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Summary

We analyze the optimal investment strategy of a monopolist which has subscribed a concession contract to provide a public utility, i.e. water service. We present a strategic model in which a monopolist chooses both the timing of the investment and the capacity. We focus not only on the value of the immediate investment, but rather on the value of the investment opportunity. We then extend the model to two interdependent projects, where investing in the first project provides the opportunity to acquire the benefits of the new investment by making a new outlay. We show that flexibility to defer an investment may generate, ceteris paribus, additional profits which may induce positive effects in terms of policy and consumers surplus.

Keywords: Irreversible investment, Flexibility to defer, Capacity expansion choice

JEL Classification: D81, G31, L95

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1 Introduction

In recent years water sector reforms have concentrated on involving the private sector in the operation and management of water utilities. In Italy following the promulgation of Law 36/94, known as Legge Galli, an attempt has been made to open up the water service sector to competition in order to guarantee efficiency in production and management of the resource (declared to be scarce).[1] The increase in the opportunity cost of investments devoted to the provision of public services has induced the Government to promote the involvement of private firms in the production of water services. The aim is to capture new financial resources and reduce the inefficiency which has characterized the public production of water services up to now (Dosi and Muraro, 2003). Unlike what has happened in telecommunications where technological innovations eroding some monopolistic aspects have introduced competition into the sector, the structural and technical characteristics of the water sector constrain the legislator to promote efficiency through "competition for the market" (Muraro and Rebba, 2003).[2] [3] In other words the private firms interested in provision of the water service compete to be entitled to a contract which gives them the right to produce, operate and manage the water utilities for a certain period of time. Under Law n° 36/94 the legislator establishes a separation between water resource planning and the operation of water utilities. The resource planning is assigned to the local water authority (ATO)[4] which, in turn, assigns the operation to a private provider which will be selected via an auction

[1] See Muraro (2003).

[2] It is not reasonable to construct parallel pipelines to distribute drinking water and collect wastewater. An exception is represented by common carriage competition in Great Britain (Webb and Ehrhardt, 1998), where several water utilities compete for customers using a single set of pipes. This solution might be adopted for providing the service to big industrial users but it is difficult to implement for domestic users because of the existence of strong economies of scale and scope (Dosi and Muraro, 2003).

[3] The water sector is characterized by some constraints related to the nature of the resource itself and to technological and physical features of the infrastructures (i.e. water flows by gravity in the network). These put some limitations on network interconnections and provision of the service on a large scale.

[4] The Galli Law establishes new local water authorities (ATOs), whose borders are set by the Italian Regions. As an example of their jurisdiction consider that in Veneto Region there are 8 local water authorities. The ATO are now taking over control functions which were previously state-run (decentralization). Generally speaking the term ATO refers to both the water authority and the area where the authority operates. When the reform is accomplished, only one private firm will operate in each ATO.

mechanism. The ATO sets the price (tariff)[5] cap for the water utilities (including aqueduct systems, sewerage systems and treatment plants). Furthermore, the ATO draws up the "Piano d'Ambito" (a 30 year plan) which includes the timing and level of infrastructure investments, and ensures that the provider fulfills the contract requirements.

In this specific case, the "Piano d'Ambito" sets out the typology and timing of the investments the provider has to make, ruling out any managerial flexibility. Designers and planners choose among different alternative technical solutions (e.g. ground water vs. river basin abstraction, branching pipe systems vs. interconnected pipe systems, etc.) and make capital budgeting decisions according to the Net Present Value (NPV) rule.

Nevertheless, a wide range of feasible alternative technical solutions exists from which designers and planners can choose as regards operation and management of the infrastructures making up the system. Technological innovations lead to the construction of more complex systems characterized by a high operational flexibility. It is quite common today to design "integrated" aqueduct systems (namely vertical integrated systems with several interconnections between the network infrastructures) which can be expanded by sequential or modularized investments (Zanovello, 1977). Such systems can easily be modified over time in order to meet the requirements of facing and adapting to changes in the state variables (e.g. average day demand, number of users, input costs, adoption of new technologies, etc.). Moreover the interconnection and integration between supply sources enables the system to handle crisis in the provision of the service caused, for example, by pollution emergencies or peaks in day demand curves.

This flexibility, arising from technical aspects, has an economic value, which is strongly related to the provider's "ability" to decide whether and when it is optimal to invest. That is, a firm which has the possibility to decide whether and when it is optimal to invest is holding something like a financial (call) option. By deciding to exploit this "opportunity", the firm exercises its (real) option and consequently pays an opportunity cost which becomes part of the investment costs.

In recent years, following early papers by Brennan and Schwartz (1985), McDonald and Siegel (1985, 1986), Majd and Pindyck (1987) and Paddock *et al.* (1988), there has been an increasing production of literature concerning

[5] The Law n° 36/94 defines a new pricing mechanism. The tariff determined on the basis of "Metodo Tariffario Normalizzato" (ex. Lege: "Decreto del Ministero dell'Ambiente e del Territorio I° agosto 1996") introduces a price cap regulation which guarantees at the same time ex-post full recovery of the service costs and an "adequate" capital rate of return (Moretto and Valbonesi, 2003).

applications of the real option approach to investment decisions in varied industrial sectors.[6] Teisberg (1993) and Saphores *et al.* (2004) apply the real option approach to regulated firms in the energy sector, while Teisberg (1994), Trigeorgis (1996) and Childs and Triantis (1999) are among the few interested in the analysis of multi-stage investments in R&D. Nevertheless, these contributions do not refer to interdependent projects concerned with different capacity levels to be realized by regulated firms.[7]

