate a basic understanding of how regulated prices are determined in a simple cost-based pricing setting and second, to illustrate the distinctive features and changes that result from the specific model setup.

4.2.1 General Pricing Procedure

In the model basics the general determination of the regulated prices was briefly addressed. The regulator allows the company to charge a price which in each period covers exactly the costs. Since variable operating costs are normalized to be zero, these costs are the capital costs, namely depreciation plus interest on invested capital.[186] Hence the general formula for the regulated price $\overline{p}_t$ in period t is

$$\overline{p}_t = D_t + rV_{t-1},$$

where D_t denotes the depreciation charge in period t, V_t denotes the value of the asset at point in time t and r is the interest rate.

If just one single investment in asset C_t is considered, this investment determines the regulated price of the two following, consecutive periods (recall that assets are assumed to fully depreciate within two periods):

$$\begin{aligned}\overline{p}_1 &= D_1 + rV_0 = D_{1,C_t} + rC_t \\ \overline{p}_2 &= D_2 + rV_1 = D_{2,C_t} + r(C_t - D_1) = (C_t - D_{1,C_t}) + r(C_t - D_{1,C_t}).\end{aligned}$$

In this notation, D_{i,C_t} is the depreciation charge in period i caused by C_t. This formulation takes into account that the sum of the depreciation charges in the two periods has to be equal to the original asset value, i.e. $C_t = D_1 + D_2 = D_{1,C_t} + (C_t - D_{1,C_t})$ and that the asset value at $t = 1$ is equal to the original asset value minus the first depreciation charge, i.e. $V_1 = C_t - D_1 = C_t - D_{1,C_t}$. Figure 4.3 serves as an illustration.

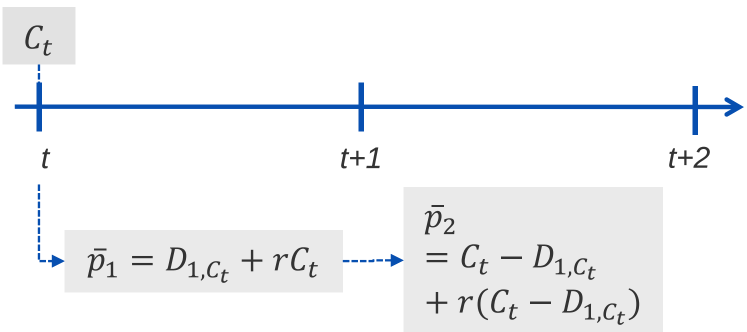


Figure 4.3: Price determination with isolated investments.

In the present model, not a single investment is in the focus of the analysis, but two investments which overlap. However, in order to illustrate the significance of the specific situation, the model setup is extended stepwise: next, as the baseline-case the price determination for two consecutive non-overlapping investments will be considered. In a third step in section 4.2.2 the actual situation of the present model, namely the price determina-

[186] In the context of pricing the use of capital-intensive utility infrastructure, this is not the only way to determine regulated prices. In fact, many authors like Boiteux (1949), Coase (1946), Laffont and Tirole (1993) or Schuler (2012) argue for the use of peak-load pricing, congestion pricing or other two-part tariffs. Alternative forms in regulatory pricing are addressed in section 3.4.4.

tion with two overlapping investments, will be analyzed.

If two consecutive investments C_0 and C_1 do not overlap, then the regulated prices $\overline{p}_t$ in the periods 1 to 4 can be determined analogously to one single investment:

$$\begin{aligned}
\overline{p}_1 &= D_1 + rV_0 = D_{1,C_0} + rC_0 \\
\overline{p}_2 &= D_2 + rV_1 = D_{2,C_0} + r(C_0 - D_1) = (C_0 - D_{1,C_0}) + r(C_0 - D_{1,C_0}) \\
\overline{p}_3 &= D_3 + rV_2 = D_{1,C_1} + rC_1 \\
\overline{p}_4 &= D_4 + rV_3 = D_{2,C_1} + r(C_1 - D_3) = (C_1 - D_{1,C_1}) + r(C_1 - D_{1,C_1}).
\end{aligned}$$

Figure 4.4 serves as an illustration.

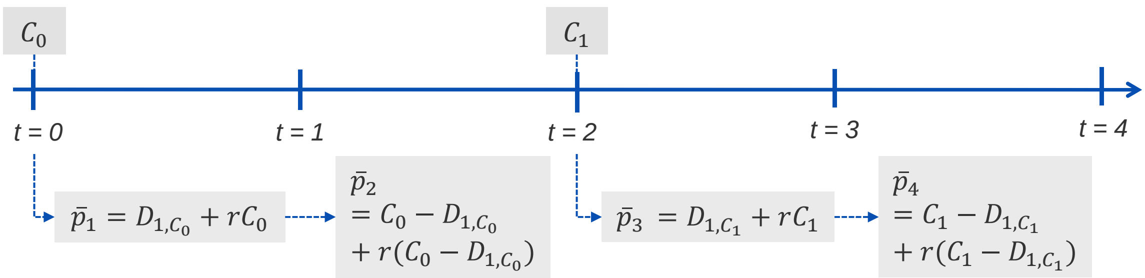


Figure 4.4: Price determination with two non-overlapping investments.

Clearly, the employed depreciation method has a strong influence on the regulated price and therefore on the company's investment decision: different depreciation methods result in different regulated prices and these prices are part of the capacity constraints (see equation (4.4)) upon which the company will decide on its investment levels. By choosing a specific depreciation pattern, the regulator determines the regulated price and hence he influences the company's investment decision. As shown in prior research,[187] if investment decisions are separable like in this non-overlapping scenario, the regulator can induce efficient investment[188] by using the *annuity depreciation rule* when determining the regulated prices.[189]

If depreciation charges are defined as $D_t = d_t \cdot C_t$, then with annuity depreciation over

[187] See for instance Friedl (2007).
[188] The efficient investment levels from the regulator's perspective are specified in section 4.1.3.
[189] For the remainder of this chapter, the use of annuity depreciation is assumed. However, it can easily be shown that the results of the analysis are exactly the same for straight-line depreciation which is more prevalent in practice.

two periods, the depreciation charges in period t, $t \in \{1, 2\}$ are calculated according to

$$d_t = \frac{r(1+r)^{t-1}}{(1+r)^2 - 1} \,.$$

An important characteristic of the annuity depreciation method is that it leads to constant regulated prices. Namely, with annuity depreciation the regulated prices for the investment C_t are

$$\overline{p}_1 = \overline{p}_2 = \frac{C_t(1+r)^2}{2+r} = \frac{C_t}{\gamma + \gamma^2}.$$

Hence, for the non-overlapping setting in Figure 4.4 the regulator can induce efficient investment by defining

$$\begin{aligned} \overline{p}_1 &= \overline{p}_2 = \frac{C_0(1+r)^2}{2+r} = \frac{C_0}{\gamma + \gamma^2} \\ \overline{p}_3 &= \overline{p}_4 = \frac{C_1(1+r)^2}{2+r} = \frac{C_1}{\gamma + \gamma^2}. \end{aligned}$$

Concluding this section, for two consecutive non-overlapping investments, prior research has already proven that the key to induce efficient investment is the implementation of the annuity depreciation rule. However, in the following it will be shown that the fact that two investments overlap changes the situation significantly.

4.2.2 Influence of Overlapping Investment

This section now illustrates the significance of the fact that two investments overlap. Again, two consecutive investments at $t = 0$ and $t = 1$ are considered with capacity costs C_0 and C_1 respectively. As illustrated in the previous section, if the two investments are regarded isolatedly, they both lead to two regulated prices. Although now the focus is on two overlapping investments, the assumption still holds that regulated prices consist of depreciation and interest.

In detail, the investment of C_0 leads to the two prices

$$\begin{aligned} \overline{p}_1 &= D_{1,C_0} + rC_0 \text{ and} \\ \overline{p}_{2,C_0} &= (C_0 - D_{1,C_0}) + r(C_0 - D_{1,C_0}). \end{aligned}$$

On the other hand, investing C_1 leads to the two prices

$$\begin{aligned} \overline{p}_{2,C_1} &= D_{1,C_1} + rC_1 \text{ and} \\ \overline{p}_3 &= (C_1 - D_{1,C_1}) + r(C_1 - D_{1,C_1}). \end{aligned}$$

If again the annuity depreciation method is used, the regulated prices are

$$\begin{aligned} \overline{p}_1 &= \overline{p}_{2,C_0} = \frac{C_0(1+r)^2}{2+r} = \frac{C_0}{\gamma+\gamma^2} \\ \overline{p}_3 &= \overline{p}_{2,C_1} = \frac{C_1(1+r)^2}{2+r} = \frac{C_1}{\gamma+\gamma^2}. \end{aligned}$$

In the previous section there was no doubt about what price should be implemented in each period, because the two investments were completely separable. In contrast to this, with the two overlapping investments, the regulator has scope in the determination of the regulated price in period 2. Both the two prices $\overline{p}_{2,C_0}$ or $\overline{p}_{2,C_1}$, or any combination of the two, are possible candidates for the regulated price in period 2, and it is unclear which of the two should be picked. Figure 4.5 illustrates the setting for the overlapping issue in period 2.

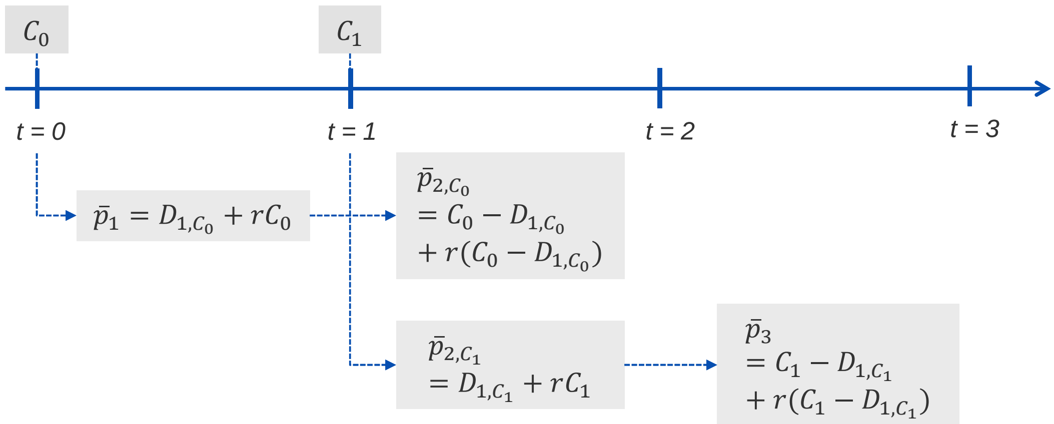


Figure 4.5: Scope in price determination with two overlapping investments.

The following numerical example shows the situation for a specific set of variable values.

Example 1 *Assume that $C_0 = 10$, $C_1 = 8$, $r = 10\%$ and prices are determined using the annuity* *depreciation rule. Then*

$$\overline{p}_{2,C_0} = \frac{C_0(1+r)^2}{2+r} = \frac{10(1+0.1)^2}{2+0.1} = 5.76$$
$$\overline{p}_{2,C_1} = \frac{C_1(1+r)^2}{2+r} = \frac{8(1+0.1)^2}{2+0.1} = 4.61.$$

However, it is unclear whether the regulator should set $\overline{p}_{2,C_0} = 5.76$ *or* $\overline{p}_{2,C_1} = 4.61$ *as the regulated price in period 2.*

The following Table 4.2 picks up the earlier example of Table 4.1 and determines the regulated prices in all three periods for the four already introduced sets of parameters. In period 2, both $\overline{p}_{2,C_0}$ and $\overline{p}_{2,C_1}$ are options for the regulated price. Note that since capacity costs are assumed to be decreasing, $\overline{p}_{2,C_1}$ is always smaller than $\overline{p}_{2,C_0}$.

INPUT		C_0	10	10	20	30
		C_1	9	8	10	20
		a	8	8	17	23
		b	0.2	0.2	0.1	0.1
REGULATED PRICES	period 1	$\overline{p}_1$	5.76	5.76	11.52	17.29
	period 2	$\overline{p}_{2,C_0}$	5.76	5.76	11.52	17.29
		$\overline{p}_{2,C_1}$	5.19	4.61	5.76	11.52
	period 3	$\overline{p}_3$	5.19	4.61	5.76	11.52

Table 4.2: Example: regulated prices for selected parameters.

Thinking further, it even does not have to be exactly one of the candidates $\overline{p}_{2,C_0}$ and $\overline{p}_{2,C_1}$, but also any combination of the two appears to be a viable option. In fact, an intuitive way of dealing with this scope would be to simply use the average of $\overline{p}_{2,C_0}$ and $\overline{p}_{2,C_1}$ and the regulated price in period 2. The exact effects of the choice of $\overline{p}_2$ on the company's investment behavior are going to be analyzed in section 4.3.1. For now, the most important message is to recognize that there is a possible conflict in the price determination due to the specific model setup with the one overlapping period.

4.2.3 Reasoning for the Relevance of the Three Period Model

This section provides a rationale why it is important to consider a three period model as described. The relevance of the model setting might not be obvious at a first glance, because one can argue that an investment sequence is usually not done after three periods.

Rogerson (2011) showed that for an infinite investment sequence there exists an approach for inducing efficient investment. In his model the problem of setting the right regulated price becomes separable. Similar to the present analysis, he assumes asset prices to be weakly decreasing.

For the present model, is has been argued that for two consecutive investments and a two-period depreciation scheme, capacities overlap in period 2, and therefore, there is scope in the selection of the regulated price in this particular period.

However, if three consecutive investments were considered, the situation is different: again the company needs to simultaneously decide at time $t = 0$ about the three investments at $t = 0, 1$ and 2, which result in the capacities x_0, x_1 and x_2. In contrast to the basic problem with two overlapping investments, this problem can be reduced to two separable problems without any overlapping issue. This is done by canceling the investment at $t = 1$. Figure 4.6 illustrates the setting for two and three investments.

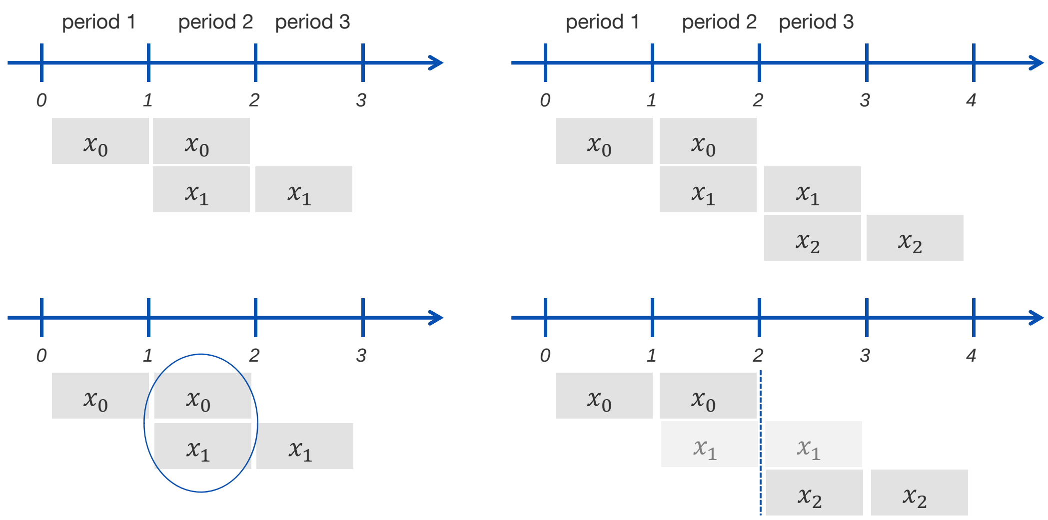


Figure 4.6: Reduced problem for depreciation over two periods.

Simply canceling the investment in x_1 might seem odd at first, but having a closer look, it is not problematic to do so: in the general model setting this investment is not necessary. Demand remains constant in all periods and therefore, no additional capacity is needed in period 2. Consequently, by canceling the investment in x_1, only the investments in x_0 and x_2 remain. These investments of the baseline case form of section 4.2.1 and efficient investment can be induced by implementing the annuity depreciation.

This insight still holds if more than three investments are considered. For depreciation over two periods, it holds that whenever there are $2n$, $n \in \mathbb{N}$, investments, then even after reducing the problem, there is still one overlapping period remaining. Hence, for the three last periods of the investment sequence, the present analysis is valid. Whenever there are $2n + 1$, $n \in \mathbb{N}$ investments, then the multi-period problem can be completely reduced to only $n + 1$ separable problems.

