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INVESTMENT TIMING AND CAPACITY CHOICE UNDER RATE-OF-RETURN REGULATION FOR RENEWABLE ENERGY SUPPORT

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ABSTRACT

This study analyzes a renewable energy (RE) support scheme recently introduced in Russia and compares it to the most frequently applied policy measures, feed-in tariff (FiT) and feed-in premium (FiP) schemes. In particular, we present an analytical formulation of the problem set-up and study optimal investment timing and capacity choice employing a real options approach. In addition, we conduct detailed sensitivity analyses to highlight how different policies shape investment behavior. The contributions of this paper include modeling the Russian RE support mechanism in a dynamic programming framework that allows us to show that such a RE support design offers a strong case for transferring market risks away from the investor and has potential for a unique combination of effectiveness and cost efficiency.

Keywords: capacity mechanism, renewable energy policy, real options, dynamic programming

1. INTRODUCTION

This paper aims to present and analyze a new type of renewable energy (RE) support design that is crucially different from common schemes used worldwide. A critical trade-off for any mechanism to support emerging technologies, including RE, is to balance between policy effectiveness in technology deployment and policy cost efficiency in minimizing the resulting burden on ratepayers. Different policy types have been shown to address this trade-off differently. But is there a way to design a policy that is both effective and cost efficient simultaneously? This research investigates a support design that can potentially combine both effectiveness and cost efficiency.

Worldwide employed types of RE support instruments for non-residential projects include feed-in tariffs (FiTs), feed-in premiums (FiPs), certificate trading or renewable portfolio standards, and tendering schemes (REN21, 2017). All these types have been receiving considerable attention in the academic field (Kozlova, 2017). Comparative studies bring valuable insights on the mechanisms' relative efficiency and effectiveness. The FiT, by providing fixed payments per unit of electricity produced, totally eliminates electricity price uncertainty and is therefore the fastest in triggering new investments (Boomsma and Linnerud, 2015; Boomsma et al., 2012). Nevertheless, this mechanism does not necessarily provide cost efficiency, because of the absence of competition that pushes prices downwards, and because of the difficulty in setting the right tariff value that can lead to over- or underinvestment (Maurer and Barroso, 2011). The tradable certificates scheme leaves the definition of the RE electricity price exclusively to the market, but introduces another source of price risk, that is, the one associated with the certificates. The exposure to additional uncertainty has been shown to increase an investor's incentive to delay market entry. However, as soon as certificate prices develop in a favorable way, this scheme incentivizes larger projects (Boomsma and Linnerud, 2015; Boomsma et al., 2012) and creates a propensity to innovate (Scatasta and Mennel, 2009). A tradable certificate scheme is shown to be cost-efficient in RE promotion (Hustveit et al., 2017). FiP falls somewhere in between these two extremes (Boomsma et al., 2012), because the RE compensation consists of both a certain component (fixed premium) and an uncertain one (electricity price).

The compromise between policy effectiveness and cost efficiency can be customized by combining features of different schemes. In this vein, Kim and Lee (2012) propose two hybrid policy designs combining features of fixed-tariff and fixed-premium schemes, namely a minimum price guarantee, and a sliding premium with a cap and a floor. They conclude that policy effectiveness in RE promotion can be customized in accordance with policymakers' targets for controlling the ratepayers' burden. One can say that they have introduced a Pareto frontier of policy effectiveness and cost efficiency, along which a policymaker can pick up the most satisfying combination. An extensive RE policy study (Azuela and Barroso, 2012) concludes that a tailor-made approach is necessary, one that should reflect system and market conditions, nature and level of risks, and institutional and administrative factors. Indeed, many countries have been trying to customize RE support by adopting various modifications of the mentioned types, for example, France and Greece retained FiT only for small-scale installations and introduced FiP for larger projects, and a mix of FiT and tenders was presented in Germany and Poland (REN21, 2016).

In contrast, Russia, following its tradition of rate-of-return regulation for conventional power investments, introduced a modification of this approach to support RE (Boute, 2015). A so-called capacity mechanism aims at providing a certain return on investment, shielding its profitability from market-related factors, but promoting high project performance (Kozlova and Collan, 2016). (In this paper we use the terms 'capacity mechanism' and 'rate-of-return regulation' interchangeably.) The remuneration is designed as annuity payments to compensate investors for their capital costs per MW of planned installed capacity. Annual automatic recalculation of the subsidy captures changes in the market environment and project performance in terms of electricity production. The government sets target capacity factors, sets limits on capital costs (per MW), and sets overall capacity to be selected for each year and each type of technology supported. The projects are selected at annual auctions by the criterion of the lowest capital costs until the target capacity amount is reached. This scheme has been in force since 2013 (Government of the Russian Federation, 2013) and more than 4GW of RE power capacity have been auctioned and this capacity is to be built by 2022 (Trading System Administrator, 2017).

The capacity mechanism has received modest attention in the academic literature. Qualitative studies discuss the relevance of the idea of compensating RE investors not for electricity produced but for capacity installed (Boute, 2012) and discuss the overall policy advantages and disadvantages (Smeets, 2017). The first numerical inquiry on the effects the capacity mechanism has on RE investments highlights the capacity mechanism's ability to secure the profitability of RE investments (Kozlova and Collan, 2016; Kozlova et al., 2017). However, no study of the mechanism's generic design or its effects on investment timing and capacity choice has been done, and no comparative analysis of its design with the prominent RE support types has been undertaken so far. Such analysis would shed light on the mechanism's relative effectiveness and cost efficiency.

RE power investments are characterized by capital intensity, long payback periods, and limited operational flexibility (Kozlova, 2017; Martinez-Cesena et al., 2013). Market uncertainty, including electricity prices that affect revenues and interest rates that affect financing costs, constitutes a crucial investment risk. Subsidies represent a crucial tool in mitigating this risk. It can be considered proven practice that investments under uncertainty should be evaluated using a real options approach that, in contrast to the net present value (NPV) method, is able to correctly account for this uncertainty and capture it in the valuation (Block, 2007; Ryan and Ryan, 2002). Many studies on designing support policies opt for the investment valuation to tune the policy instruments and their effects on investors. For RE-related studies, the real options approach has commonly been used for policy analysis purposes (Kozlova, 2017). This approach allows one to analyze optimal investment timing and capacity choice in the presence of market uncertainty as well as the effect of different support instruments, features that are crucial for policy planning. In addition, many empirical studies show that the real options approach can be used to explain investors' behavior (Moel and Tufano, 2002; Fleten et al., 2017; Bulan et al., 2009; Linnerud et al., 2014).

This study adopts a real options approach to study the capacity mechanism and compare it with FiT and FiP schemes. We model a stylized RE project and derive optimal timing and capacity choice. We extend the real options framework of "Boomsma et al. (2012)" to analyze the capacity mechanism. The sensitivity analysis is conducted to highlight differences in the policies' effects. The emerging evidence from the Russian auctions further supports our findings. The focus on the rate-of-return regulation for RE support in combination with the application of the real options approach is the distinctive feature of this study.