This paper is a first attempt to apply real option results to capital budgeting in the water service as a regulated sector. We present a simple model to value the flexibility of aqueduct systems. The aqueduct systems are characterized by a high degree of technological and operational flexibility and, among the water utility infrastructures, are the ones which require higher irreversible sunk costs.[8] In particular our aim is to show that managerial and technical flexibility might turn out to be economically relevant in the case the "Piano d'Ambito" gives to the provider the option to strategically decide when to invest.[9] We also correct the option value to take into account that the length of concession contracts is generally shorter than plants' useful life. Finally we investigate the effects of flexibility on consumer surplus and tariff reduction.

The paper is organized as follows. The next section presents a simplified model to value the flexibility to defer investments. Section 3 deals with investment decisions in capacity expansion (i.e. a water abstraction plant) and investigates the profitability of devising interdependent projects to face uncertain future demand. Section 4 illustrates the concluding remarks.

[6] See also Dixit and Pindyck (1994) and Trigeorgis (1996) for a systematic treatment of the real option approach.

[7] Interdependent projects differ from multi-stage projects because in order to generate a stream of profits they do not require an earlier investment-installment cost to acquire a subsequent option to continue operating the project until the next installment becomes due (see Trigeorgis, 1996, Chapter 4).

[8] 61% of the total turnover of the water service sector industry is represented by profits coming from the production and distribution of water (in 1999 it was equal to 3.85 billion Euros). The 2002 report to the Italian Parliament on the state of the art of the water sector and accomplishment of the reform laid down by the Galli Law points out the need for huge investments (15.78 Euros per year per capita) in the aqueduct system in order to improve the efficiency of existing infrastructures, search for new catchment areas and springs and construct new plants.

[9] However the supply of the service is obligatory.

2 The model

The aim of this section is to show how flexibility can be valued with reference to plants for the production of drinking water. To emphasize the role of flexibility embedded in water production plants, we introduce some simplifying assumptions in order to obtain a close form solution for the investment's value.[10]

Conventional capital budgeting techniques and in particular the NPV rule fail to capture the strategic impact of projects and the additional value deriving from the opportunity to delay an investment decision. The NPV rule gives a measure of an investment's profitability according to a now-or-never proposition, that is if the investor does not make the investment now, he will lose the opportunity forever. A project whose NPV is negative or equal to zero, though, might have a positive NPV in the future. Similarly a project whose NPV is positive might have an even greater NPV in the future. Therefore the NPV rule does not take into consideration the opportunity cost to delay the investment. By deciding to make an expenditure for an irreversible investment the investor gives up the possibility of waiting for new information that might affect the desirability or the timing of the investment itself should market conditions change adversely. This opportunity cost might be relevant in the water service sector where only a private firm has the right to make the investment. The ability to defer an irreversible investment expenditure might profoundly affect the decision to invest.

The real option approach, first proposed by Myers (1977), Kester (1984) and McDonald and Siegel (1986)[11], establishes a theoretical framework which permits introduction into the valuation model of the flexibility to postpone investments, whose value is not captured by NPV. In other words the real option approach provides the decision-maker with a tool to address the issues of irreversibility, uncertainty and timing, drawing the valuation procedures from the body of knowledge developed for financial options during the past decades.

The investor with an opportunity to invest is holding something like a financial call option where the investment project is the underlying asset, the

[10] We believe that the adoption of more sophisticated models which can be solved only by means of numerical methods would not give any additional value to the analysis and would not make any improvment in the quality of the results, owing to the quality of information the ATOs and the providers have at their disposal while awaiting the reform (Law 36/94) to be accomplished soon.

[11] To learn about the theory of the real option approach and for an overview of recent developments, see Dixit and Pindyck (1994) and Trigeorgis (1996).

investment costs represent the strike price and the expiry of the concession contract is the upper bound of the call option's maturity time.

2.1 An investment in capacity expansion

We use a simplified version of the model proposed by McDonald and Siegel (1986). In particular:

1. The investment project A is a large-scale project which generates, once installed, an instantaneous profit flow equal to:

$$\Pi_t^A = \Pi_t(X^A)$$

   where X^A is the project's dimension (expressed in m^3).

2. The project lifetime is T_u, i.e. at T_u the salvage value is zero.

3. Π_t evolves over time according to a geometric Brownian motion with instantaneous expected return $\mu \geq 0$ and instantaneous volatility $\sigma > 0$

$$d\Pi_t^A = \mu \Pi_t^A dt + \sigma \Pi_t^A dz_t \quad \text{with } \Pi_0^A = \Pi^A \tag{1}$$

   where dz_t is the increment of a standard Brownian process with mean zero and variance dt (i.e. $E(dz_t) = 0$ and $E(dz_t^2) = dt$). From (1) we get $E(\Pi_t^A \mid \Pi^A) = \Pi^A e^{\mu t}$, therefore μ represents the expected cash flow growth rate.