In analogy to this reasoning, the same situation can be illustrated for longer depreciation schedules. For instance, if assets are assumed to depreciate over three periods, then there is an overlapping period for three investments (in general: $3n$, $n \in \mathbb{N}$) and the problem is completely reducible for four investments (in general: $3n + 1$, $n \in \mathbb{N}$). The setting for a depreciation over three periods is illustrated in Figure 4.7.

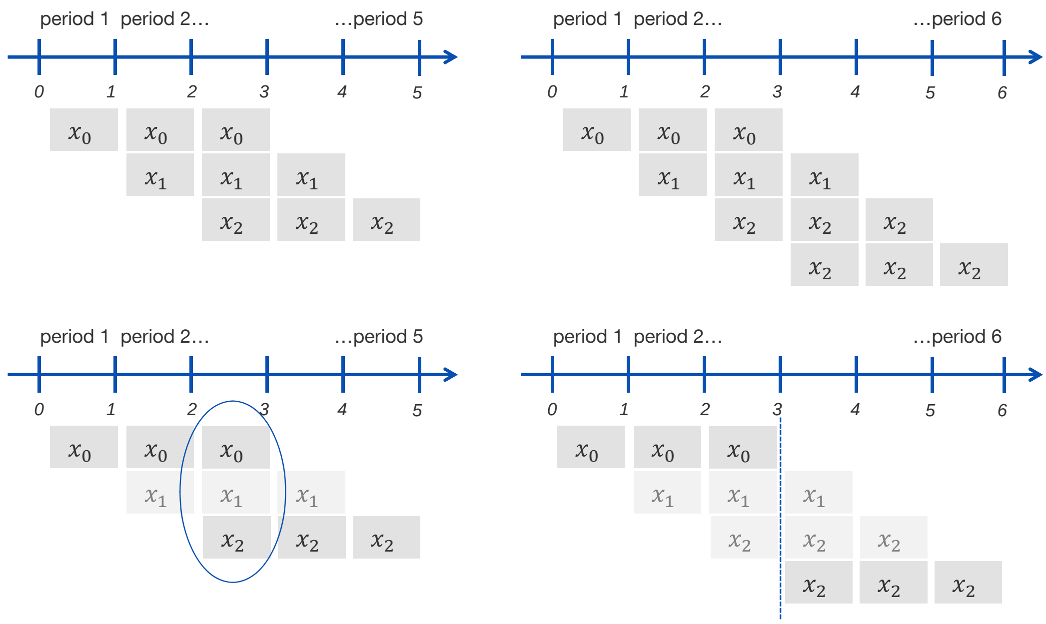


Figure 4.7: Reduced problem for depreciation over three periods.

Generally speaking, if assets fully depreciate over N periods, then there is an overlapping issue in the last periods of the investment sequence for $N \cdot n$, $n \in \mathbb{N}$, investments. The multi-period problem can be completely reduced to only $n+1$ separable problems for $N \cdot n + 1$, $n \in \mathbb{N}$, investments.

Hence, the overlapping issue does not only occur in a very specific investment setting, but this seemingly specific setting is a simplification for a problem which is prevalent in many multi-period investment sequences.

4.3 Solution of the Model

In the previous section the model setup has been completed by illustrating the existing scope in the actual price determination and by justifying the setup from a theoretical perspective. In this section, the model is solved. To this end, first the different alternatives in setting the regulated price are discussed and the optimal choice for the regulator is identified in section 4.3.1. Then the investment levels of company and regulator are compared in section 4.3.2.

4.3.1 Analysis and Discussion of Pricing Alternatives

Effects of pricing alternatives on investment

In order to answer the question which regulated price the regulator should set in period 2, the effects of the price choice on the company's investment decision have to be analyzed. Recall that the regulator's objective is to induce the company to choose an efficient investment level from the social welfare perspective.[190] In particular, he wants to avoid underinvestment or at least mitigate it in the best possible way. Analogously to a single investment case, the regulator furthermore allows the company a maximum NPV of zero.[191] Nevertheless if higher social welfare can be achieved with an NPV greater than zero, the regulator would approve that. However, to anticipate one important finding of this section, it will be illustrated in the following that an NPV of greater than zero corresponds to more underinvestment.

Regarding the scope in determining the regulated price in period 2, it must be assessed how the different possibilities affect the capacity levels chosen by the company. These capacity levels are determined in the following. It will be revealed that the regulator's efficient capacity choice cannot be achieved. Consequently, the option is identified which induces the capacity choice closest to the regulator's chosen capacities, and hence fulfills the regulator's objective to the best possible extent.

In section 4.1.3 the company's objective function was illustrated. As in equation (4.3) the

[190] See section 4.1.3.

[191] Throughout this model, it is assumed that the company prefers investing as compared to not investing. Consequently, it would invest with an NPV of zero.

company's objective is to maximize the NPV function

$$NPV(x_0, x_1) = (-C_0 + \overline{p}_1\gamma + \overline{p}_2\gamma^2) \cdot x_0 + (-C_1 + \overline{p}_2\gamma + \overline{p}_3\gamma^2) \cdot x_1\gamma$$

subject to the following constraints:

$$x_0 \leq \frac{a - \overline{p}_1}{b}, \qquad x_0 + x_1 \leq \frac{a - \overline{p}_2}{b}, \qquad x_1 \leq \frac{a - \overline{p}_3}{b}.$$

Note that $\overline{p}_2$ appears in both partial derivatives of the NPV formula. The partial derivatives are denoted P_0 and P_1:

$$P_0 := \frac{\partial NPV(x_0, x_1)}{\partial x_0} = -C_0 + \overline{p}_1\gamma + \overline{p}_2\gamma^2 \tag{4.9}$$

$$P_1 := \frac{\partial NPV(x_0, x_1)}{\partial x_1} = (-C_1 + \overline{p}_2\gamma + \overline{p}_3\gamma^2) \cdot \gamma \tag{4.10}$$

Whether these partial derivatives are positive or negative is crucial for the company's investment decision. If P_0, for instance, is smaller than zero, then any positive x_0, i.e. any investment in x_0, decreases the NPV and the company would not invest in x_0. The same holds for P_1.

On the contrary, the regulator wants to allow a maximum NPV of zero. In order to achieve this independently of the choices of x_0 and x_1, both partial derivatives P_0 and P_1 have to equal zero simultaneously. However, setting both P_0 and P_1 equal to zero requires two different regulated prices $\overline{p}_2$, as illustrated below. Note that the regulated prices in period 1 and period 3 are kept fixed, as there is no scope in determining them. As illustrated in section 4.2.2, this means $\overline{p}_1 = C_0/(\gamma + \gamma^2)$, $\overline{p}_3 = C_1/(\gamma + \gamma^2)$.

$$\begin{aligned}
\frac{\partial NPV(x_0, x_1)}{\partial x_0} &= -C_0 + \overline{p}_1\gamma + \overline{p}_2\gamma^2 \\
&= -C_0 + \frac{C_0}{\gamma + \gamma^2} \cdot \gamma + \overline{p}_2\gamma^2 = 0 \;\Leftrightarrow\; \overline{p}_2 = \frac{C_0}{\gamma + \gamma^2} = \overline{p}_{2,C_0} \\
\frac{\partial NPV(x_0, x_1)}{\partial x_1} &= -C_1 + \overline{p}_2\gamma + \overline{p}_3\gamma^2 \\
&= -C_1 + \overline{p}_2\gamma + \frac{C_1}{\gamma + \gamma^2} \cdot \gamma^2 = 0 \;\Leftrightarrow\; \overline{p}_2 = \frac{C_1}{\gamma + \gamma^2} = \overline{p}_{2,C_1}.
\end{aligned}$$

In theory, two different $\overline{p}_2$'s are required to turn P_1 and P_2 equal to zero simultaneously. However, naturally, there can only be one single regulated price in period 2. This is because identical products result from both investments. Note that in this situation the regulator has different options to set the regulated price, and the effect of each option on the company's investment decision is not straightforward to see. Hence, these effects need to be analyzed beforehand, and the most efficient price choice must be implemented.

In the following, the different possibilities to set $\overline{p}_2$ are going to be discussed, together with the resulting consequences of each possibility on the company's capacity choice. Generally speaking, there are five different ways to choose $\overline{p}_2$ relative to $\overline{p}_{2,C_0}$ and $\overline{p}_{2,C_1}$. Recall that $C_0 > C_1$ is assumed and hence $\overline{p}_{2,C_1} < \overline{p}_{2,C_0}$.[192]

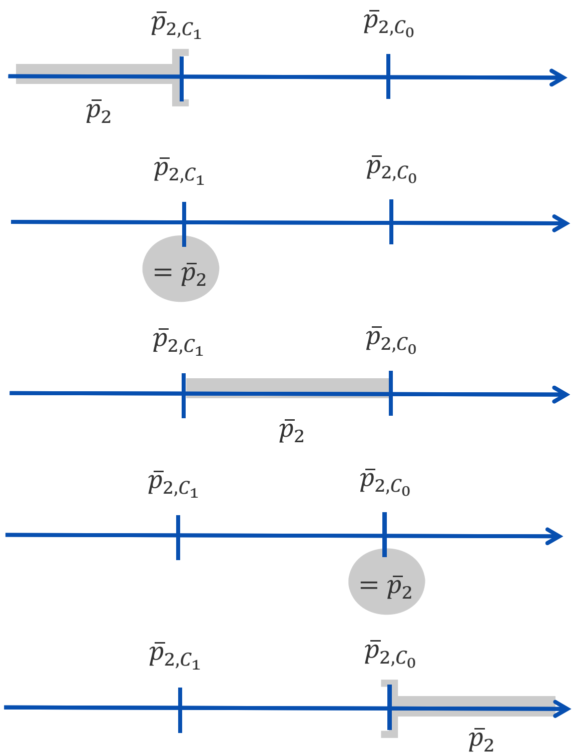
(i) $\overline{p}_2 < \overline{p}_{2,C_1}$

(ii) $\overline{p}_2 = \overline{p}_{2,C_1}$

(iii) $\overline{p}_2 \in]\overline{p}_{2,C_1};\overline{p}_{2,C_0}[$

(iv) $\overline{p}_2 = \overline{p}_{2,C_0}$

(v) $\overline{p}_2 > \overline{p}_{2,C_0}$



The effect of each choice (i) to (v) on the company's NPV is illustrated in Table 4.3 and discussed afterwards:

(i) If $\overline{p}_2$ is smaller than $\overline{p}_{2,C_1}$ both partial derivatives P_0 and P_1 are smaller than zero. Consequently, the company will not invest at all.

(ii) If $\overline{p}_2 = \overline{p}_{2,C_1}$ then P_0 is smaller than zero and P_1 is equal to zero. Hence, any invest-

[192]Note that the following options (i) and (v) are not directly applicable, because they are not combinations of $\overline{p}_{2,C_0}$ and $\overline{p}_{2,C_1}$ and hence, strictly speaking, not cost-based. Nevertheless, these options are also illustrated below for reasons of completeness.

		P_0	P_1	Capacities	NPV
(i)	$\overline{p}_2 < \overline{p}_{2,C_1}$	< 0	< 0	no investment.	–
(ii)	$\overline{p}_2 = \overline{p}_{2,C_1}$	< 0	$= 0$	$x_0 = 0,\ x_1 = (a - \overline{p}_2)/b$	$= 0$
(iii)	$\overline{p}_2 \in]\overline{p}_{2,C_1}; \overline{p}_{2,C_0}[$	< 0	> 0	$x_0 = 0,\ x_1 = (a - \overline{p}_2)/b$	> 0
(iv)	$\overline{p}_2 = \overline{p}_{2,C_0}$	$= 0$	> 0	$x_0 = 0,\ x_1 = (a - \overline{p}_2)/b$	> 0
(v)	$\overline{p}_2 > \overline{p}_{2,C_0}$	> 0	> 0	$x_0 = 0,\ x_1 = (a - \overline{p}_2)/b$	> 0

Table 4.3: Effects of different regulated price choices (1).

ment in x_0 will decrease the company's NPV, so it will choose x_0 to be zero. For the choice of x_1 the capacity restriction $x_0 + x_1 = x_1 \leq (a - \overline{p}_2)/b$ is relevant,[193] hence the company will choose $x_1 = (a - \overline{p}_2)/b$. The resulting NPV is equal to zero.

(iii) If $\overline{p}_2$ lies in between $\overline{p}_{2,C_1}$ and $\overline{p}_{2,C_0}$, then P_0 is still smaller than zero, but P_1 is larger than zero. Again, the company will choose x_0 to be zero and x_1 according to $x_1 = (a - \overline{p}_2)/b$. Since P_1 is positive, this choice will result in a positive NPV for the company.

(iv) If $\overline{p}_2 = \overline{p}_{2,C_0}$, then P_0 is equal to zero and P_1 is larger than zero. This means that the company is indifferent about x_0 but aspires to have as much x_1 as possible. In order to fulfill the second restriction $x_0 + x_1 \leq (a - \overline{p}_2)/b$, it will choose x_0 to be zero and x_1 according to $x_1 = (a - \overline{p}_2)/b$. Again, since P_1 is positive, this choice will result in a positive NPV for the company.

(v) If $\overline{p}_2 > \overline{p}_{2,C_0}$, then both P_0 and P_1 are positive and any choice of x_0 and x_1 will cause a positive NPV. But the actual levels of x_0 and x_1 are not directly obvious. Since the company's objective is to maximize its NPV, it will shift the capacity according to this goal. More specifically, if P_1 is higher than P_0, then the company will choose x_0 to be zero and x_1 again according to the capacity restriction. This can be shown:

$$\begin{aligned} P_1 - P_0 &= -C_1\gamma + \overline{p}_2\gamma^2 + \overline{p}_3\gamma^3 + C_0 - \overline{p}_1\gamma - \overline{p}_2\gamma^2 \\ &= -C_1\gamma + \frac{C_1\gamma^3}{\gamma(1+\gamma)} + C_0 - \frac{C_0\gamma}{\gamma(1+\gamma)} \\ &= \frac{C_1\gamma(\gamma - 1 - \gamma) + C_0(1 + \gamma - 1)}{1+\gamma} \\ &= \frac{\gamma(C_0 - C_1)}{1+\gamma} > 0 \text{ as } C_0 > C_1. \end{aligned}$$

Hence, P_1 is indeed higher than P_0. Consequently, the company will choose x_0 to be zero, and x_1 according to $x_1 = (a - \overline{p}_2)/b$.

[193] Note that this is equivalent to the third capacity restriction $x_1 \leq (a - \overline{p}_3)/b$ because in this case $\overline{p}_2 = \overline{p}_3 = \overline{p}_{2,C_1}$.

Figure 4.8 summarizes the effects of the choice of $\overline{p}_2$ on the partial derivatives P_0 and P_1 of the company's NPV.

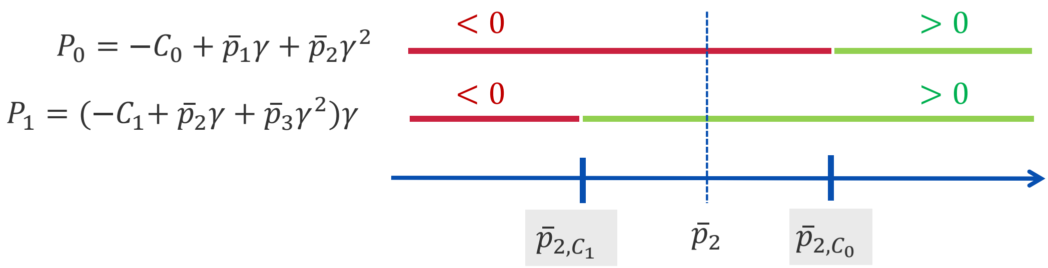


Figure 4.8: Effects of the price choice in second period on the partial derivatives.

Concluding, among the five general ways to choose $\overline{p}_2$ relative to $\overline{p}_{2,C_0}$ and $\overline{p}_{2,C_1}$, there exists only one option which ensures first, that the company does invest, and second, an NPV of zero. This is option (ii), namely choosing $\overline{p}_2$ to be equal to $\overline{p}_{2,C_1}$, which is the smaller one of $\overline{p}_{2,C_0}$ and $\overline{p}_{2,C_1}$.

Summarizing, the following Table 4.4 shows the prices which are chosen in the three periods and the resulting capacities which the company chooses.

Period	Regulated price	Capacity
Period 1	$\overline{p}_1 = \frac{C_0}{\gamma+\gamma^2}$	$x_0 = 0$
Period 2	$\overline{p}_2 = \overline{p}_{2,C_1} = \frac{C_1}{\gamma+\gamma^2}$	$x_0 + x_1 = x_1 = \frac{a-\overline{p}_{2,C_1}}{b} = \frac{a\gamma(1+\gamma)-C_1}{b\gamma(1+\gamma)}$
Period 3	$\overline{p}_3 = \frac{C_1}{\gamma+\gamma^2}$	$x_1 = \frac{a\gamma(1+\gamma)-C_1}{b\gamma(1+\gamma)}$

Table 4.4: Summary of optimal regulated prices and resulting capacities.