This paper makes several contributions to the existing academic literature by (i) presenting an alternative to commonly used designs of RE support and formulating it in the real options framework, in particular by using a dynamic programming approach; (ii) finding optimal timing and capacity choice for a stylized investment under the capacity mechanism constrasting it with the FiT and FiP schemes; (iii) showing that the capacity mechanism shields investors from the electricity market risk as effectively as tariffs do; (iv) deducing from the analysis and supporting by evidence that the capacity mechanism is so far the only RE support instrument that does not influence the choice of the investment size directly, but leaves it to other reasonable considerations, such as electricity demand, land and resources availability, etc.; (v) revealing by means of sensitivity analysis the fact that the capacity mechanism offers investors' protection from interest rate volatility whereas the other schemes do not; (vi) concluding that the capacity mechanism represents also the strongest case of the ratepayers' welfare protection by reducing the subsidies automatically when technology cost drops or when higher-than-good-enough electricity production can be reached.

The following section presents the model set-up and the derivations of optimal investment timing and the size for each policy scheme. Section 3 contains a discussion of the analytical results and a sensitivity analysis. The article concludes with a discussion of policy implications, conclusions, and potential directions for further research.

2. MODELING RE INVESTMENTS

To analyze how different RE support policy designs affect investors' behavior, we introduce a stylized RE investment case, where a profit maximizing investor has the flexibility to choose investment timing and project size optimally. We then consider three different policy designs, namely, the capacity mechanism, FiT, and FiP schemes, adapting the model accordingly. The RE project earns revenues from electricity sales and/or subsidy payments that are defined differently for each design. For the FiT and FiP schemes, we use the existing model of "Boomsma et al. (2012)" with deviations described below in the Assumptions ((21)–(32) are modifications of the existing model), while the capacity mechanism is modeled by this approach for the first time ((5)–(8) and (12)–(20) are some of the contributions of this paper).

2.1. ASSUMPTIONS

Investments in RE generation projects are capital intensive. Capital costs constitute approximately 75% of the total costs (European Wind Energy Association, 2009a). In modeling RE investments, variable costs are often neglected (Fleten et al., 2007; Boomsma et al., 2012) or modeled as a part of investment costs (Boomsma and Linnerud, 2015). Investment costs, including turbine, grid connection, foundation, land, and installation costs, are dependent on installed capacity and are generally expressed in terms of cost per MW (European Wind Energy Association, 2009a). Therefore, we model capital costs $I(x)$ as a linear function of capacity installed, denoted by x

$$I(x) = Ax, \tag{1}$$

where A is capital costs per unit of capacity installed.

Hence, we assume no economies of scale with respect to capital costs in this setting as opposed to "Boomsma et al. (2012)". For transparency in comparing the schemes, the capital costs are assumed to be deterministic (International Renewable Energy Agency, 2018).

The profits of RE electricity generation projects are first of all defined by the volume of electricity production. Following the arguments presented in "Boomsma et al. (2012)", we model them as a function of capacity installed in the following way

$$Q(x) = ax^{b} \text{ with } a > 0 \text{ and } 0 < b < 1 \tag{2}$$

Here, the parameter b represents the wake effect in wind farms, which decreases electricity production because of a decrease in wind force due to the impact of neighboring turbines. In broader terms, the wake effect could be defined as deteriorating electricity production performance with increasing installed capacity in a limited space and could be generalized to other RE sources as well.

Generally, the revenue function for any power plant can be defined as electricity production times selling price. However, revenues of RE projects are also defined by the support mechanism in place. Therefore, the revenue function is formulated separately for each scheme. In case of FiT, a fixed price is paid for each unit of electricity produced; hence, the revenue function is simply the tariff FT multiplied by the production volume $Q(x)$

$$\Pi_{FiT}(x) = Q(x)FT \tag{3}$$

Under the FiP scheme, the received price consists of the uncertain electricity price S plus a fixed premium FP

$$\Pi_{FiP}(S(t); x) = Q(x)(S(t) + FP) \tag{4}$$

To define the revenue function for the capacity mechanism, the capacity payments should be formulated first. The subsidy amount is computed as an annuity based on project capital costs, plus operating costs, and minus expected revenues from electricity sales. Further, the capital cost part is corrected by a coefficient that reflects project electricity production performance. In a simplified form, assuming an infinite lifetime of the project and neglecting operating costs, the capacity payments of such a return regulation (*RR)* can be represented as

$$RR(S(t); x) = I(x)Rk(Q(x)) - Q(x)S(t) \tag{5}$$

where *R* is the return on investment provided by the subsidy,

$I(x)R$ represents the perpetual annuity payments (the core idea of the capacity mechanism),

$Q(x)S(t)$ is revenues from electricity sales,

k is the electricity production performance coefficient that depends on the production performance $(Q(x))$. k is defined as

$$k(Q(x)) = min\left(1, \frac{Q(x)}{Q_{target}}\right) \tag{6}$$

where Q_{target} is the target electricity production level set by the policy.

Here we adopt a simplified formulation of capacity payments to be able to study the capacity mechanism analytically and highlight its main features. The mechanism design realized in Russia involves more details, such as variable interest rate considerations, not continuous but stepwise defined $k(Q(x))$, a requirement to acquire local equipment and services, a correction of any change of the exchange rate for the "foreign" part of capital costs, etc. For details and practical arrangements see, for example, "Boute (2012) and Kozlova and Collan (2016)".

The total profit of the project under the capacity mechanism consists of electricity sales and capacity payments

$$\Pi_{RR}(S(t); x) = Q(x)S(t) + RR(S(t); x) \tag{7}$$

Since capacity payments are set to account for revenue from electricity sales (6), this term cancels out making total profit independent of uncertain electricity prices

$$\Pi_{RR}(x) = I(x)Rk(Q(x)) \tag{8}$$

Here we adopt a simplified design of this mechanism; however, in practice, the capacity remuneration is decreased by the fixed centrally computed revenues from electricity sales that are calculated based on the target capacity factor. If a project delivers electricity above the target, the capacity remuneration remains the same, though electricity sales revenue essentially increases.

As in "Boomsma et al. (2012)" we assume that the project-relevant (long-term) electricity price follows a geometric Brownian motion process:

$$dS(t) = S(t)\mu dt + S(t)\sigma dz(t) \tag{9}$$

Further, following the general practice of dynamic programming established in "Dixit and Pindyck (1994)" and its particular implementation for RE support analysis presented in "Boomsma et al. (2012)", we derive project and option values, optimal timing, and capacity choice for each RE support scheme.

The firm's investment problem is then solved as an optimal stopping problem using dynamic programming. Let *V* denote the value of the firm. Then, the investment problem that the firm is facing can be formalized as follows:

$$V(S) = \sup_{\tau} \max_{x} E\left[\int_{t=\tau}^{\infty} \Pi_j(S(t);x) \exp(-rt)\, dt - I(x)\exp(-r\tau) | S(0) = S\right] \tag{10}$$

where τ is the time when investment is undertaken.