4. Investment in project A entails a sunk capital cost I^A.

5. The investment exercise time is τ.

Since the investment project we are analyzing (aqueduct system) is not traded in limited supply for investment purposes by many investors it is not considered a traded asset. Therefore its expected rate of return μ falls below the equilibrium total expected rate of return, say $\hat{\mu}$, required in the market by investors from an equivalent-risk traded financial security. The resulting rate of return shortfall $\delta \equiv \hat{\mu} - \mu > 0$ (i.e. the difference between the equilibrium expected return on a similar traded financial security and the actual project drift, μ, on the non-traded asset) represents the opportunity cost (in annuity terms) to invest at time zero, i.e. it is analogous to a constant "dividend" yield.[12] Furthermore, since the equivalent traded financial

[12] In complete markets we can hypotesize the existence of a traded asset that maintains the same price as Π^A while it pays a constant dividend yield δ, with $\widehat{\mu} - \delta = \mu$ (see McDonald and Siegel, 1984; Cox, Ingersoll and Ross, 1985).

security must satisfy the asset price equilibrium relationship $\hat{\mu} = r + RP$, where r is the risk-free rate and RP is the risk premium, we can write the expected risk-adjusted rate of return of the project as $\mu - RP = r - \delta$ where $r - \delta$ will be referred to hereafter as the cost of carry.

This is the basis of the risk-neutral valuation approach proposed by Cox and Ross (1976) and Harrison and Kreps (1979), in which the actual growth rate μ is replaced with a risk-neutral equivalent drift $r - \delta$. That is, the adjustment is analogous to discounting certainty-equivalent cash flows at the risk-free rate, so that we can rewrite (1) in the following form:

$$d\Pi_t^A = (r - \delta)\Pi_t^A dt + \sigma \Pi_t^A dz_t \qquad \Pi_0^A = \Pi^A \tag{2}$$

Hence, given the current value of Π_t^A, the market value of the project can be evaluated as the expected present value of discounted cash flows using equivalent risk-neutral probabilities and the risk-free interest rate (Cox and Ross, 1976; Harrison and Kreps, 1979):

$$V^A(\Pi^A) = E_t \left\{ \int_0^{T_u} e^{-rt} \Pi_t^A dt \right\} \equiv \frac{\Pi^A(X^A)}{\delta}(1 - e^{-\delta T_u}) \tag{3}$$

where E denotes the expectation operator under the risk neutral probability measure. Since V^A is a multiple of Π^A it is also driven by a geometric Brownian motion with the same parameters $r - \delta$ and σ, i.e.:

$$dV_t^A = (r - \delta)V_t^A dt + \sigma V_t^A dz_t, \quad V_0^A = V^A \tag{4}$$

This means that the analysis could be replicated using the present value as the state variable. Hereinafter we may take V_t^A as the primitive exogenous state variable for the regulatory process. The above assumptions make the project's value of the opportunity to invest (Extended Net Present Value) analogous to a European call option on a constant dividend-paying asset (the plant), i.e.:

$$F^A(V_t^A, t) = E_t \left\{ e^{-r(\tau - t)} \max \left(V_\tau^A - I^A, 0 \right) \right\}$$

where τ is the expiration date and V_τ^A is the project value at time τ.

Imposing a non-arbitrage condition, the extended net present value $F^A(V_t, t)$ can be obtained as the solution of the following second order differential equation (Black and Scholes, 1973; Merton, 1973):

$$\frac{1}{2}\sigma^2 (V^A)^2 F_{VV}^A + (r - \delta)(V^A) F_V^A - rF^A - F_t^A = 0 \tag{5}$$

subject to the terminal condition:

$$F^A(V_\tau^A, \tau) = \max[(V_\tau^A - I^A)^+, 0] \tag{6}$$

and to the boundary conditions:

$$F^A(0,t) = 0 \qquad \text{and} \qquad \lim_{V^A \to \infty} F^A(V_t^A, t)/V_t^A = 1 \tag{7}$$

The solution of (5) is given by the well-known formula derived by Black and Scholes (1973):

$$F^A(V_t^A, t) = e^{-\delta(\tau - t)}\Phi(d_1)V_t^A - e^{-r(\tau-t)}\Phi(d_2)I^A \tag{8}$$

where:

$$d_1(V_t^A) = \frac{\ln(V_t^A/I^A) + (r - \delta + \sigma^2/2)(\tau - t)}{\sigma\sqrt{\tau - t}}, \quad d_2(V_t^A) = d_1(V_t^A) - \sigma\sqrt{\tau - t}$$

and $\Phi(\cdot)$ is the cumulative standard normal distribution function.

So far we have implicitly assumed that the firm can exploit the profits generated by the project for its entire lifetime, once it is realized. However, concession contracts have a limited length, around 30 years, generally shorter than the project lifetime. Therefore it is necessary to add, at least, two more assumptions to take into account the limited contract life. In particular:

7. The concession contract lasts for T_c years, so that $\tau \leq T_c < T_u$.

8. The salvage value is given by:

$$S = I^A e^{-\xi(T_c - \tau)/\tau}$$

Then, by assumption 7 in order to calculate the asset value we must consider the operating life (i.e. economic life) of the project instead of its useful life (i.e. technical life). Consequently whenever the provider decides to defer the investment, he reduces the time over which he can gain profits by running the plant. Assumption 8, simply assume a salvage value as a % of the replacement cost. This % depreciates at rate ξ over the remaining years to the end of the concession. Therefore if the firm invests at $\tau = 0$ the salvage value is obviously equal to zero but if the firm invests close to the end of the concession, $\tau = T_c$, the salvage value coincides the replacement cost.