It is obvious that these results in fact mean that there is no *overlapping* investment. The company does not invest in the first period, only in the second period. This can be considered a shortcoming of the analysis, and will be critically discussed in some more detail later.

Critical assessment

The fact that it is most efficient to choose $\overline{p}_{2,C_1}$ as the regulated price in period 2 is an important and unexpected result. It is especially surprising if one thinks of more intuitive ways of setting this price: if there is scope for the determination of the regulated price, and if there are two "candidates" among which the decision will be made (in this case $\overline{p}_{2,C_0}$ and $\overline{p}_{2,C_1}$), it seems intuitive so set $\overline{p}_2$ as the *average*, or some weighted average of the two numbers. However, a (weighted) average would be equivalent to option (iii) for setting $\overline{p}_2$. It has been discussed that this option would result in a positive NPV for the company, which the regulator does not want to allow. Furthermore, it will be shown in section 4.3.2 that the least underinvestment for the total capacity x_0+x_1 occurs for the smallest possible price. Hence, using an average price as the most evident or intuitive way is not the most efficient option.

The most obvious problem is that none of the options (i) to (v) can induce any investment in x_0. Apparently the assumption that capacity costs decrease over time ($C_0 > C_1$) is the most dominant effect. This is also intuitively comprehensible: if the investing company knows that investing "becomes cheaper" if it waits one period, and if it is not forced in any other way to provide capacity, there is no reason why it should undertake the relatively "expensive" first investment. As mentioned earlier, this finding provides room for critique, because the original research question particularly addresses overlapping investment. However, instead of questioning the model setup and the related research question, this finding should just be regarded as an unexpected model result. If the model setup was modified from a deterministic setting to a sequential game - which is assertively recommended for future research - then the results will most likely change dramatically, and overlapping investment can in fact be observed.

From the fact that in this particular model setting, no investment can be induced in the first period, the question arises whether the regulator can do anything else to overcome this problem. For example the regulator could accept a higher price and therefore an NPV greater than zero if this can make the company invest in the first period. The previous illustration of the different options to set $\overline{p}_2$ showed that the partial derivative $P_0 = \partial NPV(x_0, x_1)/\partial x_0 = -C_0 + \overline{p}_1\gamma + \overline{p}_2\gamma^2$ is only greater than zero for a high $\overline{p}_2$, namely $\overline{p}_2 \geq \overline{p}_{2,C_0}$. This means that only for $\overline{p}_2 \geq \overline{p}_{2,C_0}$ an investment in x_0 does not decrease the company's NPV and consequently, the company would agree to invest in x_0. Although it has been argued in (v) that the company will still shift the capacity towards x_1, assume hypothetically that the regulator has some mean to make the company invest in x_0 nevertheless. The new problem associated with this choice of $\overline{p}_2$ is, that the underinvestment problem for the total capacity $x_0 + x_1$ will significantly worsen,[194] and it will hence cause an immense loss in social welfare. This loss in social welfare is indeed so serious that it cannot be compensated by the sheer fact that there is investment in the first period.

[194]For the analytical proof of this fact also refer to section 4.3.2.

While it can be easily proven that the higher the regulated price, the less total capacity is provided, it is impossible to show that social welfare is increasing in $x_0 + x_1$. The reason is that the social welfare function $SW(x_0, x_1)$ is a function mapping from $\mathbb{R}^2$ to $\mathbb{R}$, i.e. from two dimensions into one dimension. As there is no order relation in a two-dimensional space, there is no strict monotony as well. However, again, the example calculations in Table 4.5 clearly show that a smaller sum of x_0 and x_1 is associated with an immense loss in social welfare. In the table, the regulated prices as well as the resulting capacity choices of regulator and company can be found. The company's capacity choices are included for both $\overline{p}_{2,C_0}$ and $\overline{p}_{2,C_1}$ as the regulated price in period 2. It can easily be seen that $\overline{p}_{2,C_0}$, the higher regulated price in period 2, first of all, causes less total investment. Furthermore, the table shows the resulting social welfare of the regulator's capacity choices and the company's capacity choices.[195] The last five lines of Table 4.5 clearly demonstrate that choosing $\overline{p}_{2,C_0}$, i.e. the higher one of the two options for the regulated price in period 2, is associated with an immense loss in social welfare.[196] Summarizing, even though it seems like a reasonable idea to allow a higher price (greater or equal than $\overline{p}_{2,C_0}$) which could induce investment in x_0, this is not a viable option due to the immense loss in social welfare.

Furthermore, there is another important insight: if the first period is regarded isolatedly, the regulator "acts correctly". This means by setting $\overline{p}_1$ according to the annuity depreciation rule, he uses the method that has been proposed by the scientific literature to induce efficient investment.[197] Nevertheless, in this very specific setting, this method fails completely, meaning that the company cannot be induced to make any investment in the first period. At first, this seems counter-intuitive, but as illustrated, this is due to the fact that the company includes the later "price" of investing into its considerations: investing "becomes cheaper" one period later, which is known by the company at the time of the investment decision at $t = 0$. The insight of this is, that if the setup of the investment sequence is different, well-known methods of inducing efficient investment might fail and other means need to be investigated.

Coming back to the regulator's objective of inducing efficient investment, it can clearly be stated that with the company's choice of $x_0 = 0$ there is severe underinvestment for x_0. However, at this stage it has not been investigated yet if the company's choice of x_1 is efficient from the regulator's perspective. This will be analyzed in the following section.

[195] Social welfare is calculated based on the formula introduced in section 4.1.3.

[196] Note that an analytical proof is missing. Table 4.5 only contains few example calculations, based on which a generalization of the insight is strictly speaking impossible. However, the example calculations support the conjecture that the less total capacity is provided, the smaller is the resulting social welfare.

[197] See also section 4.2.1.

INPUT		C_0	10	10	20	30
		C_1	9	8	10	20
		a	8	8	17	23
		b	0.2	0.2	0.1	0.1
REGULATED PRICES	period 1	$\overline{p}_1$	5.76	5.76	11.52	17.29
	period 2	$\overline{p}_{2,C_0}$	5.76	5.76	11.52	17.29
		$\overline{p}_{2,C_1}$	5.19	4.61	5.76	11.52
	period 3	$\overline{p}_3$	5.19	4.61	5.76	11.52
REGULATOR'S CHOICES		x_0^R	5.98	4.15	1.66	3.32
		x_1^R	10.94	14.78	111.51	113.02
		SUM Regulator	16.92	18.93	113.17	116.34
COMPANY'S CHOICES	with $\overline{p}_2 = \overline{p}_{2,C_1}$	x_0^C	0.00	0.00	0.00	0.00
		x_1^C	14.07	16.95	112.38	114.76
		SUM Company	14.07	16.95	112.38	114.76
		Company's NPV	0.00	0.00	0.00	0.00
	with $\overline{p}_2 = \overline{p}_{2,C_0}$	x_0^C	0.00	0.00	0.00	0.00
		x_1^C	1.35	1.35	1.47	1.32
		SUM Company	1.35	1.35	1.47	1.32
		Company's NPV	0.64	1.29	6.98	6.31
TOTAL SOCIAL WF	with regulator's capactiy choices		35.90	47.59	996.49	1039.70
	with company's capacity choices ($\overline{p}_2 = \overline{p}_{2,C_1}$)		31.24	45.34	996.31	1038.98
	Difference		4.66	2.25	0.18	0.72
	with company's capacity choices ($\overline{p}_2 = \overline{p}_{2,C_0}$)		5.72	6.95	25.83	23.85
	Difference		30.18	40.64	970.66	1015.85

Table 4.5: Example: loss in social welfare for higher regulated price in period 2.

4.3.2 Investment Levels in Different Periods

It has been shown in the previous section that due to decreasing capacity costs, the existing scope in determining $\overline{p}_2$ can not be used to induce investment in period 1. Hence, there is severe underinvestment for x_0. However, it still needs to be analyzed if the investment levels in period 2 and in period 3 are efficient.

Capacity level in second period

The investment level in period 2 is the sum of x_0 and x_1. As illustrated before, the company will choose the capacity in period 2 such that it fulfills the capacity restriction:

$$(x_0 + x_1)_{Comp} \leq \frac{a - \overline{p}_2}{b}.$$

Providing less capacity than the restriction is not beneficial for the company, so in fact $(x_0 + x_1)_{Comp}$ can be assumed to be equal to $(a - \overline{p}_2)/b$.[198]

In section 4.1.3, the efficient investment levels from the regulator's perspective were determined. For the sum of x_0 and x_1 the regulator considers the following level efficient:

$$(x_0 + x_1)_{Reg} = \frac{-C_0\gamma - C_1 + a\gamma(1+\gamma)^2}{b\gamma(1+\gamma+\gamma^2)}.$$

From these two equations, a threshold $\overline{p}_{2,Reg}$ for the regulated price can be determined. If the real regulated price is above this threshold, then there is underinvestment for $x_0 + x_1$:

$$\begin{aligned} (x_0 + x_1)_{Comp} &< (x_0 + x_1)_{Reg} \\ \Leftrightarrow \frac{a - \overline{p}_2}{b} &< \frac{-C_0\gamma - C_1 + a\gamma(1+\gamma)^2}{b\gamma(1+\gamma+\gamma^2)} \\ \Leftrightarrow \overline{p}_2 &> \frac{C_0\gamma + C_1 - a\gamma^2}{\gamma(1+\gamma+\gamma^2)} =: \overline{p}_{2,Reg}. \end{aligned}$$

According to the previous section, only the setting of $\overline{p}_2 = \overline{p}_{2,C_1}$ is reasonable in a way that it induces the company to invest and ensures a NPV of zero. If it can be shown that

[198] Note that in a first step $\overline{p}_2$ is kept general in order to determine a threshold for the regulated price in period 2.

$\overline{p}_{2,C_1}$ is larger than the threshold $\overline{p}_{2,Reg}$, then there is clearly underinvestment for $x_0 + x_1$.

$$\begin{aligned}
\overline{p}_{2,C_1} - \overline{p}_{2,Reg} &= \frac{C_1}{\gamma + \gamma^2} - \frac{C_0\gamma + C_1 - a\gamma^2}{\gamma(1+\gamma+\gamma^2)} \\
&= \frac{C_1(1+\gamma+\gamma^2) - C_0\gamma(1+\gamma) - C_1(1+\gamma) + a\gamma(1+\gamma)}{\gamma(1+\gamma)(1+\gamma+\gamma^2)} \\
&= \frac{C_1\gamma^2 - C_0\gamma(1+\gamma) + a\gamma^2(1+\gamma)}{\gamma(1+\gamma)(1+\gamma+\gamma^2)}
\end{aligned}$$

$$\begin{aligned}
\overline{p}_{2,C_1} - \overline{p}_{2,Reg} &> 0 \text{ for } C_1\gamma^2 - C_0\gamma(1+\gamma) + a\gamma^2(1+\gamma) > 0 \\
\Leftrightarrow a &> \frac{C_0}{\gamma} - \frac{C_1}{1+\gamma}.
\end{aligned}$$

This is exactly the same expression as in the positivity restriction for the regulator's choice of x_0, equation (4.8). As equation (4.8) has been declared an assumption for the entire analysis, it is proven that $\overline{p}_{2,C_1}$ is larger than the threshold $\overline{p}_{2,Reg}$, and hence there is underinvestment for $x_0 + x_1$.

Although this insight states that there is underinvestment for $x_0 + x_1$, i.e. for the total provided capacity in period 2, it still supports the analysis in section 4.3.1: the lowest price in the possible range should be chosen, because the higher the price, the more severe is the underinvestment for $x_0 + x_1$.

This can also be proven analytically. Define $\Delta_{x_0+x_1}(\overline{p}_2)$ to be the difference between $(x_0 + x_1)_{Reg}$ and $(x_0 + x_1)_{Comp}$ depending on $\overline{p}_2$:

$$\begin{aligned}
\Delta_{x_0+x_1}(\overline{p}_2) &:= (x_0 + x_1)_{Reg} - (x_0 + x_1)_{Comp} \\
&= \frac{-C_0\gamma - C_1 + a\gamma(1+\gamma)^2}{b\gamma(1+\gamma+\gamma^2)} - \frac{a - \overline{p}_2}{b} \\
&= \frac{-C_0\gamma - C_1 + a\gamma(1+\gamma)^2}{b\gamma(1+\gamma+\gamma^2)} - \frac{a}{b} + \frac{1}{b} \cdot \overline{p}_2. \\
\Rightarrow \Delta'_{x_0+x_1}(\overline{p}_2) &= \frac{1}{b} > 0.
\end{aligned}$$

Hence, $\Delta(\overline{p}_2)$ is a strictly increasing function in $\overline{p}_2$, meaning that the larger $\overline{p}_2$, the larger is the difference between $(x_0+x_1)_{Reg}$ and $(x_0+x_1)_{Comp}$, i.e. the more severe is the underinvestment for x_0+x_1. Again, Table 4.6 shows the resulting capacity choices of the regulator and the company for period 2. As expected, for all selected parameter specifications, the company provides less capacity than the regulator would want it to.

INPUT		C_0	10	10	20	30
		C_1	9	8	10	20
		a	8	8	17	23
		b	0.2	0.2	0.1	0.1
REGULATOR'S CHOICES		$(x_0 + x_1)_{Reg}$	16.92	18.93	113.17	116.34
COMPANY'S CHOICES	with $\overline{p}_2 = \overline{p}_{2,C_1}$	$(x_0 + x_1)_{Comp}$	14.07	16.95	112.38	114.76

Table 4.6: Example: comparison of capacity levels in period 2.

Capacity level in third period

In period 3, the provided capacity is just x_1, since the asset from the first investment is fully depreciated by the end of period 2. It has been argued that it is reasonable for the regulator to set $\overline{p}_{2,C_1}$ as the regulated price in period 2, which is equal to the regulated price in period three. Hence

$$(x_1)_{Comp} = \frac{a - \overline{p}_3}{b} = \frac{a - \frac{C_1}{\gamma+\gamma^2}}{b} = \frac{a\gamma(1+\gamma) - C_1}{b\gamma(1+\gamma)}.$$

Recall again that the efficient investment levels from the regulator's perspective were determined in section 4.1.3. For x_1 the regulator considers the following level efficient:

$$(x_1)_{Reg} = \frac{C_0 - C_1(1+\gamma) + a\gamma^2(1+\gamma)}{b\gamma(1+\gamma+\gamma^2)}.$$

As argued in section 4.3.1 the choice of $\overline{p}_{2,C_1}$ for the regulated price in period 2 can not induce any investment in period 1, i.e. $x_0 = 0$. Consequently, since there is the severe underinvestment for x_0, overinvestment for x_1 is expected.

This can be proven by analyzing $\Delta_{x_1} := (x_1)_{Reg} - (x_1)_{Comp}$. If it is possible to show that

Δ_{x_1} is less than zero, then $(x_1)_{Comp}$ is larger than $(x_1)_{Reg}$, hence there is overinvestment:

$$\begin{aligned}\Delta_{x_1} &= \frac{C_0 - C_1(1+\gamma) + a\gamma^2(1+\gamma)}{b\gamma(1+\gamma+\gamma^2)} - \frac{a\gamma(1+\gamma) - C_1}{b\gamma(1+\gamma)} \\ &= \frac{C_0(1+\gamma) - C_1\gamma - a\gamma(1+\gamma)}{b\gamma(1+\gamma)(1+\gamma+\gamma^2)}\end{aligned}$$

$$\begin{aligned}\Delta_{x_1} &< 0 \ \text{ for } \ C_0(1+\gamma) - C_1\gamma - a\gamma(1+\gamma) \ < \ 0 \\ \Leftrightarrow a &> \frac{C_0}{\gamma} - \frac{C_1}{1+\gamma}.\end{aligned}$$

As before, this is again equal to the positivity restriction for the regulator's choice of x_0, equation (4.8). Hence there is overinvestment for x_1. This is also revealed by the example calculations in Table 4.7: For all sets of parameters, in period 3, the company provides more capacity than the regulator would want it to.

INPUT		C_0	10	10	20	30
		C_1	9	8	10	20
		a	8	8	17	23
		b	0.2	0.2	0.1	0.1
REGULATOR'S CHOICES		x_1^R	10.94	14.78	111.51	113.02
COMPANY'S CHOICES	with $\overline{p}_2 = \overline{p}_{2,C_1}$	x_1^C	14.07	16.95	112.38	114.76

Table 4.7: Example: comparison of capacity levels in period 3.