2.2. RATE-OF-RETURN REGULATION

According to the Bellman equation, the return on the project (or option) is equal to instantaneous profits plus the expected appreciation of the project value

$$\rho V = \Pi + \frac{1}{dt}E(dV) \tag{11}$$

where *V* is the project (or option) value, andρ is the discount rate.

Since uncertainty in profits under the capacity mechanism is eliminated, the revenue function (9) is fully deterministic, and by design, the project value appreciation is zero. The real option value is then equal to the maximum of NPV and zero. It implies optimality of immediate investment if NPV > 0, whereas the project value upon investment is equal simply to discounted profits

$$V_{RR}(x) = I(x)k(Q(x))\frac{R}{\rho} \tag{12}$$

From this formulation, one can immediately observe that in case of sufficient electricity production performance ($k\big(Q(x)\big) = 1$), the value of the project is defined by the ratio of the provided subsidy interest rate to the actual discount rate

$$V_{RR}(x) = \begin{cases} I(x)\frac{R}{\rho}, & if\ k\big(Q(x)\big) = 1 \\ I(x)k\big(Q(x)\big)\frac{R}{\rho}, & if\ k\big(Q(x)\big) < 1 \end{cases} \tag{13}$$

The project NPV is equal to its value defined in (12) minus the investment cost

$$NPV_{RR}(x) = I(x)k\big(Q(x)\big)\frac{R}{\rho} - I(x) \tag{14}$$

or

$$NPV_{RR}(x) = I(x)\left(k\big(Q(x)\big)\frac{R}{\rho} - 1\right) \tag{15}$$

As stated above, the investment cost $I(x)$ is assumed to be deterministic. Indeed, the subsidy is calculated based on the planned investment cost declared in the auction bid. However, the actual investment cost can be different because of, for example, overspending due to a change in contractors.

$$NPV_{RR}(x) = I(x)_{planned} k\big(Q(x)\big)\frac{R}{\rho} - I(x)_{realized} \tag{16}$$

where $I(x)_{planned}$ is the stated investment cost when applying for support, and is taken into the subsidy calculation,

and $I(x)_{realized}$ is the actual realized investment cost.

Equation (16) highlights the fact that if there is unexpected overspending, the subsidy payments would not reimburse it. Nevertheless, if the realization of the investment costs coincides with the plan, $I(x)_{planned} = I(x)_{realized}$, the net payoff of a project under the capacity mechanism is defined by (15).

With respect to capacity choice, we consider two cases: first, when project electricity production performance is expected to be less than the set target and second, when it is equal to or higher than the target. The target production is defined as the target capacity factor multiplied by the installed capacity

$$Q_{target} = a_{target}x \tag{17}$$

In the first case, when project production is less than the target, $Q(x) < Q_{target}$, the coefficient (6) is equal to

$$k\big(Q(x)\big) = \frac{Q(x)}{Q_{target}} = \frac{ax^b}{a_{target}x} = \frac{a}{a_{target}}x^{b-1} \tag{18}$$

In general, optimal capacity is defined by equating the marginal present value to the marginal investment cost (Boomsma et al., 2012)

$$\frac{dV}{dx}(x^*) = \frac{dI}{dx} \tag{19}$$

Plugging in the present value (12) with the coefficient in (18) and the investment cost in (1), taking the derivative and solving for x^* we arrive at the following formulation of optimal capacity

$$x^* = \left(\frac{ab}{a_{target}}\frac{R}{\rho}\right)^{\frac{1}{1-b}} \tag{20}$$

We can conclude from (20) that the optimal capacity increases in the production function parameters *a* and *b*, and decreases in the discount rate *ρ*. In other words, the ability to reach higher electricity production by either technology or location, and a possibility of getting a lower cost of capital, incentivizes a higher installed capacity of power plants under the capacity mechanism.

In the second case, when $k\big(Q(x)\big) = 1$, the capacity term disappears when taking the derivative of the present value function (12). That leads us to conclude that in the given problem setting, an investor becomes indifferent to capacity choice if target production performance can be achieved. This indifference implies that the capacity choice will be determined by other factors, such as wind conditions, local electricity demand, grid access, and capacity, all of which shape new investments, requiring that they be practical and that they coincide with the local situation. Moreover, the same conclusion holds regardless of the type of the investment cost function.

2.3. FEED-IN TARIFF

Under the FiT scheme, the investor is not exposed to electricity price uncertainty, and therefore, the project value is simply equal to the discounted profits

$$V_{FiT}(x) = \frac{Q(x)FT}{\rho} \tag{21}$$

The NPV is therefore

$$NPV_{FiT}(x) = \frac{Q(x)FT}{\rho} - I(x) \tag{22}$$

As for the case of the capacity mechanism, there is no uncertainty in the project value, and with zero value appreciation over time, an immediate investment is optimal, if and only if NPV > 0. The optimal capacity under FiT is characterized by

$$x^* = \left(\frac{abFT}{Ar}\right)^{\frac{1}{1-b}} \tag{23}$$

As in the case with the capacity mechanism, the optimal capacity grows with higher production function parameters *a* and *b*, and with lower discount rate *ρ*. Additionally, it increases with lower marginal investment cost *A*. This is not the case for the capacity mechanism, because capacity payments compensate investors directly for their capital costs. The FiT scheme provides an incentive for larger projects when capital costs are lower. However, under the capacity mechanism, lower capital costs lead to lower subsidy payments. This feature of the capacity mechanism might lead to cost inefficiency, with investors not caring about economizing on the capital costs, since the subsidy would anyway cover them. However in reality, an upper limit is set for the marginal capital costs for each type of technology. Moreover, competition creates a downward pressure on the capital costs.

2.4. FEED-IN PREMIUM

The project revenue under a FiP scheme depends on an uncertain electricity price *S* that follows the geometric Brownian motion process with drift *μ* and volatility *σ* as stated in (9).

The value of the project is equal to the product of the electricity production and the sum of the discounted electricity price, corrected for the drift, and the FiP

$$V_{FiP}(S;x) = Q(x)\left(\frac{S}{\rho-\mu} + \frac{FP}{\rho}\right) \tag{24}$$

The net project payoff is

$$NPV_{FiP}(S;x) = Q(x)\left(\frac{S}{\rho-\mu} + \frac{FP}{\rho}\right) - I(x) \tag{25}$$

The value of the option to invest, *F*, is defined by the expectation of its appreciation with uncertain electricity prices

$$\rho F_{FiP}(S) = \frac{1}{dt}E(dF) \tag{26}$$

Applying Ito's Lemma and the boundary condition $F(0) = 0$, the option value is equal to

$$F_{FiP}(S) = BS_1^{\beta} \tag{27}$$

where β equals

$$\beta = \frac{1}{2} - \frac{\mu}{\sigma^2} + \sqrt{\left(\frac{\mu}{\sigma^2} - \frac{1}{2}\right)^2 + \frac{2\rho}{\sigma^2}} \tag{28}$$

Then the following standard boundary conditions are applied to solve for the option value, the optimal timing (i.e., the investment threshold), and the capacity choice: the value matching condition (*F = V - I*), the smooth-pasting condition (*F′ = V′ - I′*), and the capacity choice condition (19). Solving this system of equations, we arrive at the following results. The optimal capacity is equal to

$$x^* = \left(\frac{abFP}{A\rho(1+\beta(b-1))}\right)^{\frac{1}{1-b}} \tag{29}$$

Optimal timing is characterized by the threshold value

$$S^* = \frac{FP\beta(\rho-\mu)(1-b)}{\rho(1-\beta)+\rho\beta b} \tag{30}$$

where it is optimal to delay the investment for $S(t) < S^*$.