The actual value of the project turns out to be less than (3) and equals to:

$$V^A(\Pi^A) = E\left\{\int_0^{T_c-\tau} e^{-rt}\Pi_t^A dt + e^{-r(T_c-\tau)}S\right\} \equiv \frac{\Pi^A(X^A)}{\delta}(1-e^{-\delta(T_c-\tau)}) + I^A e^{-(r+\frac{\xi}{\tau})(T_c-\tau)} \quad (9)$$

Since (9) tends to zero when τ tends to T_c, condition (6) has to be substituted by:[13]

$$\lim_{\tau\to T_c} F^A(V_\tau^A,\tau) = \lim_{\tau\to T_c} \max[(V_\tau^A - \hat{I}^A)^+, 0] = 0 \quad (10)$$

where $\hat{I}^A = I^A(1-e^{-(r+\frac{\xi}{\tau})(T_c-\tau)})$.

2.2 Interdependent projects

Interdependent projects can be considered as a portfolio of growth options. We extend the above benchmark case of a single indivisible project assuming that the provider has the possibility of choosing between two alternative projects A and B of different scales. With respect to the assumptions previously introduced we add:

1. Project A is equal to the one described in the previous section, while project B is larger in scale and generates, once installed, an instantaneous profit flow equal to $\Pi_t^B(X^B)$ with $X^B > X^A$.

2. The cash flow is simplified into a linear function as:

$$\Pi_t^B(X^B) = \pi_t X^B \qquad \Pi_t^A(X^A) = \pi_t X^A$$

   where π_t is the instantaneous profit per cubic meter (m^3) equal for both the projects and described by the following geometric Brownian motion:

$$d\pi_t = (r-\delta)\pi_t dt + \sigma\pi_t dz_t \qquad \pi_0 = \pi$$

   where $r - \delta \geq 0$ is the instantaneous risk-adjusted expected rate of return and $\sigma > 0$ is the instantaneous volatility.

[13] Brennan and Schwartz (1985) introduce a similar boundary condition. Their analysis, though, do not take into account the reduction in the asset value, because in their case the contract lease does not provide for any limitations on the number of years for which the resource can be exploited.

3. Investment in projects A and B entails sunk capital costs I^A and I^B respectively, with $I^B > I^B$.

4. The investor can operate only one project at a time and the investment is constrained to be sequential, with investment A occurring before B.

5. Finally, for the sake of simplicity, we assume that for both projects the expiration time is infinite.

The last two assumptions require some further comments. Firstly, since the investment is sequential, the private firm can always invest in the smaller scale project and subsequently invest in the bigger scale one, incorporating the former into the latter by paying an additional cost. Moreover, an infinite expiration time appears to be non-restrictive referring to aqueduct systems whose lifetime is very long. This implies that we can assume $T_c = T_u = T$.

Hence, the market value of the project B can be evaluated as the expected present value of its discounted cash flows.

$$V^B(\pi) = E\left\{\int_0^T e^{-rt}\Pi_t^B dt\right\} = \frac{\pi X^B}{\delta}(1 - e^{-\delta T}) \tag{11}$$

Now, contrary to what has been done in the previous section, while determining the market value of project A we must take into account that once A is installed, it is optimal to switch to project B whenever the instantaneous profit π becomes large enough. In particular, we can express $V^A(\pi)$ as

$$V^A(\pi) = \max_{\tau^*} E\left\{\int_0^{\tau^*} e^{-rt}\Pi_t^A ds + e^{-r\tau^*}\left(V^B(\pi_{\tau^*}) - I^B\right)\right\} \tag{12}$$

where τ^* is the optimal switching time from A to B.

It is easy to check that the solution to problem (12) is to switch from A to B as soon as π exceeds the critical threshold π^*_{AB} (see Appendix A):[14]

$$\pi^*_{AB} = \frac{\alpha}{\alpha - 1}\delta\frac{I^B}{(X^B - X^A)(1 - e^{-\delta T})} \tag{13}$$

[14] The switching rule (13) can be rewritten as follows:

$$V^B(\pi^*_{AB}) - \nu^A(\pi^*_{AB}) = \frac{\alpha}{\alpha - 1}I^B$$

where $\nu^A(\pi^*_{AB}) = \frac{\pi X^A}{\delta}(1 - e^{-\delta T})$ represents the value of project A when there is no option to switch.

where $\alpha \equiv \frac{1}{2} - \frac{r-\delta}{\sigma^2} + \sqrt{\left(\frac{1}{2} - \frac{r-\delta}{\sigma^2}\right)^2 + \frac{2r}{\sigma^2}} > 1$. Moreover, the project's market value turns out to be:

$$V^A(\pi) = \begin{cases} \frac{\pi X^A}{\delta}(1 - e^{-\delta T}) + \left(\frac{\pi}{\pi^*_{AB}}\right)^\alpha \frac{I^B}{\alpha - 1} & \text{if} \quad \pi \leq \pi^*_{AB} \\ \\ \frac{\pi X^B}{\delta}(1 - e^{-\delta T}) - I^B & \text{if} \quad \pi > \pi^*_{AB} \end{cases} \tag{14}$$

Some comments on (14) are necessary. It is worth pointing out that for $\pi \in (0, \infty)$ $V^A(\pi) \leq V^B(\pi)$. The two functions coincide if and only if $\pi = 0$, while for $\pi \in [\pi^*_{AB}, \infty)$ $V^A(\pi) - V^B(\pi) = -I^B$. In other words the current value of project B's expected cash flows is always greater than A's, also taking into consideration the value of the opportunity to switch, eventually, from A to B at cost I^B.