Summarizing, by setting the regulated price in period 2, $\overline{p}_2$, to be equal to $\overline{p}_{2,C_1} = \overline{p}_3 = C_1/(\gamma+\gamma^2)$, the following effects on the company's chosen investment level relative to the regulator's efficient capacity levels result:

- Period 1: severe underinvestment for x_0, the company chooses $x_0 = 0$.
- Period 2: underinvestment for $x_0 + x_1$.
- Period 3: overinvestment for x_1.

Hence, setting $\overline{p}_2$ to be equal to $\overline{p}_{2,C_1} = \overline{p}_3 = C_1/(\gamma+\gamma^2)$ can only be considered a second best solution, since the efficient investment levels from the regulator's perspective cannot be achieved in this specific model setting. In order for these investment levels to be achieved, the regulator would need to adapt not only the regulated price in period 2, but also the regulated prices in periods 1 and 3. The following section is going to analyze this.

4.4 Model Extensions

The solution of the model revealed that with the use of "standard" depreciation methods, there is always underinvestment for the total capacity $x_0 + x_1$ and no investment can be induced in period 1. This analysis was conducted under the assumption that capacity costs decrease from period 1 to period 2, which appears to be the most important driver.

In this section two extensions of the model are analyzed. First, still holding on to the assumption of decreasing capacity costs, prices are calculated which induce efficient investment. Second, using the original prices, the assumption of decreasing capacity costs is relaxed and the changing model outcomes are demonstrated.

4.4.1 Efficient Prices

In section 4.3.2 it has been argued that in order to induce efficient investment in period 2,

$$\overline{p}_{2,Reg} = \frac{C_0\gamma + C_1 - a\gamma^2}{\gamma(1+\gamma+\gamma^2)} \tag{4.11}$$

would have to be set as the regulated price in period 2. However, it has also been analyzed in section 4.3.1 that every regulated price smaller than $\overline{p}_{2,C_1}$ will cause the company to not invest at all, and it has been shown that $\overline{p}_{2,Reg} < \overline{p}_{2,C_1}$. All of this is under the assumption that the prices in periods 1 and 3 are fixed to be determined using the annuity depreciation method, i.e. $\overline{p}_1 = C_0/(\gamma+\gamma^2)$ and $\overline{p}_3 = C_1/(\gamma+\gamma^2)$. Intuitively speaking, $\overline{p}_1$ and $\overline{p}_3$ appear to be not high enough to compensate for $\overline{p}_{2,Reg}$ which is too low.

In order to determine which $\overline{p}_1$ and $\overline{p}_3$ are necessary to compensate for the low $\overline{p}_{2,Reg}$ the partial derivatives P_0 and P_1 (see equations (4.9) and (4.10)) of the NPV-formula (4.3) need to be analyzed. The question to be answered is: if $\overline{p}_{2,Reg}$ is used, which $\overline{p}_1$ and $\overline{p}_3$ are necessary in order for P_0 and P_1 to be zero?

$$\begin{aligned}
P_0 = \frac{\partial NPV(x_0, x_1)}{\partial x_0} &= -C_0 + \overline{p}_1\gamma + \overline{p}_2\gamma^2 \\
-C_0 + \overline{p}_1\gamma + \overline{p}_{2,Reg}\gamma^2 &= 0 \\
\Leftrightarrow \ \overline{p}_1 &= \frac{C_0}{\gamma} - \overline{p}_{2,Reg}\gamma \\
&= \frac{C_0}{\gamma} - \frac{C_0\gamma + C_1 - a\gamma^2}{1+\gamma+\gamma^2} \\
&= \frac{C_0(1+\gamma) - C_1\gamma + a\gamma^3}{\gamma(1+\gamma+\gamma^2)}.
\end{aligned}$$

$$\begin{aligned}
P_1 = \frac{\partial NPV(x_0, x_1)}{\partial x_1} &= (-C_1 + \overline{p}_2\gamma + \overline{p}_3\gamma^2) \cdot \gamma \\
-C_1 + \overline{p}_{2,Reg}\gamma + \overline{p}_3\gamma^2 &= 0 \\
\Leftrightarrow \ \overline{p}_3 &= \frac{C_1}{\gamma^2} - \frac{\overline{p}_{2,Reg}}{\gamma} \\
&= \frac{C_1}{\gamma^2} - \frac{C_0\gamma + C_1 - a\gamma^2}{\gamma^2(1+\gamma+\gamma^2)} \\
&= \frac{-C_0 + C_1(1+\gamma) + a\gamma}{\gamma(1+\gamma+\gamma^2)}.
\end{aligned}$$

Hence, the following regulated prices will result in the company's NPV being equal to zero independently of the actual choice of x_0 and x_1:

$$\overline{p}_1^* = \frac{C_0(1+\gamma) - C_1\gamma + a\gamma^3}{\gamma(1+\gamma+\gamma^2)} \tag{4.12}$$

$$\overline{p}_{2,Reg} = \overline{p}_2^* = \frac{C_0\gamma + C_1 - a\gamma^2}{\gamma(1+\gamma+\gamma^2)} \tag{4.13}$$

$$\overline{p}_3^* = \frac{-C_0 + C_1(1+\gamma) + a\gamma}{\gamma(1+\gamma+\gamma^2)}. \tag{4.14}$$

Recall that $\overline{p}_{2,Reg}$ was the regulated price which results in the total provided capacity in period 2 being chosen efficiently: $(x_0 + x_1)_{Comp} = (x_0 + x_1)_{Reg}$. In addition to that, the choice of $\overline{p}_1^*$ and $\overline{p}_3^*$ for the regulated price in periods 1 and 3 respectively causes efficient investment also for x_0 and x_1 separately. As illustrated, the company will choose x_0 and x_1 such that they meet the capacity constraints (see equation (4.4)):

$$x_0 \leq \frac{a - \overline{p}_1}{b}, \ \ x_1 \leq \frac{a - \overline{p}_3}{b}.$$

It would not be beneficial for the company to provide less capacity than the upper thresholds, so in fact the company will choose

$$x_0 = \frac{a - \overline{p}_1}{b}, \;\; x_1 = \frac{a - \overline{p}_3}{b}.$$

If now $\overline{p}_1 = \overline{p}_1^*$ and $\overline{p}_3 = \overline{p}_3^*$ are set, the company will choose the following capacities:

$$\begin{aligned}(x_0)_{Comp} = \frac{a - \overline{p}_1^*}{b} &= \frac{a - \frac{C_0(1+\gamma) - C_1\gamma + a\gamma^3}{\gamma(1+\gamma+\gamma^2)}}{b} \\ &= \frac{a\gamma(1+\gamma+\gamma^2) - C_0(1+\gamma) + C_1\gamma - a\gamma^3}{b\gamma(1+\gamma+\gamma^2)} \\ &= \frac{-C_0(1+\gamma) + C_1\gamma + a\gamma(1+\gamma)}{b\gamma(1+\gamma+\gamma^2)} \\ &= (x_0)_{Reg}.\end{aligned}$$

$$\begin{aligned}(x_1)_{Comp} = \frac{a - \overline{p}_3^*}{b} &= \frac{a - \frac{-C_0 + C_1(1+\gamma) + a\gamma}{\gamma(1+\gamma+\gamma^2)}}{b} \\ &= \frac{a\gamma(1+\gamma+\gamma^2) + C_0 - C_1(1+\gamma) - a\gamma}{b\gamma(1+\gamma+\gamma^2)} \\ &= \frac{C_0 - C_1(1+\gamma) + a\gamma^2(1+\gamma)}{b\gamma(1+\gamma+\gamma^2)} \\ &= (x_1)_{Reg}.\end{aligned}$$

Hence, with the choice of $\overline{p}_1 = \overline{p}_1^*$, $\overline{p}_2 = \overline{p}_2^*$ and $\overline{p}_3 = \overline{p}_3^*$ the company chooses the efficient investment levels in all three periods.

Moreover, it is possible to prove the conjecture from the beginning of this section, that in order to compensate for a low $\overline{p}_{2,Reg}$, $\overline{p}_1$ and $\overline{p}_3$ need to be higher than the annuity prices:

$$\begin{aligned}\overline{p}_1^* - \frac{C_0}{\gamma+\gamma^2} &= \frac{C_0(1+\gamma) - C_1\gamma + a\gamma^3}{\gamma(1+\gamma+\gamma^2)} - \frac{C_0}{\gamma(1+\gamma)} \\ &= \frac{C_0 - C_1(1+\gamma) + a\gamma^2(1+\gamma)}{(1+\gamma)(1+\gamma+\gamma^2)} \\ &> 0 \;\; \text{for} \;\; C_0 - C_1(1+\gamma) + a\gamma^2(1+\gamma) \; > \; 0 \\ \Leftrightarrow a &> \frac{-C_0}{\gamma^2(1+\gamma)} - \frac{C_1}{\gamma^2}.\end{aligned}$$

This inequality is the positivity restriction for the regulator's choice of x_1 to be positive (see section 4.1.3), which is implied by the general positivity restriction (4.8). Thus it is true that $\overline{p}_1^*$ is higher than the annuity $\overline{p}_1 = C_0/(\gamma+\gamma^2)$.

$$\begin{aligned}\overline{p}_3^* - \frac{C_1}{\gamma+\gamma^2} &= \frac{-C_0 + C_1(1+\gamma) + a\gamma}{\gamma(1+\gamma+\gamma^2)} - \frac{C_0}{\gamma(1+\gamma)} \\ &= \frac{-C_0(1+\gamma) + C_1\gamma + a\gamma(1+\gamma)}{\gamma(1+\gamma)(1+\gamma+\gamma^2)} \\ &> 0 \ \text{ for } \ -C_0(1+\gamma) + C_1\gamma + a\gamma(1+\gamma) \ > \ 0 \\ \Leftrightarrow a &> \frac{C_0}{\gamma} - \frac{C_1}{1+\gamma}.\end{aligned}$$

One more time, this is the well known positivity restriction (4.8). Thus it is also true that $\overline{p}_3^*$ is higher than the annuity $\overline{p}_3 = C_1/(\gamma+\gamma^2)$. Figure 4.9 illustrates the ranges in which $\overline{p}_1^*$, $\overline{p}_2^*$ and $\overline{p}_3^*$ can possibly lie. Table 4.8 shows the efficient prices together with the standard annuity prices for the four sets of parameters. As expected, in all four examples, $\overline{p}_2^*$ is smaller than the annuity $\overline{p}_{2,C_1}$, whereas $\overline{p}_1^*$ and $\overline{p}_3^*$ are larger.

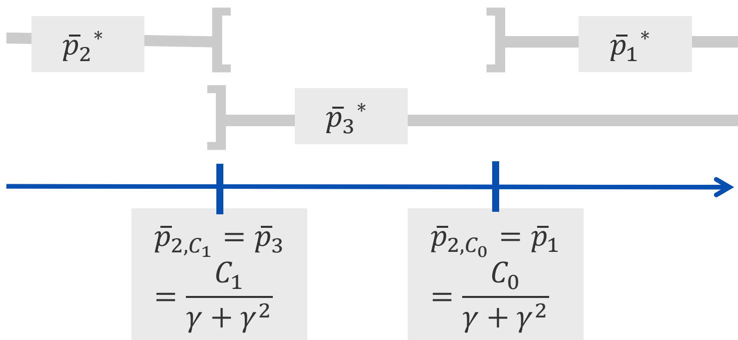


Figure 4.9: Ranges for efficient prices relative to annuity prices.

Having a closer look at $\overline{p}_1^*$, $\overline{p}_2^*$ and $\overline{p}_3^*$, their definitions are quite surprising regarding their required input. Look at $\overline{p}_1^*$: at a point in time when the second investment has not been made yet, the asset of this investment, namely C_1, is already incorporated in the definition of $\overline{p}_1^*$. Analogously, in period 3, when the first asset C_0 is already fully depreciated, C_0 is still part of the definition of $\overline{p}_3^*$.

Furthermore, one part of the demand function, namely the maximum willingness to pay a, is part of all three prices $\overline{p}_t^*, \ t \in \{1;2;3\}$. This does not match the general constitution of regulated prices, which consist of a depreciation charge and an interest charge (see section 4.2.1). It is at least unusual to incorporate the demand function into the determination of

INPUT		C_0	10	10	20	30
		C_1	9	8	10	20
		a	8	8	17	23
		b	0.2	0.2	0.1	0.1
REGULATED PRICES	period 1	Annuity $\overline{p}_1$	5.76	5.76	11.52	17.29
		$\overline{p}_1^*$	6.80	7.17	16.83	22.67
	period 2	Annuity $\overline{p}_{2,C_1}$	5.19	4.61	5.76	11.52
		$\overline{p}_2^*$	4.62	4.21	5.68	11.37
	period 3	Annuity $\overline{p}_3$	5.19	4.61	5.76	11.52
		$\overline{p}_3^*$	5.81	5.04	5.85	11.70

Table 4.8: Example: comparison of standard and efficient regulated prices.

regulated prices.

Consequently, although $\overline{p}_1^*$, $\overline{p}_2^*$ and $\overline{p}_3^*$ induce efficient investment from a theoretical point of view, they do not appear to be a viable option in practice.

4.4.2 Variation of Capacity Cost Development

All the results achieved so far were under the assumption that capacity costs decrease from period 1 to period 2, i.e. $C_0 > C_1$ (see section 4.1.2). In the following section, this assumption is relaxed.

Results for constant costs

It is now assumed that capacity costs remain constant over time, i.e. $C_0 = C_1 = C$. In this case the regulator's capacity choices from section 4.1.3 simplify to:

$$\begin{aligned} x_0 &= \frac{a\gamma(1+\gamma) - C}{b\gamma(1+\gamma+\gamma^2)} \\ x_1 &= \frac{a\gamma(1+\gamma) - C}{b(1+\gamma+\gamma^2)} \\ x_0 + x_1 &= \frac{a\gamma(1+\gamma)^2 - C(1+\gamma)}{b\gamma(1+\gamma+\gamma^2)}. \end{aligned}$$

Note that x_0 is larger than x_1 since $x_0 = x_1/\gamma = x_1(1+r)$.

For constant capacity costs, the analysis gets simplified, because all three regulated prices are equal: $\overline{p}_1 = \overline{p}_2 = \overline{p}_3 = C/(\gamma+\gamma^2) =: \overline{p}$. Consequently, the capacity constraints for the company (see equation (4.4)) change:

$$x_0 \leq \frac{a-\overline{p}}{b}, \qquad x_0 + x_1 \leq \frac{a-\overline{p}}{b}, \qquad x_1 \leq \frac{a-\overline{p}}{b}.$$

If the constraint for the sum of x_0 and x_1 is fulfilled, the other two constraints are implied. Hence, the company will choose $x_0 + x_1$ according to:

$$x_0 + x_1 = \frac{a-\overline{p}}{b} = \frac{a\gamma(1+\gamma)-C}{b\gamma(1+\gamma)}.$$

Note that in contrast to the analysis before, where there was scope in choosing the regulated price in period 2 (see section 4.2.2), the regulator does not face such a situation now. Comparing this choice of $x_0 + x_1$ with the regulator's choice above yields the following:

$$\begin{aligned}(x_0+x_1)_{Reg} &= \frac{a\gamma(1+\gamma)^2 - C(1+\gamma)}{b\gamma(1+\gamma+\gamma^2)} \\ &= \frac{(1+\gamma)^2}{1+\gamma+\gamma^2} \cdot \frac{a\gamma(1+\gamma)-C}{b\gamma(1+\gamma)} \\ &= \frac{(1+\gamma)^2}{1+\gamma+\gamma^2} \cdot (x_0+x_1)_{Comp}.\end{aligned}$$

The fraction $\frac{(1+\gamma)^2}{1+\gamma+\gamma^2}$ is greater than one, hence $(x_0+x_1)_{Reg}$ is greater than $(x_0+x_1)_{Comp}$. This means, there is still underinvestment for x_0+x_1 for constant capacity costs. It remains to be discussed how the company will distribute $x_0 + x_1$. The company's NPV with constant capacity costs and $\overline{p} = \frac{C}{\gamma+\gamma^2}$ is zero, independently of the choice of x_0 and x_1. This means that the company will be indifferent about the distribution of x_0 and x_1. However, just as one random example, a natural choice would be to choose x_0 and x_1 evenly, hence

$$x_0 = x_1 = \frac{1}{2} \cdot (x_0+x_1) = \frac{1}{2} \cdot \frac{a\gamma(1+\gamma)-C}{b\gamma(1+\gamma)}.$$

In this case

$$\begin{aligned}
(x_0)_{Reg} &= \frac{a\gamma(1+\gamma)-C}{b\gamma(1+\gamma+\gamma^2)} \\
&= \frac{2(1+\gamma)}{1+\gamma+\gamma^2}\cdot\frac{1}{2}\cdot\frac{a\gamma(1+\gamma)-C}{b\gamma(1+\gamma)} \\
&= \underbrace{\frac{2(1+\gamma)}{1+\gamma+\gamma^2}}_{>1}\cdot(x_0)_{Comp} \\
&> (x_0)_{Comp}
\end{aligned}$$

$$\begin{aligned}
(x_1)_{Reg} &= \frac{a\gamma(1+\gamma)-C}{b(1+\gamma+\gamma^2)} \\
&= \frac{2\gamma(1+\gamma)}{1+\gamma+\gamma^2}\cdot\frac{1}{2}\cdot\frac{a\gamma(1+\gamma)-C}{b\gamma(1+\gamma)} \\
&= \underbrace{\frac{2\gamma(1+\gamma)}{1+\gamma+\gamma^2}}_{>1}\cdot(x_1)_{Comp} \\
&> (x_1)_{Comp}.
\end{aligned}$$

This means that if the company distributed the capacity levels evenly, then there would be underinvestment for both x_0 and x_1.