The option value is given by

$$F_{FiP}(S) = S^{\beta} \frac{a\left(\frac{abFP}{A\rho(1+\beta(b-1))}\right)^{\frac{b}{1-b}}}{\beta(\rho-\mu)\left(\frac{FP\beta(\rho-\mu)(1-b)}{\rho(1-\beta)+\rho\beta b}\right)^{\beta-1}} \tag{31}$$

And the option value upon investment with optimal capacity is equal to

$$NPV_{FiP}(S) = a\left(\frac{abS}{A(\rho-\mu)} + \frac{abFP}{A\rho}\right)^{\frac{b}{1-b}} - A\left(\frac{abS}{A(\rho-\mu)} + \frac{abFP}{A\rho}\right)^{\frac{1}{1-b}} \tag{32}$$

Details on the derivations are presented in Appendix 1.

3. RESULTS AND DISCUSSION

3.1. ANALYTICAL RESULTS

The summary of the results for each support scheme is presented in Table 1.

Table 1. Summarizing results for different support schemes

Scheme	Capacity mechanism	Feed-in tariff	Feed-in premium
Uncertainty	none	none	electricity prices
Optimal timing	immediately if NPV > 0	immediately if NPV > 0	$S^* = \left(\frac{FP}{\rho} - \frac{A}{a}x^{*1-b}\right)\frac{(\rho-\mu)\beta}{1-\beta}$
Optimal capacity	If production volume meets the target – indifference; otherwise $x^* = \left(\frac{ab}{a_{target}}\frac{R}{\rho}\right)^{\frac{1}{1-b}}$	$x^* = \left(\frac{abFT}{A\rho}\right)^{\frac{1}{1-b}}$	$x^* = \left(\frac{abFP}{A\rho(1+\beta(b-1))}\right)^{\frac{1}{1-b}}$
Total value	$F_{RR} = \max(NPV, 0)$ $NPV_{RR} = I(x)\left(k(Q(x))\frac{R}{\rho} - 1\right)$	$F_{FiT} = \max(NPV, 0)$ $NPV_{FiT}(x) = \frac{Q(x)FT}{\rho} - I(x)$	for S<S* $F_{FiP}(S) = BS^{\beta}$, otherwise $NPV_{FiP}(S;x) = Q(x)\left(\frac{S}{\rho-\mu} + \frac{FP}{\rho}\right) - I(x)$

Both the capacity mechanism and the FiT scheme eliminate market uncertainty with respect to electricity prices and make project payoffs independent of them. If electricity price uncertainty is the only source of risk perceived, there is no value in waiting.

A peculiar feature of the capacity mechanism is that it makes investors indifferent to the capacity choice in the case when a project reaches and overshoots the target production volume. This indifference implies that capacity choice is shaped by other factors. Since the Russian capacity mechanism was introduced relatively recently, and is different from commonly adopted schemes, it has not deserved investors' confidence from the beginning. The first auctions saw small bids in terms of installed capacity. However, with time and experience, investors proposed larger projects, whose sizes were determined more by practical considerations, such as chosen locations and capacity demand in the area. Indeed, evidence from the 190 projects of the first five Russian RE capacity auctions confirms this conclusion (Table 2).

Table 2. Average capacity of selected projects in Russian RE auctions, MW

Auction year	2013	2014	2015	2016	2017
Small hydro	-	7	25	-	25
Solar PV	12	15	20	-	20
Wind	15	51	35	23	38
Total average	**13**	**16**	**21**	**23**	**31**
Growth rate (to previous year)		**121%**	**138%**	**109%**	**133%**

An installed capacity of 10 to 30 MW is relatively small for an industrial-scale project. In Europe, for instance, already in 2007 the prevailing size of onshore wind projects was from 10 to 50 MW, and larger projects up to 100 MW constituted more than 10% of all projects (European Wind Energy Association, 2009b). However, as can be seen from Table 2, the average RE project size in Russia is increasing, with a growth rate of 9% to 33% from year to year, reflecting an increasing confidence in the new scheme by investors.

In case a project production level is below the target, investors have an incentive to reduce installed capacity (20). The lower the production and the higher the financing costs, the smaller the optimal project size. The same holds for the capacity choice under FiT; however, in addition, FiT creates an incentive to increase capacity if capital costs are decreasing. In other words, with the learning effect in place, FiT encourages larger sizes of RE projects. High technology learning rates require successive adjustments to the policy design that in turn increase risk exposure for stakeholders (Azuela and Barroso, 2012). In contrast, this does not hold under the capacity mechanism, since the subsidy amount reflects changes in marginal capital costs (the term A cancels out in the denominator of (20)), thereby preventing oversubsidizing in times of rapid technology development. A discussion of this issue is further developed in the sensitivity analysis section.

Under the premium scheme, investors are exposed to uncertainty with respect to electricity prices. Therefore, the timing of investment, as well as the capacity choice, depends on the current realization of the prices and on other factors that shape expectations of their future development. As concluded in "Boomsma et al. (2012)", the more uncertainty a support policy renders, the later, but larger, investments it incentivizes.

3.2. SENSITIVITY ANALYSIS

To highlight and further study the effects of the capacity mechanism on RE investment profitability, we conduct a sensitivity analysis that demonstrates similarities and differences of the three schemes. The analysis is placed in a country-independent context to emphasize differences in the support design rather than in country-specific conditions. For instance, discount rates in Russia and in the EU are different; however, we use a single numerical case to illustrate all the schemes.

For comparative purposes, we assume a base case, where the value of a 10 MW wind farm is equal under the three schemes. The base case is chosen to consider the Finnish FiT, that is, €83.5/MWh (Finnish Energy Authority, 2015), that yields a NPV of €23M for an investment of €15M. (Finland introduced high FiTs in 2010 to boost investments and to achieve RE penetration of 38% in the energy production mix by 2020.) The level of support under the other schemes is defined by equalizing project values to that of the base case. In particular, the €50.5/MWh FiP and the 12.4% guaranteed rate of return under the capacity mechanism will result in the same NPV as under the FiT scheme, ceteris paribus. Details on parameter estimates are presented in Table 3.