In order to determine under which conditions it is optimal to proceed with sequential investments, let's consider the opportunity to invest in project A, which entails the option to switch subsequently to project B. For each $t \leq \infty$, this is equivalent to solving the following problem:

$$F^A(\pi_t) = \max_{\tau^*} E_t \left\{ e^{-r(\tau^* - t)} \left(V^A(\pi_{\tau^*}) - I^A \right) \right\} \tag{15}$$

By (14) the expression for $V^A(\pi_{\tau^*})$ is non-linear in π, therefore there is a discontinuity in the threshold π^*_A beyond which it is optimal to invest in project A. This threshold is given by (see Appendix B):

$$\pi^*_A = \begin{cases} \frac{\alpha}{\alpha - 1} \delta \frac{I^A}{X^A(1 - e^{-\delta T})} & \text{if} \quad \frac{X^B}{X^A} - 1 < \frac{I^B}{I^A} \\ \\ \frac{\alpha}{\alpha - 1} \delta \frac{I^B + I^A}{X^B(1 - e^{-\delta T})} & \text{if} \quad \frac{X^B}{X^A} - 1 \geq \frac{I^B}{I^A} \end{cases} \tag{16}$$

The first expression shows that $\pi^*_A < \pi^*_{AB}$ therefore it is optimal to invest first in project A and then to wait until the instantaneous profit exceeds π^*_{AB} to invest in project B incorporating A. By analyzing (16), investment in A is myopic: it occurs as if the option of ultimately switching to B were not present, that is $\nu^A(\pi^*_A) = \frac{\pi^*_A X^A (1 - e^{-\delta T})}{\delta} = \frac{\alpha}{\alpha - 1} I^A$.

On the contrary when $\pi^*_A \geq \pi^*_{AB}$ it is optimal to invest in both the projects simultaneously and, therefore, proceed directly with the implementation of B.

3 The value of flexibility to invest in an aqueduct system

3.1 The case of a water abstraction plant

With reference to the previous section let's suppose, as an example, that the "Piano d'Ambito" plans an investment capacity expansion due to an increase in water demand (i.e. number of users) or an increase in water supply (i.e. average day demand per capita). In order to meet the requirements the provider could choose between two different alternative projects: a) buy the volume X necessary to provide the water service to the new users via another private firm (alternative O), it being allowed by the law; b) construct a new water abstraction plant (well field)[15] designed on the basis of volume X (alternative A).

Since the price of trading water among ATO is established by the regulator according to solidarity and fairness criteria, we can form the hypothesis that the expected Net Present Value of this alternative is zero, that is $NPV^O = 0$.

Alternative A consists of: a) well field (3 wells); b) pumping station; c) treatment plant; d) storage system (capacity equal to 10,000 m^3); e) treatment plant; f) electrical system for the equipment installed. The treatment plant includes a filtration process on Granular Activated Carbon (GAC) and the storage system includes disinfection and chlorination procedures.[16] In fact groundwater extraction guarantees the provision of good quality water, which does not need highly specific treatment to meet the regulations for drinking water standards.

The project's useful life T_u is equal to 50 years and the system guarantees a water provision of about 300 l/s (equivalent to 9,460,800 $m^3/year$) but it is subject to water losses in the network i ranging from 20 to 30%. We assume that the plant's construction and installment costs are not time-dependent and amount to about 3,500,000 Euros.

We evaluate the flexibility of waiting to invest in project A, by treating the opportunity to defer the investment as a European Call Option. As it has already been pointed out, the discounted expected cash flows represent

[15] A well field is the sinking of several moderately sized boreholes, spaced apart in some pattern, their yields being collected together. This system is used in order to develop a good yield from an area where a single well could not be expected to guarantee a large enough yield.

[16] For a more detailed overview of technical solutions, technologies and design criteria see Hammer (1993) and Twort *et al.* (2000).

the current value of the asset and the investment cost I^A represents the exercise price of the option. Assuming profit is a linear function of the dimension X^A, profit at time t can be written as:

$$\Pi_t^A = R_t^A(1-i)X^A - C_t^A X^A \tag{17}$$

where R_t^A are the revenues per cubic meter at time t; C_t^A are operating costs (including maintenance costs) per cubic meter0 at time t; X^A is the plant dimension; i are the volume losses in the network. We also make the following simplifying assumptions:

1. Revenues are deterministic and we draw their value using projections of water price and demand estimated by the ATO on the basis of the "Metodo Tariffario Normalizzato"over the entire concession period.

2. The operating costs[17] (sum of production, maintenance and running costs) [18] are a random variable following a geometric Brownian motion with a growth rate $r-\delta$ and volatility σ:

$$dC_t = (r-\delta)C_t dt + \sigma C_t dz_t$$

3. The risk-free discount rate r is known, deterministic and not time-dependent.

4. Revenues can be discounted at the constant risk-free rate r, the number of users (consumers) being certain over time (Brennan and Schwartz, 1985).

5. The discounted value of the project's future cash flows is a good approximation of the present value of the asset.

6. The project's salvage value at the end of its lifetime is zero.

[17]Variable costs, in particular the expenditure for chemicals used in water treatment (chlorination) and energy (pumping plant), are the most relevant ones as regards an abstraction plant consisting of wells. In this case the expenditure for chemicals is non-significant when compared with energy costs and can therefore be ignored. The price of energy is likely to follow an exogenous diffusive and geometric stochastic process.