This result has fair significance and is quite surprising: it shows that simply implementing annuity depreciation does not solve the underinvestment issue here. With constant capacity costs C the scope for choosing the regulated price disappears. In other words the regulator would not actively have to decide if he wants to implement the one or the other $\overline{p}_2$ in period 2. He would implement $\overline{p}$, which is determined using the annuity depreciation method, in all three periods. Recall that Friedl (2007) for instance finds that the use of annuity depreciation leads to efficient investment behavior of the company. This analysis yet shows that by changing the investment pattern, i.e. modeling two consecutive investments which overlap for one period, the annuity depreciation method fails. This is again due to the deterministic model setup.

Again, a theoretical solution to this issue are the efficient regulated prices determined in section 4.4.1. If $C_0 = C_1 = C$ the efficient regulated prices simplify to:

$$\begin{aligned}\overline{p}_1^* &= \frac{C + a\gamma^3}{\gamma(1+\gamma+\gamma^2)}\\ \overline{p}_2^* &= \frac{C(1+\gamma) - a\gamma^2}{\gamma(1+\gamma+\gamma^2)}\\ \overline{p}_3^* &= \frac{C+a}{1+\gamma+\gamma^2}.\end{aligned}$$

Note that in contrast to the annuity depreciation, there are again different regulated prices for the three periods. With these regulated prices, the following capacities result:

$$\begin{aligned}(x_0)_{Comp} &= \frac{a-\overline{p}_1^*}{b} = \frac{a - \frac{C+a\gamma^3}{\gamma(1+\gamma+\gamma^2)}}{b}\\ &= \frac{a\gamma(1+\gamma+\gamma^2) - C - a\gamma^3}{b\gamma(1+\gamma+\gamma^2)} = \frac{a\gamma(1+\gamma) - C}{b\gamma(1+\gamma+\gamma^2)}\\ &= (x_0)_{Reg}.\end{aligned}$$

$$\begin{aligned}(x_0+x_1)_{Comp} &= \frac{a-\overline{p}_2^*}{b} = \frac{a - \frac{C(1+\gamma)-a\gamma^2}{\gamma(1+\gamma+\gamma^2)}}{b}\\ &= \frac{a\gamma(1+\gamma+\gamma^2) - C(1+\gamma+a\gamma^2}{b\gamma(1+\gamma+\gamma^2)} = \frac{a\gamma(1+\gamma)^2 - C(1+\gamma)}{b\gamma(1+\gamma+\gamma^2)}\\ &= (x_0+x_1)_{Reg}.\end{aligned}$$

$$\begin{aligned}(x_1)_{Comp} &= \frac{a-\overline{p}_3^*}{b} = \frac{a - \frac{C+a}{1+\gamma+\gamma^2}}{b}\\ &= \frac{a\gamma(1+\gamma+\gamma^2) - C - a}{b(1+\gamma+\gamma^2)} = \frac{a\gamma(1+\gamma) - C}{b(1+\gamma+\gamma^2)}\\ &= (x_1)_{Reg}.\end{aligned}$$

Again, the regulated prices $\overline{p}_1^*$, $\overline{p}_2^*$ and $\overline{p}_3^*$ cause efficient investment. However, as discussed in section 4.4.1, these prices can rather be considered a theoretical result than useful for practical purposes.

Results for increasing costs

In order to complete the assessment of the different relations between C_0 and C_1 this section analyzes the investment decisions for increasing capacity costs.

		P_0	P_1	Capacities	NPV
(i)	$\overline{p}_2 < \overline{p}_{2,C_0}$	< 0	< 0	no investment.	–
(ii)	$\overline{p}_2 = \overline{p}_{2,C_0}$	$= 0$	< 0	$x_0 = (a - \overline{p}_1)/b,\ x_1 = 0$	$= 0$
(iii)	$\overline{p}_2 \in]\overline{p}_{2,C_0}; \overline{p}_{2,C_1}[$	> 0	< 0	$x_0 = (a - \overline{p}_1)/b,\ x_1 = 0$	> 0
(iv)	$\overline{p}_2 = \overline{p}_{2,C_1}$	> 0	$= 0$	$x_0 = (a - \overline{p}_1)/b,\ x_1 = 0$	> 0
(v)	$\overline{p}_2 > \overline{p}_{2,C_1}$	> 0	> 0	$x_0 = (a - \overline{p}_1)/b,\ x_1 = 0$	> 0

Table 4.9: Effects of different regulated price choices (2).

But first, in order to illustrate the different effects more clearly, recall that in the first part of the analysis decreasing capacity costs are assumed. It has been demonstrated that in the second period $\overline{p}_{2,C_1}$ should be chosen as the regulated price, which is the smaller one of the two “candidates”, $\overline{p}_{2,C_1}$ and $\overline{p}_{2,C_0}$. As a result, the company chooses x_0 to be zero, and overinvests for x_1.

If now $C_0 < C_1$ is assumed, $\overline{p}_{2,C_0}$ is smaller than $\overline{p}_{2,C_1}$:

$$\overline{p}_1 = \overline{p}_{2,C_0} = \frac{C_0}{\gamma + \gamma^2} < \frac{C_1}{\gamma + \gamma^2} = \overline{p}_{2,C_1} = \overline{p}_3.$$

Similar to section 4.3.1, $\overline{p}_2$ can be chosen in five different ways relative to $\overline{p}_{2,C_0}$ and $\overline{p}_{2,C_1}$. Again, the effect of each choice (i) to (v) on the company’s NPV is illustrated in table and discussed afterwards.

Apparently, the dynamics are the same as in section 4.3.1, but the effects are the exactly the opposite:

- Neither one of the options (i) to (v) can incentivize any investment in x_1 (before it was x_0).
- The best choice to mitigate underinvestment is to set $\overline{p}_2$ equal to $\overline{p}_{2,C_0}$ (before it was $\overline{p}_{2,C_1}$), which is now the smaller one of the two “candidates” $\overline{p}_{2,C_0}$ and $\overline{p}_{2,C_1}$.

In the following section, the effects of all the three possible relations of C_0 and C_1 will be summarized.

Conclusion on capacity costs

The following table summarizes the results for the different possible relations of C_0 and C_1.

	Best choice for $\overline{p}_2$	x_0	$x_0 + x_1$	x_1
$C_0 > C_1$	$\overline{p}_{2,C_1} = C_1/(\gamma + \gamma^2)$	under-investment	under-investment	over-investment
$C_0 = C_1 = C$	$\overline{p} = C/(\gamma + \gamma^2)$	under-investment	under-investment	under-investment
$C_0 < C_1$	$\overline{p}_{2,C_0} = C_0/(\gamma + \gamma^2)$	over-investment	under-investment	under-investment

Table 4.10: Summary of results for different developments of capacity costs.

First of all, in all three cases there is underinvestment for x_0+x_1. Hence independently of the relation between the capacity costs, the regulator cannot induce sufficient investment regarding the total provided capacity. This also means that overinvestment in one period cannot compensate for underinvestment in the other period. As already mentioned earlier in this section this is particularly surprising for the case of constant capacity costs, because then the regulator does not face any scope in the determination of the regulated prices and still the annuity depreciation method fails to induce efficient investment.

Second, by separately analyzing the cases of decreasing and increasing capacity costs ($C_0 > C_1$ and $C_0 < C_1$) it becomes obvious that the relation between the capacity costs is the most dominant factor for the investment incentives:

- In both cases, the smaller one of $\overline{p}_{2,C_0}$ and $\overline{p}_{2,C_1}$ should be set as the regulated price in period 2. Only this choice ensures an NPV of at least zero and at the same time minimizes underinvestment for $x_0 + x_1$.

- As already discussed in section 4.3.1, when capacity costs are decreasing ($C_0 > C_1$), no investment can be induced in period 1 ($x_0 = 0$). This is due to the fact that investing becomes "cheaper" if the company waits for one period.

- When capacity costs are increasing ($C_0 < C_1$), no investment can be induced in period 2 ($x_1 = 0$). This is due to the fact that investing becomes "more expensive" if the company waits for one period.

4.5 Conclusion, Limitations and Implications

4.5.1 Model Insights and Limitations

Summarizing, the model developed in this chapter analyzes a cost-based regulation issue over multiple periods. In the specific model setup, investments overlap in the second considered period. The model answers the questions what effect the actual price determination has on the affected company's investment decision in all periods, and which determination results in the highest social welfare.

In one sentence, under the assumption that investment becomes cheaper for the company, i.e. capacity costs decrease, section 4.3 demonstrates that the smallest possible price should be chosen. This is because the higher the regulated price the higher is the underinvestment for total capacity over all periods and consequently the loss in social welfare. A higher regulated price would result in an NPV of greater than zero for the company. This by itself would not be a problem for a social welfare maximizing regulator, but as underinvestment and hence the loss in social welfare increase with a higher regulated price, the regulator only allows an NPV of zero. This is the minimum NPV at which the company is still willing to invest.

Whereas the fact that the company invests *less* with a *higher* price might sound counterintuitive at first, the reason is the demand restriction the company is subject to. Only the amount of capacity is provided that can actually be sold. Even with the best possible price choice under these circumstances, one severe problem remains: no investment can be induced in period 1.

It could further be proven that the optimality of choosing the smallest possible price also holds for increasing capacity costs with the difference that no investment can be induced in period 2. This means that for both increasing and decreasing capacity costs, the feature of *overlapping* investments de facto ceases to exist. There is no overlapping investment, the company invests either in the first or the second period. As already discussed in section 4.3.1, this is not considered a shortfall regarding the initial research questions. It is an unexpected result that is due to the specific deterministic model setup, in which the company decides upon both investments simultaneously. It is likely that the overlapping feature does not fall away for a sequential setup of the investment process.

The analysis has been conducted under some strict assumptions which provide room for further investigation.

First, it is a discrete-time model in which investment is made only once at the beginning of each period. As one extension, ongoing but still discrete investment within one period would be interesting to implement into the model. Consequently, in such a setting, more than just two investments are relevant for the regulated price. Thereby, the real situation of the German incentive regulation would be better reflected. Moreover, in this setting the influence of the exact timing of the price review could be assessed. It is likely that different effects can be observed depending on whether the photoyear is three, two, or just one year before the new regulation period. With the photoyear being close to the new regulation period, the time lag between an investment outlay and its recognition in the revenue cap is reduced. As another extension, the model could be analyzed in a complete continuous time setting. This analysis would mainly be interesting from a theoretical perspective.

Second, the model only considers one monopolist that does not face competition at all. Although this does reflect the situation in the German electricity grid, analyzing different market structures and hence the effects of an oligopoly or even perfect competition would be natural extensions to the analysis.[199] Furthermore, only a one-product case was considered, and the extension to several products would be a natural extension. However, for the electricity industry assuming just one product is still a reasonable assumption.

Third, one could think of a different objective function for the regulator. The model assumes that the regulators pursues the maximization of social welfare subject to the company's NPV being zero, but there are other possibilities as well.[200] For instance, the regulator might be concerned with the speed of investment. He might want to induce fast and immediate investment instead of a formally maximizing welfare. In this matter, the strict assumption of allowing a maximum NPV of zero might be relaxed as well. This seems to be particular appropriate in the context of the thesis with the necessity of grid investment today.

Fourth, the way capacity is chosen is simplified. It is assumed that at any time, the amount of invested capacity can freely be chosen. In other words, the company can decide to provide another x units of new capacity, with x being any natural number. In many real life applications, this is not the case. In fact, investment is lumpy. If one thinks of a unit of capacity as one meter of power grid, it is impossible to just invest e.g. 150 meters of new line if the two nodes needing to be connected are 200 meters apart from each other. For the model, that means that capacity can only be increased by certain fixed amounts. Most

[199] However, it has to be noted that perfect competition would make the regulator obsolete. Nevertheless, it is not uncommon in the literature to analyze a competitive setting, see for instance Dixit (1991).

[200] Recall that as illustrated in section 4.3.1, a deviation of the NPV=0 requirement causes an immense loss in social welfare.

likely, accounting for this aspect will strong affect the model results.

Concerning the capacity choice, one might furthermore wonder why it is important that capacity and demand match in every single period.[201] One can imagine that it might be beneficial for the company to provide excess capacity today to be able to serve tomorrow's demand as well. The effects of such shifts in demand require further investigation too.[202]

Fifth, one further strict assumption is constant demand which has been used throughout the analysis. Allowing changing demand will most likely tremendously change the analysis and would be very important to further investigate analytically. For instance, Friedl (2007) analyzes the effects of changing demand. He considers linear demand functions with constant saturation quantity. He is able to show that in his setting, instead of the annuity depreciation rule, the relative benefit cost allocation rule[203] leads to efficient investment. Furthermore, he is able to prove that straight-line depreciation only results in efficient investment, if the maximum willingness to pay decreases at a very specific rate. Hence, Friedl (2007) is a convincing example for how different assumptions about the demand function lead to different results.

Moreover, not only changing demand will most likely make a big difference, but also other forms of the demand function. The demand function can be piecewise constant, which includes perfectly inelastic demand up to a certain point and not demand beyond that point. As another option, it could even be modeled as a very general demand function, without explicitly specifying it. All these possibilities in modeling demand will make a big difference, in particular because the assumed linear demand function is very crucial in the model.

As for another restriction concerning the parameters, the interest rate used throughout the analysis was exogenous and its influence was not analyzed. The same interest rate was used for both regulator and company, which is also a very strong assumption.

Sixth, the model is completely deterministic. Before all decisions are made, all relevant influencing factors are known and do not unexpectedly change later. This holds for demand, capacity costs, pricing procedure and interest rates. Of course this is a very strong assumption which can have a great impact on the model outcome. Uncertainty about any of these factors is very likely to dramatically influence the results and needs to be

[201] See the capacity restrictions in section 4.1.3.
[202] However, in this case the restriction to NPV=0 projects would have to be relaxed.
[203] In this thesis, the rule is illustrated in section 3.3.2.

accounted for in future research.[204] Furthermore, the deterministic setup also results in the fact that the regulator can fully commit to a certain pricing procedure which is known to the company ex ante. The company's investment decision relies very strongly on this fixed price in period 2. Knowing that the regulator might change his policy again will also significantly change the model outcome.

The deterministic nature of the present model with the resulting full certainty and full commitment of the regulator is considered an important limitation which requires further investigation. This has not been achieved by the presented formal model, and naturally, there are not any contributions which analyze the issue of information, commitment and uncertainty, but the discussion of these topics in section 3.4 provided a basis idea of their importance.

In addition to the level of information and uncertainty there are more important drivers which were left out in the formal model. In the model, the cost base used for the determining depreciation charges was chosen in the simplest way possible, namely just taking the original historic cost. This in another important limitation of the analysis. In analogy to section 3.4.1, section 3.4.3 discussed existing literature which deals with this issue. Based on this discussion, starting points for an extension of the model can be identified.

Lastly, in the model only capital costs, i.e. depreciation and interest, were included into pricing. In fact, as illustrated in section 3.4.4, there is a large stream of literature which suggests other forms of pricing, for instance peak-load pricing. These other pricing approaches are not incorporated in the model too, which is another limitation of it. Here again, the discussion in section 3.4.4 provides the literature framework for possible future research.

4.5.2 Conceptual Discussion of Model Results

Having assessed the model limitations in detail, in this section the model results are discussed conceptually. The model results raise several questions that were not or only partly answered in an analytical way. This section picks up these issues and discusses them.

One dominant theme of the model is the question which regulated price should be employed by the regulator if there are different options for this price. These options result

[204] An example for this is Friedl (2011) which is an article on regulation and investment incorporating uncertainty and real options. Friedl (2011) can be considered an advancement to Friedl (2007) which did not include uncertainty.

from the fact that different investments were made at different capacity costs. In the context of the model, it turned out that for both decreasing and increasing capacity costs, the smaller one of the two prices should be chosen.