Table 3. Parameter estimates for the base case

Variable	Value	Source
Capacity factor	26%	Average capacity factor for wind farms in Finland in 2013 (International Energy Agency (IEA) Wind, 2013)
Production function parameter, a	2867	Estimated to provide a capacity factor of 26% with b = 0.9
Production function parameter, b	0.9	Assumption regarding the wake effect
Capital costs per MW	€1.53M/MW	Average capital costs in the EU in 2009 plus 25% of the maintenance cost (European Wind Energy Association, 2009a)
Electricity price	€30/MWh	Average 2015 electricity spot price in Finland (NordPool, 2016)
Discount rate	6%	Average RE project discount rate in Nordic countries (Grant Thornton and Clean Energy Pipeline, 2018)
Electricity price drift	0.6%	Based on the 2040 price forecast for Nordic countries (Statnett, 2016)
Guaranteed rate of return, R	12.4%	Calculated from consideration to equalize the project payoff under the capacity mechanism to the one under the FiT
Feed-in premium	€51/MWh	Calculated from consideration to equalize the project payoff under the FiP scheme to the one under FiT

The sensitivity analysis shows how the project values are affected by changing key profitability factors, namely the electricity price, electricity production, investment costs, and the discount rate (Figure 1). The analysis covers the range of the key profitability factors at ±50% of the base case. The sensitivity analysis also serves as an illustration of the model's robustness and provides justification for the chosen numerical assumptions. Nevertheless, the aim of the analysis is not to arrive at a particular crisp value characterizing the project value, but rather to understand the patterns of how the project value is affected by the key parameters under different schemes.

The project value is represented by *max(NPV,* 0*)* for the capacity mechanism and the FiT schemes, and by a combination of the option value (below the threshold price) and NPV (above the threshold price) for the FiP scheme (see Table 1). Due to a high support level, the given inputs (Table 3) lead to a low threshold price of €9/MWh for the FiP. Therefore, the sensitivity graphs display only NPVs (Figure 1), and a separate graph illustrates the option value and NPV under the FiP scheme having an optimal capacity of 200 MW (Figure 2).

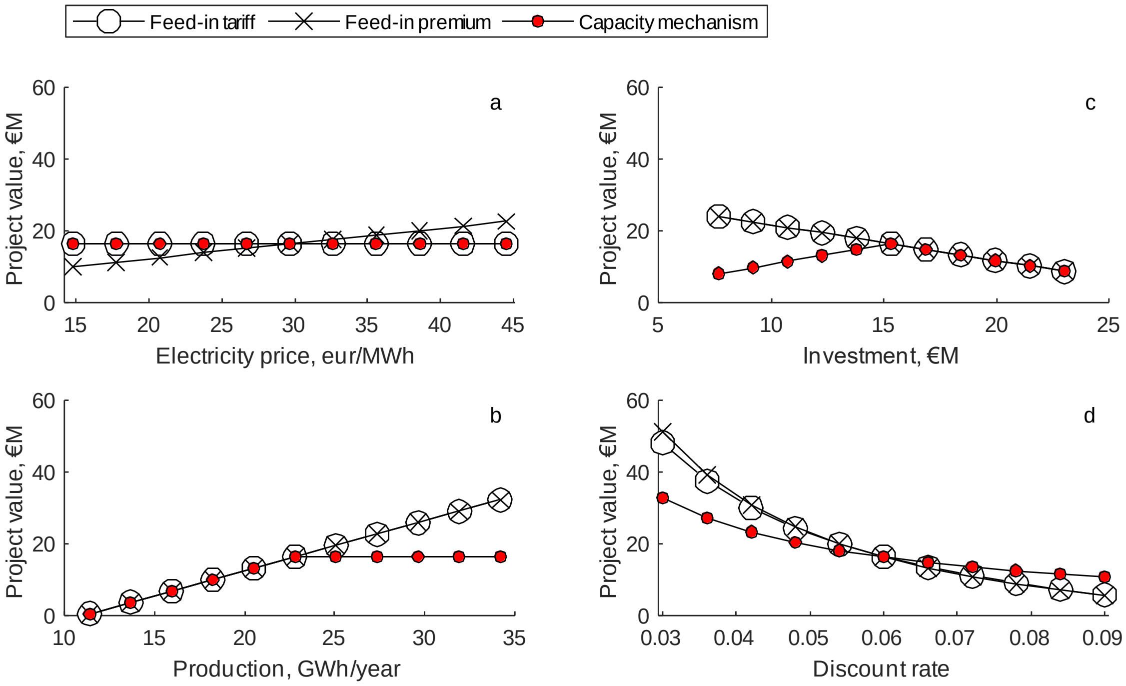

Figure 1. Sensitivity analysis of RE project payoff under the three schemes

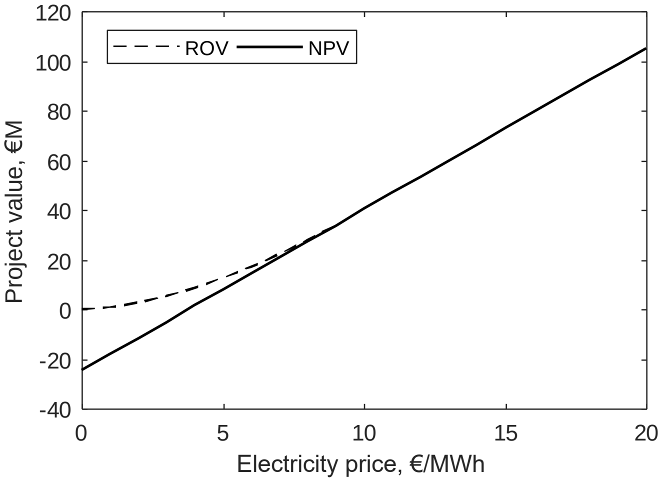

Figure 2. Real option value and NPV under the FiP scheme for optimal capacity

Naturally, project payoffs under the capacity mechanism and the FiT scheme are independent of electricity prices (Figure 1 a), and the risk in electricity market prices is eliminated for investors under these schemes. On the other hand, the premium scheme leaves investors exposed to this market risk. However, as is clear from Figure 2, the value of waiting under the FiP appears only at electricity prices substantially lower than the current price level. The FiT is argued to be the most effective scheme in terms of fast investment deployment, since it has no electricity price risk (Boomsma et al., 2012). The capacity mechanism has the same effect.

One of the crucial factors for RE project profitability is the project's electricity production. All widespread support schemes, though having different mechanisms to define the support amount, remunerate projects for the units of electricity produced (MWh). Therefore, the FiT and FiP schemes leave RE project profitability with a strong dependency on the project's production levels (Figure 1 b). In contrast, the capacity mechanism provides remuneration for a unit of capacity installed (MW). To incentivize electricity production, the subsidy amount is adjusted by the electricity production performance coefficient (6). As discussed in "Boute (2012)", this measure prevents the so-called "steel-in-the-ground" effect, whereby projects with close to zero electricity production are remunerated. The coefficient decreases the project payoff when production levels are lower, so its sensitivity (Figure 1 b) coincides with that of other schemes to the left of the base case. However, if the target production set by the policymakers (equal to the base-case production in the present analysis) is achieved, a further increase in production would not be reflected in the subsidy amount, and, hence, the project payoff under the capacity mechanism remains the same to the right of the base case. By setting the upper bound of the production volume and restricting the subsidy to reflect production beyond that bound, the capacity mechanism does not encourage project developers to strive for higher capacity factors. In practice, it equalizes locations having resource availability sufficient to achieve the target production and locations that are more preferable otherwise, reducing competition for land. Furthermore, this measure protects ratepayers from contributing to higher support expenses due to favorable locations of RE power plants. Nevertheless, setting a proper target production level is a challenge for policymakers. Too high a target would hinder the mentioned benefits, while too low a target would demotivate investors to reach higher production and would decrease the overall efficiency of the policy.