[18]Fixed costs for running the plant are generally estimated as a percentage of operating costs (20-30%) and vary significantly depending on the management and the organization of the firm running the service.

Recalling (3), the value of the project is:[19]

$$
\begin{aligned}
V^A &= E\left[\int_0^{T_u} (e^{-rt}(1-i)R_t^A - e^{-rt}C_t^A)X^A dt\right] \\
&= \left[\frac{(1-i)R^A}{r}\left(1-e^{rT_u}\right) - \frac{C^A}{\delta}(1-e^{-\delta T_u})\right]X^A
\end{aligned}
\tag{18}
$$

Estimates of costs, revenues and other variables were derived from discussions with water industry experts. Table 1 shows estimates of the project's technical and economic parameters (e.g. dimension, project life, investment cost, etc.).

X^A (m^3/s)	0.300
I^A $(Euro)$	$3,500,000$
T_u $(years)$	50
$C^A(Euro/m^3)^*$	0.13
R^A $(Euro/m^3)^{**}$	0.30
i	20% 30%
δ	1% 2% 3% 4%
r^{***}	5%
σ^{****}	30% 40%

Table 1: Summary information for alternative A.

*Designers and industry experts interviewed agree on estimating the average operational costs of this type of plant at

[19] Water service experts use an expected rate of return (WACC) $\hat{\mu}$ equal to 7%. This value is the capital rate of return provided for by Law 36/94 and subsequent implementation decrees. In this case (18) should be written as:

$$V^A = E\left[\int_0^{T} (e^{-rt}(1-i)R_t^A - e^{-\hat{\mu}t}C_t^A)X^A dt\right]$$

where the cost growth rate is μ. Obviously the two expressions for the project's value are equivalent.

around 0.13 Euro/m^3. The average has been calculated over a distribution.

**Revenues per cubic meter have been determined by a statistical analysis performed over a distribution whose parameters have been estimated on the basis of the average tariff paid by users for the provision of drinking water.

***The risk-free rate is assumed to be equal to the rate of return of stated-owned bonds.

****Variance has been estimated considering analogous investment projects realized in the past, whose operating costs were known throughout the project life. A scenario analysis was conducted to prove the consistency of these estimates which can be considered representative for this kind of plant.

If the private firm can decide at time $\tau = 3, 5, 10$ years to proceed or not with the investment, the Extended Net Present Value of the projects can be determined using (8). Tables 2 and 3 display the results. The value of the flexibility to defer the investment (that is the difference between the Extended Net Present Value, F^A, and the Net Present Value, NPV^A) decreases for increasing values of δ and increasing exercise time of the option.

Let's consider first the case where $\sigma = 30\%$, $i = 20\%$ and $\delta = 2\%$. Project A whose NPV^A is negative ($NPV^A = -700$ thousands of Euros) might have a positive NPV^A in the future (e.g. F^A=1.100 thousands of Euros when $\tau = 10$). Therefore, the optimal strategy is to delay the investment. On the contrary, everything else being equal and assuming $i = 30\%$, project A has such a highly negative NPV^A that is never profitable either to invest or wait to invest.

Let's now consider the case where $\sigma = 30\%$ and $\delta = 3\%$. Assuming $i = 20\%$, F^A is less than the corresponding NPV^A, therefore there is no advantage in deferring the investment and the provider should start construction immediately. On the contrary, assuming $i = 30\%$, F^A is greater than the corresponding NPV^A and consequently it is expedient to delay the investment.

In all other cases (i.e. $\delta = 4\%$ and $i = 20 - 30\%$) the option value is not high enough to suggest waiting to invest, therefore the optimal investment strategy is to start construction immediately.

Finally, comparing Table 2 and Table 3 it is easily demonstrated that for increasing values of σ the Extended Net Present Value of the project increases and consequently the option value of deferring the investment increases.

		τ							
		NPV		F^A					
		0		3		5		10	
		i=20%	i=30%	i=20%	i=30%	i=20%	i=30%	i=20%	i=30%
δ	2%	-700	-5,900	400	-	600	-	900	-
	3%	6,300	1,100	6,000	1,500	5,800	1,600	5,300	1,800
	4%	11,600	6,400	10,400	5,800	9,600	5,400	8,100	4,700

Table 2: NPV^A and F^A for $\sigma = 30\%$ and different expiration times of the option.

		τ							
		NPV^A		F^A					
		0		3		5		10	
		i=20%	i=30%	i=20%	i=30%	i=20%	i=30%	i=20%	i=30%
δ	2%	-700	-5,900	600	-	800	-	1,100	-
	3%	6,300	1,100	6,100	1,700	5,900	1,900	5,500	2,000
	4%	11,600	6,400	10,500	5,900	9,700	5,600	8,300	5,000

Table 3: NPV^A and F^A for $\sigma = 40\%$ and different expiration times of the option.

As already mentioned in section 2.1, the literature on the estimate of Extended Net Present Value in regulated industrial sectors does not consider that in general the length of concession is shorter than the project lifetime. This results in an over-estimation of the current value of the asset and a consequent distortion in the option value.