While this might not seem obvious at first, it is a convincing result, if demand is taken into account. For the assumed linear inverse demand function, a low price corresponds to high demand. Companies are encouraged to invest if high demand for a certain product or service can be observed. Hence, if the regulator keeps the price reasonably low, demand is encouraged and consequently investment. Of course, the price can not be arbitrarily lowered, because an NPV of at least zero must be guaranteed for the company. In section 4.4.1 it was shown that the price which the regulator considers efficient in period 2 is indeed smaller than the smallest possible price making the company's NPV equal to zero. Thus, the regulated price must not be too low. On the other hand, it was illustrated that the higher the regulated price, the less the company invests in period 2. In total, the analysis revealed that the smallest possible price still making the company's NPV equal to zero should be implemented.

An important fact that is missing in the analysis is the provision for an already existing asset base. In reality, whenever the company invests, there are already assets, which were acquired at different points in time. Consequently, these assets will be fully depreciated at different points in time in the future. Moreover, the length of their useful life can be different. As for an example, the German power grid already exists all throughout Germany, and the related assets have already caused costs consisting of depreciation and interest for many years. Still, the expansion of the grid, as illustrated in section 2.2, necessitates new investment, and moreover, replacement investment is required as well.

This shows that an investment sequence in reality differs clearly from the setup of this thesis' model. In the model, there is no existing asset base, and the decision about two investments for two consecutive regulation periods is made simultaneously. In reality, whenever an investment decision is made, the company has to consider different factors: first, capacity costs, potentially together with their foreseeable future development. Second, demand for the product, and how more provided capacity might influence demand. Third - assuming the regulatory policy is fully transparent and reliable - how the new investment will affect the regulated price in the following regulation period. This is particularly important, because the regulated price in the following period is part of the investment project's NPV and consequently, it can determine whether this project is beneficial for the company or not. All of these factors are additionally influenced by the existing asset base.

It could be argued, that whenever - regarded isolatedly - one investment would result in a lower regulated price, then this price should be the one chosen by the regulator. However, if this is the procedure pursued by the regulator, and if capacity prices are declining, then this would mean that the regulated price becomes smaller with every new investment. As a consequence, the originally determined NPV of investments that have been made earlier may not be greater or equal than zero any more. This would cause big losses for the affected company and can not be in the best interest of the regulator. Thus, despite the rationale above, the actual implications of such a procedure must be taken into account precisely.

Another significant difference between the model setup and reality is that many different investments are made within one regulation period, which are all relevant for the regulated price one period later.[205] This insight leads to several more issues that must be accounted for in order to make the model more realistic. First, if n investments are made within one regulation period, the aggregate capacity of all investments, i.e. the sum $\sum_{i=0}^{n} x_i$ must fulfill the capacity restriction in the relevant period. For instance, if all resulting assets still exist in the second regulation period, then - in analogy to equation (4.4) - it must hold that $\sum_{i=0}^{n} x_i \leq (a - \overline{p}_2)/b$. This restriction must be taken into account by the company for all investments. Furthermore, as mentioned earlier, it is crucial that each project's NPV is at least zero in order to not destroy value.

One further important point in this context is that assets in the power grid mostly have a very long useful life. For instance, the StromNEV specifies straight-line depreciation over around 40 years for most fixed assets. As a consequence, once an investment is made, it will cause costs consisting of depreciation and interest for the next 40 years. These costs must be accounted for in the regulated price. Furthermore, the entire provided capacity is subject to the above mentioned capacity constraint. However, it must be noted that while this is an important constraint for the analytical analysis, it is very likely that in the real current state, no investment in the power grid would cause excess capacity. Currently, all expansion and replacement investments in the power grid are doubtlessly necessary for the integration of renewable energies. In other words, sufficient demand for transmission exists.

This conceptual discussion of the model setup and the model results reveals several important points. First, the result that the smaller regulated price should the chosen, must be treated with a lot of caution. This procedure can become problematic when the price is too low and then turns the NPVs of past investments negative. This difficulty is based on the fact that an existing asset base must be accounted for, and assets are depreciated over

[205] This abstracts away from the AReg feature of investment budgets.

a very long time. Ideally, the model setup should be modified such that it accounts for both issues. Furthermore, the fact that in reality, many single investments with different capacity costs are relevant for a regulated price, should be allowed for in the model setup.

4.5.3 Practical Implications

This section presents some thoughts and considerations about practical implications of the analysis. Whereas some practical implications were already touched upon in the previous section, the discussion here intends to demonstrate how designers of regulatory policies, affected companies and the energy industry as a whole may benefit from the insights in this thesis. However, it must be noted that the model insights have all been achieved through a very abstract analysis, and conclusions for reality or practical purposes must be drawn with a lot of caution. Hence, all implications illustrated in this section require more investigation.

In the specific model setup, overlapping investment is considered. In other words, capacity adds up, and at the time of the second investment, the first investment has not been depreciated yet. It has been demonstrated that this very particular setup changes existing findings substantially. For instance, the use of the annuity depreciation rule does not lead to efficient investment while it does so in other similar models. The failure of the annuity depreciation in this particular setting points out that it is crucial to account for the existing asset base when prices are determined, not just for new investment. In the German AReg, this is realized: when costs are determined as the basis for the revenue cap, all costs including depreciation from past investments must be incorporated.

The analysis further showed that the development of the capacity costs - i.e. whether investing becomes "cheaper" or not - is an important driver. It could be found that when capacity costs decrease, no investment can be induced in the first period. On the opposite, when capacity costs increase, no investment can be induced in the second period. An implication which can be drawn for practical purposes is simply that the development of capacity costs must be taken into consideration. When it is very likely that investing becomes cheaper *tomorrow*, for instance because of economies of scale or economies of scope, then the companies particularly need incentives for investing *today*. When investing is expected to become more expensive, then means must be implemented to shift investment from today into the future.

Another insight of the model was that in the second period, where scope in determining the regulated price evolves, the most intuitive way of dealing with this scope - i.e. using a simple average of both possibilities - is not the best choice. The discussion showed that choosing the smaller one of the two candidates is the best option. Whereas this is again due to the specific model setup, the message which still can be taken away is that the simplest or most intuitive solution may not be the optimal one. Furthermore, the solution that a *smaller* price is in fact more beneficial for investment than a higher price is also surprising and leads to another insight: whereas one might think that a regulated company would always prefer to charge higher prices and that this consequently results in more investment, this is not true if a capacity constraint exists. Capacity constraint means that only the amount of capacity is provided that can be sold. This appears if demand for the product is limited. Hence, when designing a regulatory policy, the demand for the product must not be neglected.

Furthermore, it turned out that underinvestment cannot be avoided in the context of the model in chapter 4. Whereas this is of course again due to the very specific setup, for practical purposes it shows that there may be certain circumstances making it impossible to achieve the social welfare optimum. In this case, other instruments for inducing investment must be developed. This could be a governmental subsidy, or any other mean like the investment budgets in the German AReg. If efficient investment is a prior concern - as it is in the context of the German energy turnaround - then a regulator cannot rely on the believe that the basic design of the regulation (for instance the AReg without the feature of investment budgets) will solve this issue. Even if such a specific investment inducing feature is introduced, it must be ensured that the actual design serves the original intention. This issue for instance appeared in the approval process of the investment budgets, as illustrated before.

While it was not assessed analytically in the formal model, and while this clearly beyond the core scope of this thesis, insights concerning the regulator's commitment still deserve being mentioned. The literature review of selected special issues in the context of regulation and investment in section 3.4 revealed another important message for the design of a regulatory policy. It was illustrated that the regulator's commitment as well as the level of uncertainty can have a substantial impact on investment behavior. Consequently, the regulator should put a lot of emphasis on his credibility, and policies should be designed such that they cannot be significantly modified in an easy way. The possible change of a regulatory policy also directly affects the uncertainty about the future value of an investment project. Hence, creating a stable and reliable regulatory environment should be a major concern for regulators.

As for the affected companies, only a few recommendations can be given, because they cannot actively influence the decisions of the regulator concerning the regulatory policy.[206] One recommendation could be that when deciding upon a specific investment project, i.e. when determining that project's NPV, it is risky for the company to assume that a particular regulated price will stay fixed over all regulation periods. To value this project in a sound fashion, it would be important for the company to be well informed about, and to analyze precisely how the investment will translate into the regulated price. In particular, it is crucial whether this investment will decrease or increase the regulated price. However, in most cases, the company is either not perfectly informed, the analysis is too complex, or it involves too many uncertainties. If this is the case, then investment projects should at least be valued in different scenarios.

Under the - admittedly implausible - assumption that first, full commitment of the regulator is possible, and second that the company is perfectly informed about future development of capacity costs and future demand, then it is beneficial for the company to not invest today, but to postpone projects to the future, if capacity costs decrease. This is intuitive because expressed differently, investment becomes cheaper in the future. However, this level of full information is beyond any realistic assumptions.

As for the energy industry as a whole, several starting points can be identified for an explanation why the expansion of the power grid in Germany progresses slowly. As discussed earlier, grid operators might expect decreasing capacity costs and thus postpone certain investment projects. Furthermore, uncertainty about several factors, for instance about future demand or about the regulatory environment, might be investment drawbacks as well. While the following is not an insight of the analytical model, the conceptual discussion of the AReg in chapter 2 revealed that certain elements of the AReg need some revision. The shortcomings in the design of the investment budgets were recently resolved, but other features such as the allowed rate of return and the time lag resulting from the early photoyears still deserve improvement.

In summary, even if the developed model in this thesis is very abstract and analyzes a very specific setting, it is still possible to draw important conclusions for the design of regulatory policies in general. Of course, these insights are neither new or particularly surprising, and many of them have been accounted for in the design of the AReg. Still, they are again justified by the model findings, and their importance has another theoretical foundation.

[206]This abstracts away from lobbying.

5 Final Conclusion

5.1 Summary

In order to come to the final conclusion, insights and findings of the thesis are summarized briefly and put in relation to the research questions of this thesis.

In chapter 1 the following research questions were posed:

(1) How does the German incentive regulation (AReg) affect investment in the power grid?

(2) What effect does the actual price determination have on the affected company's investment decision when overlapping investments over multiple periods are considered in a cost-based price-cap regulation environment? What is the optimal price from the regulator's perspective?

Chapter 2 illustrated the background for the thesis: the electricity industry itself, as well as necessary investments in the power grid and the regulation of the grid. The chapter showed that while the expansion of renewable energies results in a need for massive investments in the grid, price regulation is known to cause distortions in investment behavior. The currently effective regulatory regime in Germany, the *Anreizregulierung*, was described in detail and its known effects on investment were shown. Hence, the conceptual discussion of the AReg along with a thorough review of existing literature provides the answer to research question (1).

Without a doubt, the AReg was designed carefully. While its primary objective is to set incentives for cost reductions and efficiency improvements, it also includes elements which foster investment. The most important elements are the investment budgets that apply to particular investment projects and that are separated from the revenue cap. Furthermore, a quality element is included in the AReg. However, there are also weaknesses in the design of the policy: some elements have room for improvement to avoid negative effects on investment behavior. Three commonly discussed major aspects are investment budgets, cost of equity, and a time lag issue. Investment budgets now are approved based on planned instead of realized costs. Second, according to several experts, the approved cost of equity is too low to guarantee an adequate return to the grid operating company. Third, apart from investment budgets, all relevant costs for the revenue cap are only calculated in the photoyear. As a result, it can take up to seven years until costs become effective for the revenue cap. This long time lag between realization of costs and their effectiveness is considered another problem. These insights were all illustrated in detail in chapter 2.

Chapter 3 comprised on the one hand an extensive literature review of regulation and investment. It discussed empirical, theoretical and analytical research, structured by methodology. The focus was put on the influence of incentive regulation on investment, as opposed to other forms of regulation such as rate-of-return regulation. The review proved that there is an essential connection between regulation and the investment behavior of the affected company. In most cases, incentive regulation discourages infrastructure investment. Solutions suggested in the literature to overcome this problem were discussed. In total, the literature review created the framework for the developed model in the following chapter.

On the other hand, the general literature review was enhanced by a discussion of selected issues in the context of regulation and investment. These issues were the level of information and regulator's commitment, uncertainty, choice of cost basis and alternative pricing approaches. These topics were discussed extensively as they are recurring issues in the relevant literature and hence of particular importance. As the analysis of these topics in the formal analytical model was beyond the scope of this thesis, they were still accounted for by the academic discussion in section 3.4.

The analytical model developed in chapter 4 answered the second set of research questions. Using a cost-based price-cap regulation environment, an analysis was conducted of the effect of the actual price determination on the affected company's investment decision, when overlapping investments over multiple periods are considered. The main finding is that, when productive capacity is accumulated in the second considered period, an average price must not be implemented, but the smaller option must be chosen. This choice minimizes the underinvestment problem and hence it is optimal from the regulator's perspective. Any other price determination causes more underinvestment and is worse, as a result. However, the predominant remaining problem is that in the specific considered model setup, with decreasing capacity costs and all parameters known to the company from the very beginning, it is impossible to induce any investment in the first period. This effect is accredited to the decreasing capacity costs. Ultimately, the optimal price determination under the specific circumstances was proven. Still the optimal capacity from the social welfare perspective cannot be achieved in this particular model setup.

In the end of chapter 4, first model limitations were discussed extensively. Second, a conceptual discussion of the model results completed the analytical investigation by conceptually addressing important issues. Finally, practical implications concerning the design of the actual regulatory policy were identified in section 4.5.3.

5.2 Contribution to Existing Literature

This thesis contributes two main findings. As illustrated in section 1.2, one purpose of this thesis is to conceptually assess the German AReg and its influence on the investment behavior of affected companies based on existing literature. Additionally, this thesis aims to analyze a specific aspect of an investment sequence in a formal model.

First, the contribution of the conceptual discussion of the AReg is the holistic academic investigation of its influence on investment. The single elements of the policy were discussed and the focus was put on how those elements affect investment. Several issues were identified which are drawbacks for investing. Relevant literature was reviewed in detail, such that the reader has gained a broad view on this topic.

Second, the formal model in chapter 4 provides an extension to existing models. As argued previously, the distinguishing aspect is that investments overlap and consequently, capacity aggregates in the second period. In reviewed analytical models on regulation and investment, this aspect is not explicitly analyzed. Yet, it is important since overlapping investments and capacity aggregation do occur in many real settings: grid operators do continuously invest in their network, for instance, because a new photovoltaic plant must be connected to the grid. At the same time, the existing asset base is not yet depreciated. Both the existing asset base and the new assets form the cost basis for the regulated price, and how the new asset should be accounted for or how the regulated price must change because of this new asset is not self-explanatory. To the best of this author's knowledge, no existing literature investigates this issue explicitly.

5.3 Recommendations for Extension and Future Research

Several extensions of the thesis can be considered. These apply to the two parts of the thesis separately - the AReg discussion and the analytical model - as well as to a closer connection between the two parts.

As for the AReg analysis, a prior concern is to empirically investigate the effects of the AReg on investment. It is highly likely that there is a relationship, but this conjecture still lacks a formal empirical proof. As the AReg is in effect since 2009, four complete years of data on investment can now be collected. As 2013 is the last year of the first regulation period, analyses of the entire first regulation period are possible from 2014 on. In these analyses, the AReg could be assessed as a whole, or the effects of single elements could be investigated. The investment budgets are the most prominent feature, but also the quality element or the rate of return deserve further analysis.

Concerning the formal model, its limitations have already been illustrated in different sections of this thesis. Section 4.5.1 discussed the major model assumptions and limitations, and the conceptual discussion in section 4.5.2 showed several starting points for future research. Furthermore, section 3.4 provided an extensive and substantiated literature framework of how the level of information, commitment and uncertainty, the cost base choice and the pricing methods affect investment behavior.

Among these assumptions and limitations there are some which appear most promising and most pressing. One is the deterministic design of the model. All information concerning the relevant factors is known to the regulator as well as to the company from the beginning of the game. In other words, the model assumes full information. As it has been illustrated in section 3.4.1, model outcomes are extremely sensitive to changes to the assumptions. Observing these changes is not only interesting from a theoretical point of view, but also brings the model closer to reality. For instance, companies subject to the German AReg cannot completely trust the regulator to not change his policy from the first to the second regulation period. Hence, limited regulator's commitment is one aspect which merits further analysis.

Furthermore, uncertainty about the regulator's commitment and policy is not the only concern. The development of demand and capacity costs is equally important for the investment decision of the company, and this development is subject to uncertainty as well. It has been demonstrated that in the context of the model, both factors are important drivers of the result. Future research exploring these uncertainties will ensure important progress in the field.

As the German power grid will stay regulated, and infrastructure and quality investment are unlikely to lose any of their importance, investigating the relationship between regulation and investment will continue to be a promising area of research.