Figure 1 c illustrates the sensitivity of project NPV to investment costs. Again, the two well-known schemes, FiT and FiP, demonstrate the same obvious picture, where project payoff is linearly dependent on the investment costs, decreasing when the costs rise and vice versa. Project profitability under the capacity mechanism is affected differently by the change in investment costs. When project developers submit a bid to a RE capacity auction, they have to specify the planned investment costs. The capacity price is calculated based on this stated planned figure (5). The lower the stated planned investment costs, the lower the subsidy received by a project (though the return on investment remains the same (Kozlova et al., 2017)). This lower subsidy essentially demotivates investors to reduce expenses. However, the limit on capital expenditures is set by policymakers, such that bids with capital costs higher than the limit are discarded from the auction. This limit is different for different commercialization years that difference reflects technology learning. Additionally, the project's capital cost is the key competitive parameter in the auction, where projects with lower capital costs win the right to receive the subsidy; therefore, this competition is expected to impose a downward pressure on the capital costs.

For the sensitivity analysis, we assume that in the base case, the investment costs are equal to the capital cost limit €1.53M (set by the capacity mechanism) and the increase of the investment costs represents the situation when there is an actual overspending compared to the planned costs. The sensitivity line to the right of the base case is obtained from (16) where the subsidy payment remains the same but the realized costs increase. Such an assumption makes the change in the project payoff under the capacity mechanism equal to the change under the other schemes (Figure 1 c). The higher the investment costs, the lower the project profitability under unchanged subsidy payments. This effect incentivizes investors to reduce costs as much as possible. The same fact becomes the reason to defer investment if the costs are subject to uncertainty because of raw material prices (Boomsma et al., 2012) or technology learning effects (Lin and Wesseh Jr, 2013; Martinez-Cesena et al., 2013).

To the left of the base case, Figure 1 c, we refer to the decrease in the planned investment cost for the case of the capacity mechanism. When lower capital costs are stated in the bid, the capacity price reflects this change, thereby diminishing project profitability. Here we demonstrate a crucial feature of the capacity mechanism: it prevents oversubsidizing when technology costs decline. Since capacity prices are calculated with the purpose to provide a certain return on investment, when investment costs decrease the same guaranteed return would result in lower subsidy payments and consequently in lower NPV. In theory, such an effect shields ratepayers from a rapid decrease of RE technology costs. On the other hand, an unchanging return on investment and a deteriorating NPV are a strong demotivation for investors to submit bids having lower capital costs. This conclusion is supported by the evidence from the first experience of this scheme's implementation in Russia, where investors tend to submit bids having planned capital costs equal to the set limit. As for the target production, setting an appropriate capital cost limit is an important issue, since too strict a limit would make it impossible for investors to participate in the auction, whereas too loose a limit could lead to oversubsidizing. Indeed, the low number of bids in the wind category in Russia, due to the strict initially set capital cost limits, forced policymakers to reconsider this requirement and to introduce amendments to the policy that would lower the capital cost limit for wind projects (Government of the Russian Federation, 2015). This and other barriers in the first steps of implementing the new RE policy in Russia are discussed in "Kozlova and Collan (2016)".

Considering the capital intensity of RE investments and their long payback periods, it is essential to model investors' cost of capital according to market interest rates. The higher interest rates can affect the profitability of the project through either increased floating rate debt expenses or increased shareholders' required return on investment. Sensitivity to the discount rate is shown in Figure 1 d. Apparently, higher discount rate lowers project profitability, because higher financing costs reduce projects' payoffs. However, the magnitude of this effect is different for the three schemes. The capacity mechanism provides the lowest response to discount rate changes. In this analysis, we simplify the definition of the capacity payment definition to a simple annuity of investment costs. In practice, it is realized as a variable rate annuity that automatically adjusts to a changing local base rate every year. This automatic adjustment completely shields investors under the capacity mechanism from the interest rate risk and this shielding becomes especially beneficial in a volatile market of an emerging economy. The other schemes do not offer such security to investors. However, this phenomenon raises the question about adequate risk transfer. Shielding investors from the interest rate risk automatically transfers it to ratepayers, who will suffer from relatively heavier subsidization in times of high interest rates. In Russia, even though the local interest rates were very volatile in past years, the overall consumer capacity price was not much affected, because few such projects existed.

Another aspect of the interest rate risk is the extra burden on ratepayers in situations when market interest rates are lower. Under FiT and FiP schemes, NPVs skyrocket from €16M at 6% to about €50M at 3% (Figure 1 d). This visualization sheds light on the reasons behind massive retrospective changes in RE policies (European Renewable Energies Federation, 2013). The capacity mechanism in this analysis doubles the project payoff because of stylized modeling; however, as pointed out above, the capacity payments can be designed to entirely offset the interest rate influence on project NPV. To sum up, the capacity mechanism's design can potentially be as effective as the design of the FiT scheme and simultaneously more cost efficient than the designs of any of the analyzed schemes.

The sensitivity analysis has also been performed for the certificate trading scheme. However, with an assumption of uncorrelated electricity and certificate prices, the project value sensitivity did not provide any additional insight to this analysis.

4. CONCLUSION

This paper presents an alternative to commonly used RE support schemes, the capacity mechanism, recently implemented in Russia. The idea behind the capacity mechanism is to apply rate-of-return regulation to RE support. We adopt a real options framework to analyze optimal investment timing and capacity choice under the capacity mechanism in comparison with the FiT and the FiP schemes. The sensitivity analysis highlights similarities and differences of the capacity mechanism. The results shed light on the effects the capacity mechanism has on RE investments, in particular its influence on the optimal project size. That influence is, to the best of our knowledge, analyzed for the first time in the academic literature.

In support of previous modeling results (Kozlova and Collan, 2016; Kozlova et al., 2017), this study shows that the capacity mechanism, as well as the FiT scheme, shields RE investment profitability from electricity price fluctuations. It is also shown that the capacity mechanism provides less interest rate risk than the other instruments do. However, this feature falls under the risk transfer issue, who to burden in times of high interest rates – ratepayers or investors? This choice must be made by policymakers. Nevertheless, the capacity mechanism has more welfare considerations than other support tools do when it comes to electricity production performance and general technology cost reduction. The subsidy remains the same for projects with production above the policy target, shielding ratepayers from remunerating better than "good enough" electricity production performance. Automatic reduction of the subsidy amount with decreasing technology costs eliminates oversubsidizing in the presence of high technology learning rates. Though these policy features provide questionable incentives for technology development in terms of both cost reduction and efficiency increase, they might be appealing to policymakers in an economy with ratepayers' welfare as a priority. Finally, the capacity choice under the capacity mechanism, as opposed to the other support instruments reviewed here, is independent of the marginal capital costs. In other words, while other schemes incentivize larger projects because of falling technology costs, investors under the capacity mechanism remain indifferent to this driver and the project size is determined by practical considerations and presumably reflects investors' confidence in the support instrument. This conclusion is supported by the emerging evidence from the Russian market.