For example, in the above case we assumed that the private firm has the possibility of making profits throughout the useful life of the project, but usually concession contracts last for about 30 years. Therefore in determining the asset's present value we have to take into consideration the plant's operating life (economic life, $T_c = 30$ years) instead of its useful life (technical life, $T_u = 50$ years). Consequently, by exercising the option to defer the investment, the private firm reduces the period of time over which it can make profits from running the plant and then it reduces the expected revenue cash flow. In the light of these considerations the present value of the project should be given by (9) including a salvage value.

Nevertheless, since the Galli Law does not make an explicit reference to the procedures to be used to guarantee the firm an amount of money corresponding to the asset's salvage value and the formula adopted to determine the water tariff ("Metodo Tariffario Normalizzato") already includes some form of the depreciation allowances, we maintain here the assumption of salvage value equal to zero.[20] The present value of the project is now:

$$\begin{aligned} V^A &= E\left[\int_0^{T_c-\tau} e^{-rt}[(1-i)R_t^A - C_t^A]X^A dt\right] = \\ &= \left[\frac{(1-i)R^A}{r}\left(1-e^{r(T_c-\tau)}\right) - \frac{C^A}{\delta}(1-e^{-\delta(T_c-\tau)})\right] X^A \end{aligned}$$

while the formula for evaluating its Extended Net Present Value (8) does not vary.

Analyzing the results obtained assuming $\sigma = 30\%$ and 40% and $i = 20\%$ (illustrated in Figure 1 and 2 respectively) we find that, everything else being equal, the value of flexibility increases as σ increases but, as it has been previously shown, it decreases when δ increases. It is also worth noting that when τ is equal to zero the Extended Net Present Value, F^A, and the conventional Net Present Value, NPV^A, coincide. In particular when τ is equal to 30 years (i.e. when the concession contract ceases) the Extended Net Present Value of the asset is zero. The option value to delay represents the opportunity cost of waiting to invest (Figure 3 and 4).

Let's consider, as an example, the scenario characterized by $\sigma = 30\%$, $\delta = 2\%$. In this case the Net Present Value of the project is $NPV^A = 4,000,000$ Euros. The extended NPV has a maximum for $\tau = 9$ and it is about $F^A = 4,970,000$ Euros (Figure 1). Therefore the firm's opportunity cost to invest by waiting 9 years is approximately $970,000$ Euros or, put differently, the Net Present Value of investing today is $NPV^A - F^A = 4,000,000 - 4,970,000 = -970,000$, i.e. the NPV of investing today which includes the opportunity cost is negative.

[20] This assumption seems to be non-restrictive at least for one more reason. The capital depreciation functions are generally of hyperbolic type (Mauer and Ott, 1995) with an estimated rate of depreciation ξ substantially high. Nevertheless, introducing a salvage value in the valuation model would not substantially modify the results obtained as regards the NPV and the Extended Net Present Value. Under the hypothesis of the salvage value being equal to zero we obtain a cautious estimate of the flexibility value.

Figure 1:
F^A assuming $\sigma = 30\%$ and $i = 20\%$ (in thousands of Euros).
Figure 2:
F^A assuming $\sigma = 40\%$ and $i = 20\%$ (in thousands of Euros).
Figure 3:
Opportunity cost to defer the investment assuming $\sigma = 30\%$ and $i = 20\%$ (in thousands of Euros).
Figure 4:
Opportunity cost to defer the investment assuming $\sigma = 40\%$ and $i = 20\%$ (in thousands of Euros).

The analysis of flexibility could have interesting effects in terms of policy and consumer surplus (i.e. tariff reduction). The possibility of delaying investment decisions may induce the firm to bid more aggressively in order to win the concession race (Muraro, 2002). For example assuming water losses in the network equal to 20% and $\sigma = 30\%$, the value of flexibility has a maximum for $\tau = 15$ and $\tau = 9$ years for $\delta = 1\%$ and $\delta = 2\%$ respectively (Figure 1). For these reference cases the potential tariff reductions are displayed in Table 5.[21]

	$\tau_{\vert \max F^A}$	ΔR
$\delta = 1\%$	15 years	28%
$\delta = 2\%$	9 years	4%

Table 5: Maximum tariff reduction assuming $\sigma = 30\%$.

3.2 The case of interdependent projects

Most of the investments occurring in the water service sector and in particular investments in aqueduct systems offer a wide range of choice between alternative technical solutions. In fact the planners can combine the single plants and elements making up the system in several different ways in order to guarantee greater operational flexibility (D'Alpaos, 2003). It is quite common today to design complex aqueduct systems which can be expanded by sequential or modularized investments. Such systems can easily be modified over time in order to meet the requirements of facing and adapting to changes in the state variables (e.g. future demand, number of users, input cost increments, adoption of new technologies, etc.). This flexibility arising from technical aspects has an economic value.

[21] Assuming $\delta = 1\%$ the NPV^A is negative, therefore we determined the tariff reduction assuming a Net Present Value equal to zero as the benchmark.

As an example let's consider a firm's need to invest in capacity expansion in order to face uncertain future growth in demand and suppose it has the opportunity of proceeding with sequential investments, whose characteristics are analogous to those of alternative A described in section 4.1. Assuming that the firm can switch from a smaller scale project to a bigger scale one by paying an additional cost. The costs related to different discharge values are displayed in Table 4.

	Discharge (l/s)				
	300	900	1,200	1,500	2,100
I (*Euro* 10^3)	3,500	7,100	9,400	12,200	15,000

Table 4: Plant costs depending on different discharge values.