Bibliography

Abel, A. (1990). Consumption and Investment. In Friedman, B. and Hahn, F. (editors), *Handbook of Monetary Economics*, volume II, (pp. 725–778). Elsevier North Holland, Amsterdam.

Acton, J. and Vogelsang, I. (1989). Introduction. *RAND Journal of Economics*, volume 20(3), pp. 369–372.

Affuso, L. and Newberry, D. (2000). Investment, Re-Procurement and Franchise Contract Length in the British Railway Industry. *CEPR Discussion Papers*, (2619).

Ai, C. and Sappington, D. (2002). The impacts of state incentive regulation on the U.S. telecommunications industry. *Journal of Regulatory Economics*, volume 22(2), pp. 133–59.

Ajodhia, V., Petrov, K. and Scarsi, G. (2004). Quality, Regulation and Benchmarking - An Application to Electricity Distribution Networks. *Zeitschrift für Energiewirtschaft*, volume 2(29), pp. 107–120.

Alesina, A., Ardagna, S., Nicoletti, G. and Schiantarelli, F. (2005). Regulation and Investment. *Journal of the European Economic Association, MIT Press*, volume 3(4), pp. 791–825.

Alexander, I., Mayer, C. and Weeds, H. (1996). Regulatory structure and risk and infrastructure: An international comparison. *World Bank Policy Research Working Paper*, (1698).

Amram, M. and Kulatilaka, N. (1999). *Real Options. Managing Strategic Investment in an Uncertain World*. Harvard Business School Press, Boston.

Armstrong, M. and Sappington, D. (2006). Regulation, competition, and liberalization. *Journal of Economic Literature*, volume 44(2 XLIV), pp. 325–366.

Armstrong, M. and Sappington, D. (2007). Recent Developments in the Theory of Regulation. In Armstrong, M. and Porter, R. (editors), *Handbook of Industrial Organization*, volume 3, (pp. 1557–1700). Elsevier, Amsterdam.

Averch, H. and Johnson, L. (1962). Behavior of the Firm Under Regulatory Constraint. *American Economic Review*, volume 52(5), pp. 1052–1069.

Bailey, E. (1972). Peak-Load Pricing under Regulatory Contraint. *Journal of Political Economy*, volume 80(4), pp. 662–679.

Bailey, E. (1974). Innovation and regulation. *Journal of Public Economics*, volume 3(3), pp. 285–295.

Bailey, E. and Coleman, R. (1971). The effect of lagged regulation in an Averch-Johnson model. *The Bell Journal of Economics and Management Science*, (2), pp. 278–292.

Baldenius, T. and Ziv, A. (2003). Performance Evaluation and Corporate Income Taxes. *Review of Accounting Studies*, (8), pp. 283–309.

Ballwieser, W. (2008a). *Investitionsrechnungen für Netze im Rahmen der Anreizregulierung*. Berlin, Frankfurt am Main, Heidelberg.

Ballwieser, W. (2008b). *Investitionsrechnungen für Netze nach Festlegung der Eigenkapitalzinssätze im Rahmen der Anreizregulierung*. Berlin, Frankfurt am Main, Heidelberg.

Bareket, M. and Mohnen, A. (2007). Performance Measurement for Investment Decisions Under Capital Constraints. *Review of Accounting Studies*, (10), pp. 527–52.

Baron, D. (1989). The Design of Regulatory Mechanisms and Institutions. In Schmalensee, R. and Willig, R. (editors), *Handbook of Industrial Organization*, volume II, chapter 24, (pp. 1347–1447). North Holland, Amsterdam.

Baron, D. and Besanko, D. (1987). Commitment and Fairness in a Dynamic Regulatory Relationship. *Review of Economic Studies*, volume 54(179), pp. 413–446.

Baron, D. and Myerson, R. (1982). Regulating a Monopolist with Unknown Cost. *Econometrica*, volume 50(4), pp. 910–930.

Bauchmüller, M. and Szymanski, M. (2011). Stromnetz-Betreiber warnen vor Blackout. *Süddeutsche Zeitung vom 23.05.2011*.

Bauknecht, D. (2011). Incentive Regulation and Network Innovations. *EUI Working Paper RSCAS, IRIN, Öko-Institut Freiburg*.

Bauknecht, D., Leprich, U., Späth, P., Skytte, K. and Esnault, B. (2007). Regulating Innovation and Innovating Regulation. *DG-GRID project report*.

Baumol, W. and Bradford, D. (1970). Optimal Departures From Marginal Cost Pricing. *American Economic Review*, volume 60(3), pp. 265–283.

Baumol, W. and Klevorick, A. (1970). Input choices and rate-of-return regulation: An overview of the discussion. *The Bell Journal of Economics and Management Science*, (1), pp. 162–190.

Baumol, W. and Sidak, J. (2002). The Pig in the Python: Is Lumpy Capacity Investment Used and Useful? *Energy Law Journal*, (23), pp. 383–458.

Bawa, V. and Sibley, D. (1980). Dynamic Behaviour of a Firm Subject to Stochastic Regulatory Review. *International Economic Review*, (21), pp. 627–642.

BDEW (Bundesverband der Energie- und Wasserwirtschaft e.V.) (2010). Investitionen der deutschen Stromversorger.

Beesley, M. and Littlechild, S. (1989). The regulation of privatized monopolies in the United Kingdom. *RAND Journal of Economics*, volume 20(3), pp. 454–472.

Besanko, D. and Sappington, D. (1987). *Designing Regulatory Policy with Limited Information*. Harwood Academic Publishers, Chur, Switzerland.

Besanko, D. and Spulber, D. (1992). Sequential-equilibrium investment by regulated firms. *RAND Journal of Economics*, volume 23(2), pp. 153–170.

Bialek, J. (2004). Recent Blackouts in the US and Continental Europe: Is Liberalization to Blame? *Cambridge Working Papers in Economics*, (0407).

Biglaiser, C. and Riordan, M. (2000). Dynamics of Price Regulation. *RAND Journal of Economics*, volume 31(4), pp. 744–767.

Black, F. and Scholes, M. (1973). The Pricing of Options and Corporate Liabilities. *Journal of Political Economy*, volume 81, pp. 637–659.

Böckem, S. and Schiller, U. (2009). Level Playing Fields in Regulated Network Industries: Cost-Based Access Pricing, Depreciation, and Capacity Choice. *Zeitschrift für Betriebswirtschaft*, volume 80(3), pp. 1–20.

Boiteux, M. (1949). La Tarification des demandes en point: application de la theorie de la vente au cout marginal. *Revue Générale de l'Eléctricité*, (58), pp. 321–40. Translated as: Peak Load Pricing. In: Journal of Business 33(2) (1960):157-79.

Boldt, J., Hankel, L., Laurisch, L., Lutterbeck, F., Oei, P.Y., Sander, A., Schröder, A., Schweter, H., Sommer, P. and Sulerz, J. (2012). Renewables in the Grid - Modeling the German Power Market of the Year 2030. *Technische Universität Dresden, Technische Universität Berlin*.

Bork, C., Müller, K., Petersen, H. and Wirths, S. (1995). Wider den Sachzeitwert: Untersuchung zur Frage des angemessenen Übernahmepreises von Elektrizitätsversorgungsnetzen. Finanzwissenschaftliche Diskussionsbeiträge, No. 6.

Braeutigam, R. (1981). Regulation of multiproduct enterprises by rate of return, markup, and operating ratio. *Research in Law and Economics*, volume 1(3), pp. 15–38.

Braeutigam, R. and Panzar, J. (1993). Effects of the Change from Rate-Of-Return Regulation to Price Cap Regulation. *American Econimic Review*, volume 83(2), pp. 191–198.

Braeutigam, R. and Quirk, J. (1984). Demand uncertainty and the regulated firm. *International Economic Review*, volume 25(1), pp. 45–60.

Brennan, M. and Schwartz, E. (1982a). Consistent Regulatory Policy under Uncertainty. *The Bell Journal of Economics*, volume 13(2), pp. 506–521.

Brennan, M. and Schwartz, E. (1982b). Regulation and Corporate Investment Policy. *The Journal of Finance*, volume 37(2), pp. 289–300.

Brennan, M. and Schwartz, E. (1985). Evaluating Natural Resource Investments. *Journal of Business*, volume 58, pp. 135–157.

Brennan, T. (1989). Regulating by Capping Prices. *Journal of Regulatory Economics*, volume 2(1), pp. 133–147.

Brennan, T. (2009). Network Effects in Infrastructure Regulation. *Review of Network Economics*, volume 8(4), pp. 279–301.

Brunekreeft, G. (2004). Market-based investment in electricity transmission networks: controllable flow. *Utilities Policy*, volume 12(4), pp. 269–281.

Brunekreeft, G. and Bauknecht, D. (2009). Regulierung und Innovationstätigkeit - eine ökonomische Perspektive. In Eifert, M. and Hoffmann-Riem, W. (editors), *Innova-*

tionsfördernde Regulierung: Innovation und Recht II. Berlin, 2009.

Brunekreeft, G. and Borrmann, J. (2011). The Effect of Monopoly Regulation on the Timing of Investment. *Bremen Energy Working Papers, Bremer Energie Institut*, (01).

Brunekreeft, G. and Meyer, R. (2011). Netzinvestitionen im Strommarkt: Anreiz- oder Hemmniswirkung der deutschen Anreizregulierung? *Energiewirtschaftliche Tagesfragen*, volume 1/2(61), pp. 40–43.

Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit (2012). Entwicklung der erneuerbaren Energien in Deutschland im Jahr 2011. Grafiken und Tabellen.

Bundesministerium für Wirtschaft und Technologie (2011). Rösler: Investitionsrahmen für Netzausbau wird verbessert. Press release Dec 14.

Bundesministerium für Wirtschaft und Technologie (2012). Verordnung zur Änderung der Anreizregulierungsverordnung. Berlin.

Bundesnetzagentur (2006). Bericht der Bundesnetzagentur nach §112a EnWG zur Einführung der Anreizregulierung nach §21a EnWG. Bonn.

Bundesnetzagentur (2011a). Monitoringbericht gemäß §63 Abs. 4 EnWG i.V.m. §35 EnWG. Monitoringbericht 2011, Bonn.

Bundesnetzagentur (2011b). Beschluss BK 3c-11/003. Bonn.

Burness, H., Montgomery, W. and Quirk, J. (1980). Capital Contracting and the Regulated Firm. *American Economic Review*, volume 70, pp. 342–354.

Burns, P. and Riechmann, C. (2004). Regulatory instruments and investment behaviour. *Utilities Policy*, volume 12(4), pp. 211–219.

Bye, T. and Hope, E. (2005). Deregulation of electricity markets - the Norwegian experience. *Economic and Political Weekly*, volume 40(50), pp. 5269–5278.

Cabral, L. and Riordan, M. (1989). Incentives for cost reduction under price cap regulation. *Journal of Regulatory Economics*, volume 1(2), pp. 93–102.

Caillaud, B., Guesnerie, R., Rey, P. and Tirole, J. (1985). The Normative Economics of Government Intervention in Production. *Technical Report (Stanford University, Institute for Mathematical Studies in the Social Sciences)*, (473).

Cambini, C. and Jiang, Y. (2009). Broadband investment and regulation: A literature review. *Telecommunications Policy*, volume 33(10), pp. 559–574.

Cambini, C. and Rondi, L. (2010). Incentive regulation and investment: evidence from European energy utilities. *Journal of Regulatory Economics*, volume 1(38), pp. 1–26.

Chao, H.P. (1983). Peak load pricing and capacity planning with demand and supply uncertainty. *The Bell Journal of Economics*, volume 14(1), pp. 179–190.

Clark, T., Elsby, M. and Love, S. (2001). Twenty-Five Years of Falling Investment? Trends in Capital Spending on Public Services. *The Institute for Fiscal Studies, Briefing Note*, (20).

Coase, R. (1946). The marginal cost controversy. *Economica*, (13), pp. 169–189.

Cowan, S. (2002). Price cap regulation. *Swedish Economic Policy Review*, (9), pp. 167–188.

Crew, M. and Kleindorfer, P. (1976). Peak Load Pricing with a Diverse Technology. *The Bell Journal of Economics*, volume 7(1), pp. 207–231.

Crew, M. and Kleindorfer, P. (1992). Economic Depreciation and the Regulated Firm under Competition and Technological Change. *Journal of Regulatory Economics*, volume 4(1), pp. 51–61.

Crew, M. and Kleindorfer, P. (2002). Regulatory Economics: Twenty Years of Progress. *Journal of Regulatory Economics*, volume 21(1), pp. 5–22.

Crew, M., Fernando, C. and Kleindorfer, P. (1995). The Theory of Peak-Load Pricing: A Survey. *Journal of Regulatory Economics*, volume 8(3), pp. 215–248.

Dalen, D. (1998). Yardstick Competition and Investment Incentives. *Journal of Economics and Management Strategy*, (7), pp. 105–1026.

Deutsche Energie-Agentur GmbH (2005). Energiewirtschaftliche Planung für die Netzintegration von Windenergie in Deutschland an Land und Offshore bis zum Jahr 2020. Studie im Auftrag der Deutschen Energie-Agentur GmbH, Köln 2005.

Deutsche Energie-Agentur GmbH (2010). Integration erneuerbarer Energien in die deutsche Stromversorgung im Zeitraum 2015-2020 mit Ausblick auf 2025. Studie im Auftrag der Deutschen Energie-Agentur GmbH, Berlin 2010.

Dixit, A. (1991). Irreversible investment with price ceilings. *Journal of Political Economy*, volume 99(3), pp. 541–557.

Dixit, A. and Pindyck, R. (1994). *Investment under Uncertainty*. Princeton.

Dobbs, I. (2004). Intertemporal price cap regulation under uncertainty. *The Economic Journal*, volume 114(495), pp. 421–440.

Dupuit, J. (1952). On the Measurement of the Utility of Public Works. *International Economics Papers*, volume 2, pp. 83–110. (translated by Barback, R. H. from "de la Mesure de l'Utilite des Travaux Publics", Annales des Ponts et Chaussees, 2nd Series, Vol. 8, 1844).

Dutta, S. and Reichelstein, S. (2002). Controlling Investment Decisions: Depreciation- and Capital Charges. *Review of Accounting Studies*, volume 7(2-3), pp. 253–281.

Dutta, S. and Reichelstein, S. (2010). Decentralized Capacity Management and Internal Pricing. *Review of Accounting Studies*, volume 15(3), pp. 44–478.

Egert, B. (2009). Infrastructure investment in network industries: The role of incentive regulation and regulatory independence. *CESifo working paper No 2642, Category 11: Industrial organisation*.

Elsenbast, W. (2008). Anreizregulierung in der Energiewirtschaft, Wesentliche Elemente und offene Fragen. *Wirtschaftsdienst*, volume 6(88), pp. 398–403.

Evans, L. and Guthrie, G. (2005). Risk, price regulation, and irreversible investment. *International Journal of Industrial Organization*, (23), pp. 109–128.

Evans, L. and Guthrie, G. (2006). Incentive regulation of prices when costs are sunk. *Journal of Regulatory Economics*, (29), pp. 239–264.

Flauger, J. and Stratmann, K. (2010). Eon-Chef Bernotat greift die Bundesnetzagentur an. *Handelsblatt*.

Fleming, J. (1944). Price and output policy of state enterprise: A comment. *Economic Journal*, (54), pp. 328–337.

Floyd, E. and Gabel, D. (2003). An Econometric Analysis of the Factors that Influence the Deployment of Advanced Telecommunications Services. *MIT Internet and Telecommunications Convergence Consortium*.

Friedl, G. (2005). Incentive Properties of Residual Income when There is an Option to Wait. *Schmalenbach Business Review*, volume 57(1), pp. 3–21.

Friedl, G. (2006). *Real Options and Investment Incentives*. Springer, Berlin.

Friedl, G. (2007). Ursachen und Lösung des Unterinvestitionsproblems bei einer kostenbasierten Preisregulierung. *DBW*, volume 67, pp. 335–348.

Friedl, G. (2011). Kostenbasierte Preisregulierung, Realoptionen und Investitionsanreize. *Schmalenbachs Zeitschrift für betriebswirtschaftliche Forschung*, volume 63(11), pp. 136–156.

Friedl, G. and Küpper, H.U. (2011). Historische Kosten oder Long Run Incremental Costs als Kostenmaßstab für die Preisgestaltung in regulierten Märkten? *Schmalenbachs Zeitschrift für betriebswirtschaftliche Forschung*, volume 64(11), pp. 98–128.

Gilbert, R. and Newbery, D. (1994). The dynamic efficiency of regulatory constitutions. *RAND Journal of Economics*, volume 25(4), pp. 538–554.

Grenadier, S. (2002). Option Exercise Games: An Application to the Equilibrium Investment Strategies of Firms. *The Review of Financial Studies*, volume 15(3), pp. 691–721.