The rate-of-return regulation for RE support therefore represents a unique potential combination of policy effectiveness (in RE promotion) and cost efficiency. Its risk reduction capability for investors is comparable with that of the FiT scheme, and it can be very cost efficient from the overall system's and ratepayers' respective perspectives. The welfare-oriented elements include not subsidizing higher than the target production and automatic subsidy adjustment to decreasing capital costs. Additionally, the indifference of investors to capacity choice, in particular its independence from marginal capital costs, makes such a design sustainably welfare-oriented in the presence of rapid technology development. The disadvantages of the rate-of-return oriented design include its complexity, which impairs investors' confidence and could slow down market entry. Also, policymakers need to carefully set the electricity production target and the capital cost limit to ensure proper incentives. The features of the rate-of-return regulation that lead to its effectiveness in shielding investors from market risks and to its cost efficiency in limiting ratepayers' burden are of interest to policymakers and investors.

Although practical implementation of the capacity mechanism in Russia has its drawbacks (Smeets, 2017), the general logic of the rate-of-return regulation could possibly be integrated into other schemes. A relevant idea for further research is to create a tool for customizing RE support to the needs of the particular economy that could combine features of different existing schemes and, thus, promote investments in a desirable way. Another important direction for the future research is to incorporate the uncertainty in technology cost development into the model to analyze how the capacity mechanism could handle rapid technology development.

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Appendix 1. Derivations

Capacity mechanism

Total profit under the capacity mechanism consists of electricity sales and capacity payments

$$\Pi_{RR}(S(t);x) = Q(x)S(t) + \ RR(S(t);x)$$

where $Q(x)$ is electricity production volume,
$S(t)$ is market electricity price assumed to follow GBM,
$RR(S(t);x)$ is capacity payments.

Capacity payments are defined as an annuity of investment costs (perpetuity is assumed) multiplied by the electricity production performance coefficient and diminished on the revenues from electricity sales

$$RR(S(t);x) = I(x)Rk(Q(x)) - Q(x)S(t)$$

where *R* is the return on investment provided by the subsidy,
$k(Q(x))$ is electricity production performance coefficient defined as

$$k(Q(x)) = min\left(1, \frac{Q(x)}{Q_{target}}\right)$$

Therefore, revenues from electricity sales cancel out from the total profit definition

$$\Pi_{RR}(x) = I(x)Rk(Q(x))$$

According to Bellman equation return on the project is equal to instantaneous profits plus expected appreciation of project value

$$\rho V = \Pi + \frac{1}{dt}E(dV)$$

where *V* is project or option value, and
ρ is discount rate.

Uncertainty of electricity prices development does not affect the project value, therefore expectation of its appreciation, as well as the option value, is equal to 0.

The project value upon investment is equal to discounted profits

$$\rho V_{RR}(x) = I(x)k\big(Q(x)\big)R + 0$$

$$V_{RR}(x) = I(x)k(Q(x))\frac{R}{\rho}$$

NPV is equal to its value minus investment cost

$$NPV_{RR}(x) = I(x)k\big(Q(x)\big)\frac{R}{\rho} - I(x)$$

$$NPV_{RR}(x) = I(x)\left(k\big(Q(x)\big)\frac{R}{\rho} - 1\right)$$

And if realized investment cost differs from the planned stated for the capacity remuneration, NPV becomes

$$NPV_{RR}(x) = I(x)_{planned}k\big(Q(x)\big)\frac{R}{\rho} - I(x)_{realized}$$

Optimal capacity is generally defined (Boomsma et al., 2012) as

$$\frac{dV}{dx}(x^*) = \frac{dI}{dx}$$

For the capacity mechanism, the optimal capacity would depend from whether project electricity production performance is expected to meet the target on not. The target production is defined as target capacity factor multiplied by the installed capacity

$$Q_{target} = a_{target}x$$

If project production is less than the target one, the $k(Q(x))$ is less than one and equal to

$$k\big(Q(x)\big) = \frac{Q(x)}{Q_{target}} = \frac{ax^b}{a_{target}x} = \frac{a}{a_{target}}x^{b-1}$$

Having $I(x) = Ax$, the project value becomes

$$V_{RR}(x) = Ax\frac{R}{\rho}\frac{a}{a_{target}}x^{b-1} = \frac{AaRx^b}{\rho a_{target}}$$

Finding the optimal capacity

$$\frac{dV_{RR}}{dx}(x^*) = \frac{AaRbx^{*b-1}}{\rho a_{target}}$$

$$\frac{dI}{dx} = A$$

$$\frac{AaRbx^{*b-1}}{\rho a_{target}} = A$$

$$x^* = \left(\frac{ab}{a_{target}}\frac{R}{\rho}\right)^{\frac{1}{1-b}}$$

If the target production is met, or $k\big(Q(x)\big) = 1$, then

$$V_{RR}(x) = Ax\frac{R}{\rho}$$

and its derivative is independent of x

$$\frac{dV_{RR}}{dx}(x^*) = \frac{AR}{\rho}$$

implying that the investor becomes indifferent to capacity choice.

Feed-in tariff

The revenue function under FiT is

$$\Pi_{FiT}(x) = Q(x)FT$$

Again, there is no electricity price uncertainty, therefore the expectation of project value appreciation and the option value are 0. Upon investment the project value and the NPV are

$$V_{FiT}(x) = \frac{Q(x)FT}{\rho}$$

$$NPV_{FiT}(x) = \frac{Q(x)FT}{\rho} - I(x)$$

Finding optimal capacity

$$V_{FiT}(x) = \frac{ax^bFT}{\rho}$$

$$\frac{dV_{FiT}}{dx}(x^*) = \frac{abFTx^{*b-1}}{\rho}$$
$$x^* = \left(\frac{abFT}{A\rho}\right)^{\frac{1}{1-b}}$$

Feed-in premium

Under the FiP scheme, the received price consists of uncertain electricity price S_1 and a fixed premium FP

$$\Pi_{FiP}(S(t);x) = Q(x)(S(t) + FP)$$

Applying Ito's Lemma for the expectation of project appreciation, we can find the project value from the following equation

$$\frac{1}{2}\frac{\partial^2 V_{FiP}}{\partial S^2}S^2\sigma^2 + \frac{\partial V_{FiP}}{\partial S}S\mu - \rho V_{FiP} + Q(x)S + Q(x)FP = 0$$

The guess for particular solution is of the form

$$V_{FiP}(S) = aS + b$$
$$V_{FiP}{}'(S) = a$$
$$V_{FiP}{}''(S) = 0$$

Plugging it into the previous equation

$$aS\mu - \rho aS - \rho b + Q(x)S(t) + Q(x)FP = 0$$
$$S(a\mu - \rho a + Q(x)) - \rho b + Q(x)FP = 0$$
$$a\mu - \rho a + Q(x) = 0, \quad or \quad -\rho b + Q(x)FP = 0$$
$$a = \frac{Q(x)}{\rho - \mu}, \quad b = \frac{Q(x)FP}{\rho}$$

The total solution is therefore

$$V_{FiP}(S,x) = \beta_1 S^{\alpha_1} + \beta_2 S^{\alpha_2} + \frac{Q(x)S}{\rho - \mu} + \frac{Q(x)FP}{\rho}$$

After eliminating the speculative bubble ($\beta_1 = 0$), and making eligible the requirement $V(0) = 0$ ($\beta_2 = 0$), we arrive at

$$V_{FiP}(S,x) = \frac{Q(x)S}{\rho - \mu} + \frac{Q(x)FP}{\rho}$$
$$V_{FiP}(S,x) = Q(x)\left(\frac{S}{\rho - \mu} + \frac{FP}{\rho}\right)$$

And so the net project payoff is

$$NPV_{FiP}(S;x) = Q(x)\left(\frac{S}{\rho - \mu} + \frac{FP}{\rho}\right) - I(x)$$

The option value is defined by the expectation of its appreciation

$$\rho F_{FiP}(S) = \frac{1}{dt}E(dF_{FiP})$$

Applying Ito's Lemma

$$\frac{1}{2}\frac{\partial^2 F_{FiP}}{\partial S^2}S^2\sigma^2 + \frac{\partial F_{FiP}}{\partial S}S\mu - \rho F_{FiP}(S) = 0$$

Matching the requirement $F(0) = 0$, the option value is

$$F_{FiP}(S) = BS^{\beta}$$

where β is a positive root of the fundamental quadratic

$$\frac{1}{2}\sigma^2 V^2 F''(V) + \alpha V F'(V) - \rho F = 0$$

$$\frac{1}{2}\sigma^2 \beta(\beta - 1) + \alpha\beta - \rho = 0$$

$$\frac{1}{2}\sigma^2 \beta^2 + \beta(\alpha - \frac{1}{2}\sigma^2) - \rho = 0$$

$$\beta = \frac{\frac{1}{2}\sigma^2 - \alpha}{\sigma^2} \pm \sqrt{\frac{\left(\alpha - \frac{1}{2}\sigma^2\right)^2 + 2\sigma^2\rho}{\sigma^2}}$$

$$\beta = \frac{1}{2} - \frac{\mu}{\sigma^2} + \sqrt{\left(\frac{\mu}{\sigma^2} - \frac{1}{2}\right)^2 + \frac{2\rho}{\sigma^2}}$$

Finding optimal capacity

$$V_{FiP}(S,x) = ax^b\left(\frac{S}{\rho - \mu} + \frac{FP}{\rho}\right)$$

$$V'_{FiP}(S,x) = abx^{b-1}\left(\frac{S}{\rho - \mu} + \frac{FP}{\rho}\right)$$

$$\frac{dV}{dx}(x^*) = \frac{dI}{dx}$$

$$abx^{*b-1}\left(\frac{S}{\rho - \mu} + \frac{FP}{\rho}\right) = A$$

$$x^* = \left(\frac{ab\left(\frac{S}{\rho - \mu} + \frac{FP}{\rho}\right)}{A}\right)^{\frac{1}{1-b}} = \left(\frac{abS}{A(\rho - \mu)} + \frac{abFP}{A\rho}\right)^{\frac{1}{1-b}}$$

The optimal timing is defined from the boundary conditions
value-matching condition (*VM*)

$$F = V - I$$

and smooth-pasting condition (*SP*)

$$F'(S) = V'(S) - I'(S)$$

These conditions correspondingly for the FiP are

$$BS^{*\beta} = ax^{*b}\frac{S^*}{\rho - \mu} + ax^{*b}\frac{FP}{\rho} - Ax^*$$

$$\beta BS^{*\beta-1} = \frac{ax^{*b}}{\rho - \mu}$$

It can be seen that

$$\beta\, VM = S^*\, SP$$

$$\beta ax^{*b}\frac{S^*}{\rho - \mu_1} + \beta ax^{*b}\frac{FP}{\rho} - \beta Ax^* = \frac{S^* ax^{*b}}{\rho - \mu_1}$$

$$S^*\left(\frac{\beta ax^{*b}}{\rho - \mu} - \frac{ax^{*b}}{\rho - \mu}\right) = \beta Ax^* - \beta ax^{*b}\frac{FP}{\rho}$$

$$S^* \frac{ax^{*b}(\beta-1)}{\rho-\mu} = \beta A x^* - \beta a x^{*b}\frac{FP}{\rho}$$

$$S^* = \frac{\left(\beta A x^* - \beta a x^{*b}\frac{FP}{\rho}\right)(\rho-\mu)}{ax^{*b}(\beta-1)}$$

Simplifying S^* we arrive at

$$S^* = \left(\frac{FP}{\rho} - \frac{A}{a}x^{*1-b}\right)\frac{(\rho-\mu)\beta}{1-\beta}$$

From VM condition

$$x^{*1-b} = \frac{ab\left(\frac{S}{\rho-\mu}+\frac{FP}{\rho}\right)}{A}$$

Plugging x^{1-b} into S^* and simplifying, we arrive at the independent-of-capacity optimal price formulation

$$S^* = \frac{FP\beta(\rho-\mu)(1-b)}{\rho(1-\beta)+\rho\beta b}$$

Plugging S^* into the optimal capacity formulation

$$x^* = \left(\frac{abFP}{A\rho(1+\beta(b-1))}\right)^{\frac{1}{1-b}}$$

From the SP condition

$$B = \frac{ax^{*b}}{(\rho-\mu)\beta S^{*\beta-1}}$$

Plugging x^* and S^*

$$B = \frac{a\left(\frac{abFP}{A\rho(1+\beta(b-1))}\right)^{\frac{b}{1-b}}}{\beta(\rho-\mu)\left(\frac{FP\beta(\rho-\mu)(1-b)}{\rho(1-\beta)+\rho\beta b}\right)^{\beta-1}}$$

Therefore, the option value is

$$F_{FiP}(S) = S^\beta \frac{a\left(\frac{abFP}{A\rho(1+\beta(b-1))}\right)^{\frac{b}{1-b}}}{\beta(\rho-\mu)\left(\frac{FP\beta(\rho-\mu)(1-b)}{\rho(1-\beta)+\rho\beta b}\right)^{\beta-1}}$$

And the option value upon investment with optimal capacity is

$$NPV_{FiP}(S) = a\left(\frac{abS}{A(\rho-\mu)}+\frac{abFP}{A\rho}\right)^{\frac{b}{1-b}} - A\left(\frac{abS}{A(\rho-\mu)}+\frac{abFP}{A\rho}\right)^{\frac{1}{1-b}}$$