Greenstein, S., McMaster, S. and Spiller, P. (1995). The Effect of Incentive Regulation On Infrastructure Modernization: Local Exchange Companies' Deployment of Digital Technology. *Journal of Economics and Management Strategy*, volume 4(2), pp. 187–236.

Grobman, J. and Carey, J. (2001). Price caps and investment: long-run effects in the electric generation industry. *Energy Policy*, (29), pp. 545–552.

Guthrie, G. (2006). Regulating infrastructure: the impact on risk and investment. *Journal of Economic Literature*, volume 44(4), pp. 925–972.

Guthrie, G., Small, J. and Wright, J. (2006). Pricing Access: Forward-looking versus backward-looking cost rules. *European Economic Review*, volume 50(7), pp. 1767–1789.

Hammer, C. (2011). *Einflüsse des Europäischen Emissionshandels auf Produktions- und Investitionsentscheidungen bei Strom- und Wärmeerzeugern*. Ph.D. thesis, Technische Universität München.

Handelsblatt (2012). Deutsches Stromnetz droht zu kollabieren. *Handelsblatt*.

von Hirschhausen, C., Beckers, T. and Brenck, A. (2004). Infrastructure Regulation and

Investment for the Long-Term - An Introduction. *Utilities Policy*, volume 12(4), pp. 203–210.

Hotelling, H. (1925). A General Mathematical Theory of Depreciation. *Journal of the American Statistical Association*, volume 20(151), pp. 340–353.

Hotelling, H. (1938). The General Welfare in Relation to Problems of Taxation and of Railway and Utility Rates. *Econometrica*, volume 6(3), pp. 242–269.

Jamasb, T. and Pollitt, M. (2007). Incentive regulation of electricity distribution networks: Lessons of experience from britain. *Energy Policy*, volume 35, pp. 6163–6187.

Jensen, M. and Meckling, W. (1976). The Theory of the Firm: Managerial Behaviour, Agency Costs and Ownership Structure. *Journal of Financial Economics*, volume 4(3), pp. 305–360.

Joskow, P. (2006a). Competitive Electricity Markets and Investment in New Generating Capacity. *AEI-Brookings Joint Center Workig Paper*, (06-14).

Joskow, P. (2006b). Incentive regulation in theory and practice: electricity distribution and transmission Networks. *Working paper, prepared for National Bureau of Economic Research Economic Regulation Project*.

Joskow, P. (2008). Incentive regulation and its application to electricity networks. *Review of Network Economics*, volume 7(4), pp. 547–560.

Joskow, P. and MacAvoy, P. (1975). Regulation and the Financial Conditions of the Electric Power Companies in the 1970s. *American Economic Review*, (65), pp. 295–311.

Joskow, P. and Tirole, J. (2007). Reliability and competitive electricity markets. *RAND Journal of Economics*, volume 38(1), pp. 60–84.

Jost, P. (2004). *Die Prinzipal-Agenten-Theorie in der Betriebswirtschaftslehre*. Schäffer-Poeschel Verlag, Stuttgart.

Keller, K. and Wild, J. (2004). Long-term investment in electricity. A trade-off between coordination and competition. *Utilities Policy*, volume 12(4), pp. 243–251.

Kinnunen, K. (2006). Investment incentives: regulation of the Finnish electricity distribution. *Energy Policy*, (34), pp. 853–862.

Knieps, G. (2005). *Wettbewerbsökonomie*. Springer, Berlin, Heidelberg, 2nd edition.

Kretschmer, T., Küpper, H.U. and Pedell, B. (2011). Bedingungen und Prinzipien einer konsistenten Regulierung. *Zeitschrift für betriebswirtschaftliche Forschung, Sonderheft*, (2), pp. 1–31.

Kridel, D., Sappington, D. and Weisman, D. (1996). The Effects of Incentive Regulation in the Telecommunications Industry: A Survey. *Journal of Regulatory Economics*, volume 9(3), pp. 269–306.

Küpper, H.U. (2008a). *Controlling*. Schäffer-Poeschel Verlag, Stuttgart, 5th edition.

Küpper, H.U. (2008b). Marktorientierte kapitaltheoretische Bestimmung kostenorientierter Entgelte für regulierte Unternehmen. In *Steuern, Steuerung, Regulierung und Prüfung*, (pp. 67–92). Altenburger, Otto, Wien.

Küpper, H.U. and Pedell, B. (2010). Betriebswirtschaftliche Grundlagen für eine marktkonforme Bestimmung der Netznutzungsentgelte im Strom- und Gasbereich. In *Berliner Kommentar zum Energierecht*, (pp. 968–996). Säcker, F.J., 2 edition.

Kurth, M. (2008). Anreizregulierung und Netzinvestitionen. *Energie, Markt, Wettbewerb*, volume 6(4), pp. 6–11.

Laffont, J. and Tirole, J. (1986). Using Cost Observation to Regulate Firms. *Journal of Political Economy*, volume 94(3), pp. 614–641.

Laffont, J. and Tirole, J. (1993). A Theory of Incentives in Procurement and Regulation. *The MIT Press, Cambridge, MA*.

Laffont, J. and Tirole, J. (2000). Competition in Telecommunications. *The MIT Press, Cambridge, MA*.

Lerner, A. (1994). *The Econimics of Control*. New York: MacMillan Co.

Liston, C. (1993). Price-Cap versus Rate-Of-Return Regulation. *Journal of Regulatory Economics*, volume 5(1), pp. 25–48.

Littlechild, S. (1983). *Regulation of British Telecommunications' profitability*. Department of Industry, London.

Macho-Stadler, I. and Pérez-Castrillo, D. (1997). *An Introduction to the Economics of Informa-*

tion. Oxford University Press, Oxford.

Maeding, S. (2009). Investment incentives in the context of revenue cap regulation. *IET Conference Publications*, (pp. 1–4).

Majd, S. and Pindyck, R. (1987). Time to Build, Option Value, and Investment Decisions. *Journal of Financial Economics*, volume 18, pp. 7–27.

Mathios, A. and Rogers, R. (1989). The impact of alternative forms of state regulation of AT&T on direct-dial, long-distance telephone rates. *RAND Journal of Economics*, (20), pp. 437–453.

Matsukawa, I. (2008). The effects of average revenue regulation on electricity transmission investment and pricing. *Energy Economics*, volume 30, pp. 696–714.

McDonald, R. and Siegel, D. (1986). The Value of Waiting to Invest. *The Quarterly Journal of Economics*, volume 101(4), pp. 707–727.

Meade, J. (1944). Price and output policy of state enterprise. *Econimic Journal*, (54), pp. 321–328.

Melody, B. (2000). *Telecommunication Reform: Principles, Policies and Regulatory Practices*. IOS Press.

Monopolkommission (2009). Strom und Gas 2009: Energiemärkte im Spannungsfeld von Politik und Wettbewerb. Sondergutachten gemäß §62 Abs. 1 EnWG. Bonn.

Moretto, M., Panteghini, P. and Scarpa, C. (2008). Profit sharing and investment by regulated utilities: A welfare analysis. *Review of Financial Econimics*, volume 17(4), pp. 315–337.

Müller, C., Growitsch, C. and Wissner, M. (2011). Regulierung, Effizienz und das Anreizdilemma bei Investitionen in intelligente Netze. *Zeitschrift für Energiewirtschaft*, volume 35(3), pp. 159–171.

Newberry, D. (2000). *Privatization, Restructuring and Regulation of Network Industries*. Cambridge, MA and London: MIT Press.

Nezlobin, A., Rajan, M. and Reichelstein, S. (2012). Dynamics of Rate of Return Regulation. *Management Science*, volume 58(5), pp. 980–995.

Nykamp, S., Andor, M. and Hurink, J. (2012). 'Standard' incentive regulation hinders the integration of renewable energy generation. *Energy Policy*, volume 47, pp. 222–237.

Oren, S., Smith, S. and Wilson, R. (1985). Capacity Pricing. *Econometrica*, volume 53(3), pp. 545–566.

Panteghini, P. and Scarpa, C. (2003). Irreversible investments and regulatory risk. *Working Paper, CESifo Working Paper Series*, (934).

Pfeiffer, T. and Schneider, G. (2007). Residual Income-Based Compensation Plans for Controlling Investment Decisions Under Sequential Private Information. *Management Science*, volume 53(3), pp. 495–507.

Pindyck, R. (1988). Irreversible Investment, Capacity Choice, and the Value of the Firm. *American Economic Review*, volume 78(5), pp. 969–985.

Pindyck, R. (1991). Irreversibility, Uncertainty, and Investment. *Journal of Economic Literature*, volume 29(3307), pp. 1110–1148.

Pindyck, R. (1993). Investments of uncertain cost. *Journal of Financial Economics*, volume 34(1), pp. 53–76.

Pindyck, R. (2007). Mandatory Unbundling and Irreversible Investment in Telecom Networks. *Review of Network Economics*, volume 6(3), pp. 274–298.

Pollitt, M. (2000). The Declining Role of the State in Infrastructure Investments in the UK. *Cambridge Working Papers in Economics*, (0001).

Pollitt, M. (2007). The Arguments For and Against Ownership Unbundling of Energy Transmission Networks. *Cambridge Working Papers in Economics*, (0737).

Rajan, M. and Reichelstein, S. (2009). Depreciation Rules and the Relation between Marginal and Historical Cost. *Journal of Accounting Research*, volume 47(3), pp. 823–865.

Rammerstorfer, M. and Nagel, T. (2009). Modeling Investment Behavior unser Price Cap Regulation. *Central European Journal for Operations Research and Economics (CEJORE)*, volume 12(2), pp. 111–119.

Ramsey, F. (1927). A contribution to the theory of taxation. *Economic Journal*, volume 37(145), pp. 47–61.

Reichelstein, S. (1997). Investment Decisions and Managerial Performance Evaluation. *Review of Accounting Studies*, volume 2(2), pp. 157–180.

Resende, M. (2000). Regulatory regimes and efficiency in US local telephony. *Oxford Economic Papers*, (52), pp. 447–470.

Rodi, M. (2009). Innovationsförderung durch ökonomische Instrumente der Umweltpolitik. In Eifert, M. and Hoffmann-Riem, W. (editors), *Innovationsfördernde Regulierung: Innovation und Recht II*, (pp. 147–168). Berlin, 2009.

Rogerson, W. (1997). Intertemporal Cost Allocation and Managerial Investment Incentives: A Theory Explaining the Use of Economic Value Added as a Performance Measure. *The Journal of Political Economy*, volume 105(4), pp. 770–795.

Rogerson, W. (2008). Intertemporal Cost Allocation and Investment Decisions. *Journal of Political Economy*, volume 116(5), pp. 931–950.

Rogerson, W. (2011). On the Relationship between Historic Cost, Forward-Looking Cost and Long Run Marginal Cost. *Review of Network Economics*, volume 10(2).

Rood, H. and te Velde, R. (2003). Investment strategies in the Netherlands. *Telecommunications Policy*, (27), pp. 701–715.

Roques, F. and Savva, N. (2009). Investment under uncertainty with priceceilings in oligopolies. *Journal of Economic Dynamic & Control*, volume 33, pp. 507–524.

Salanié, B. (1997). *The Economics of Contracts: A Primer*. The MIT Press, Cambridge.

Salinger, M. (1998). Regulating Prices to Equal Forward-Looking Costs: Cost-Based Prices of Price-Based Costs? *Journal of Regulatory Economics*, volume 14(2), pp. 149–163.

Sappington, D. (1982). Optimal regulation of research and development under imperfect information. *The Bell Journal of Econimics*, volume 13(2), pp. 354–368.

Sappington, D. (1994). Designing Incentive Regulation. *Review of Industrial Organization*, volume 9(3), pp. 245–272.

Sappington, D. (2002). Price Regulation and Incentives. In Cave, M., Majumdar, S. and Vogelsang, I. (editors), *Handbook of Telecommunications Economics*, volume I. North Holland, Amsterdam.

Sappington, D. and Stiglitz, J. (1987). Information and Regulation. In Bailey, E. (editor), *Public Regulation. New Perspectives on Institutions and Policies*. MIT Press Series on the Regulation of Economic Activity.

Schuler, R. (2012). Pricing the use of capital-intensive infrastructure over time and efficient capacity expansion: illustrations for electric transmission investment. *Journal of Regulatory Economics*, volume 41(1), pp. 80–99.

Schweizer, U. (1999). *Vertragstheorie*. Mohr Siebeck, Tübingen.

Shleifer, A. (1985). A Theory of yardstick competition. *RAND Journal of Economics*, (16), pp. 319–327.

Sidak, G. (2006). A consumer-welfare approach to network neutrality regulation of the Internet. *Journal of Competition Law and Economics*, volume 2(3), pp. 349–474.

Solomons, D. (1965). *Divisional Performance: Measurement and Control*. Homewood, IL: Irwin.

Steiner, P. (1957). Peak Loads and Efficient Pricing. *Quarterly Journal of Economics*, volume 71(4), pp. 585–610.

Stratmann, K. (2012a). Netzbetreiber fühlen sich von der Politik im Stich gelassen. *Handelsblatt*.

Stratmann, K. (2012b). Deutschland fehlen 3500 Kilometer Hochspannungsleitung. *Handelsblatt*.

Süddeutsche Zeitung (2011). Die Wut der Bosse. *Süddeutsche Zeitung vom 30.03.2011*.

Tardiff, T. (2002). Pricing Unbundled Network Elements and the FCC's TELRIC Rule: Economic and Modeling Issues. *Review of Network Economics*, volume 9(2), pp. 132–146.

Tardiff, T. and Taylor, W. (1993). Telephone Company Performance Under Alternative Forms of Regulation in the U.S. *National Economic Research Associates*.

Taylor, W., Zarkadas, C. and Zona, J. (1992). Incentive Regulation and the Diffusion of New Technology in Telecommunications. *National Economic Research Associates*.

Teisberg, E. (1993). Capital investment strategies under uncertain regulation. *RAND Journal of Economics*, volume 24(4), pp. 591–604.

Teisberg, E. (1994). An Option Valuation Analysis of Investment Choices by a Regulated Firm. *Management Science*, volume 12(5), pp. 317–348.

Train, K. (1991). *Optimal Regulation*. Cambridge, 5th edition.

Trigeorgis, L. (1996). *Real Options. Managerial Flexibility and Strategy in Resource Allocation*. Cambridge, Massachusetts.

Turvey, R. (1968). *Optimal Pricing and Investment in Electricity Supply*. Cambridge M.I.T. Press.

Übertragungsbetreiber (2012). Netzentwicklungsplan Strom 2012. 2. überarbeiteter Entwurf der Übertragungsnetzbetreiber, Berlin 2012.

Ufer, H.W., Finger, H. and Schuchardt, L. (2010). Investitionsbudgets im Rahmen der Anreizregulierung. *Zeitschrift für Planung und Unternehmenssteuerung*, volume 21(1), pp. 109–115.

Vagliasindi, M. (2004). The role of investment and regulatory reforms in the development of infrastructure across transition economies. *Utilities Policy*, volume 12(4), pp. 303–134.

VDE Association for Electrical, Electronic & Information Technologies (2008). Energy storage in power supply systems with a high share of renewable energy sources. Study of VDE Association for Electrical, Electronic & Information Technologies, Frankfurt a.M.

Vogelsang, I. (1988). Price-Cap Regulation of Telecommunications Services: A Long-Run Approach. In Crew, M. (editor), *Deregulation and Diversification of Utilities*. Boston Kluwer Academic Publishers.

Vogelsang, I. (2001). Price regulation for independent transmission companies. *Journal of Regulatory Economics*, (20), pp. 141–165.

Vogelsang, I. (2002). Incentive Regulation and Competition in Public Utility Markets: A 20-year-Perspective. *Journal of Regulatory Economics*, volume 22(1), pp. 5–27.

Vogelsang, I. (2003). Price Regulation of Access to Telecommunications Networks. *Journal of Economic Literature*, volume 41(3), pp. 830–862.

Vogelsang, I. (2006). Electricity transmission pricing and performance-based regulation. *Energy Journal*, (27), pp. 97–126.

Vogelsang, I. (2010). Incentive Regulation, Investments and Technological Change. *CESifo Working Paper No. 2964*.

Waverman, L. (1975). Peak-Load Pricing under Regulatory Constraint: A Proof of Inefficiency. *Journal of Political Economy*, volume 83(3), pp. 645–654.

Weisman, D. (2005). Price regulation and quality. *Information Economics and Policy*, volume 17(2), pp. 165–174.

Weitzman, M. (1978). Optimal Rewards for Economic Regulation. *American Economic Review*, (68), pp. 683–691.

wirkungsvoll GmbH (o.J.) (2012). Stromanbieter in Deutschland.