By using (13) and (16) we can obtain the thresholds on the basis of which we evaluate the profitability of proceeding or not with a sequential investment, with the investment in A occurring before B. The results of the simulations we performed for different discharge values assuming $i = 20\%$ and $\sigma = 30\%$ are shown in Table 5 and 6.

The results clearly show the importance of scale economies in investment decisions related to capacity expansion.[22] When the dimension of project A is equal to 300 l/s and the dimension of B is equal to 900 l/s, assuming $\delta = 2\%$ and $\delta = 4\%$, the optimal investment strategy consists in investing first in A and then switching to B as soon as the instantaneous profit π becomes greater than the threshold π^*_{AB}. Everything else being equal, when the dimension of project B is equal to or greater than 1200 l/s it is always optimal to invest in the bigger scale project, i.e. the condition $\pi^*_{AB} > \pi^*_A$ is satisfied. Assuming that project A is designed for a discharge value greater than or equal to 900 l/s the optimal strategy consists in undertaking sequential investments.

Moreover, since the condition $\pi_0 = 0.8 \cdot 0.3 - 0.13 < \pi^*_A$ always obtains, whenever it is optimal to invest in sequential investments, it is more profitable to start constructing A (there is no time lag on A) and wait to invest in project B (Table 5 and 6).

[22] Generally, in fact, the section of the supply network and distribution network are sized on the basis of the average day demand thanks to the possibility of constructing reservoirs. Construction costs, furthermore, depend on the length of the pipes according to a virtually linear law. In this regard, see the study carried out by Venturi *et al.* (1970) on estimate of the construction cost functions in parametric form for various types of plant.

Analogous considerations can be made taking into account the results shown in Tables 7 and 8 assuming $\sigma = 40\%$, $i = 20\%$ and value losses of δ equal to 2% and 4% respectively. Everything else being equal, the trigger π^*_{AB} increases when σ increases.

	Discharge (l/s)			
	900	1200	1500	2100
300	$\pi^*_{AB} = 0.111$ $\pi^*_A = 0.108$	$\pi^*_{AB} = 0.097$ $\pi^*_A = 0.100$	$\pi^*_{AB} = 0.094$ $\pi^*_A = 0.097$	$\pi^*_{AB} = 0.077$ $\pi^*_A = 0.082$
900		$\pi^*_{AB} = 0.290$ $\pi^*_A = 0.072$	$\pi^*_{AB} = 0.188$ $\pi^*_A = 0.072$	$\pi^*_{AB} = 0.116$ $\pi^*_A = 0.072$
1200			$\pi^*_{AB} = 0.377$ $\pi^*_A = 0.073$	$\pi^*_{AB} = 0.155$ $\pi^*_A = 0.073$
1500				$\pi^*_{AB} = 0.272$ $\pi^*_A = 0.075$

Table 5: Optimal trigger assuming $\delta = 2\%$ and $\sigma = 30\%$.

	Discharge (l/s)			
	900	1200	1500	2100
300	$\pi^*_{AB} = 0.079$ $\pi^*_A = 0.078$	$\pi^*_{AB} = 0.070$ $\pi^*_A = 0.072$	$\pi^*_{AB} = 0.068$ $\pi^*_A = 0.070$	$\pi^*_{AB} = 0.056$ $\pi^*_A = 0.059$
900		$\pi^*_{AB} = 0.210$ $\pi^*_A = 0.053$	$\pi^*_{AB} = 0.136$ $\pi^*_A = 0.053$	$\pi^*_{AB} = 0.084$ $\pi^*_A = 0.053$
1200			$\pi^*_{AB} = 0.377$ $\pi^*_A = 0.052$	$\pi^*_{AB} = 0.155$ $\pi^*_A = 0.052$
1500				$\pi^*_{AB} = 0.167$ $\pi^*_A = 0.054$

Table 6: Optimal trigger assuming $\delta = 4\%$ and $\sigma = 30\%$.

	Discharge (l/s)			
	900	1200	1500	2100
300	$\pi^*_{AB} = 0.149$ $\pi^*_A = 0.147$	$\pi^*_{AB} = 0.131$ $\pi^*_A = 0.135$	$\pi^*_{AB} = 0.128$ $\pi^*_A = 0.131$	$\pi^*_{AB} = 0.105$ $\pi^*_A = 0.111$
900		$\pi^*_{AB} = 0.394$ $\pi^*_A = 0.099$	$\pi^*_{AB} = 0.255$ $\pi^*_A = 0.099$	$\pi^*_{AB} = 0.157$ $\pi^*_A = 0.099$
1200			$\pi^*_{AB} = 0.517$ $\pi^*_A = 0.098$	$\pi^*_{AB} = 0.209$ $\pi^*_A = 0.098$
1500				$\pi^*_{AB} = 0.314$ $\pi^*_A = 0.102$

Table 7: Optimal trigger assuming $\delta = 2\%$ and $\sigma = 40\%$.

	Discharge (l/s)			
	900	1200	1500	2100
300	$\pi^*_{AB} = 0.106$ $\pi^*_{A} = 0.104$	$\pi^*_{AB} = 0.093$ $\pi^*_{A} = 0.096$	$\pi^*_{AB} = 0.091$ $\pi^*_{A} = 0.093$	$\pi^*_{AB} = 0.074$ $\pi^*_{A} = 0.079$
900		$\pi^*_{AB} = 0.280$ $\pi^*_{A} = 0.070$	$\pi^*_{AB} = 0.181$ $\pi^*_{A} = 0.070$	$\pi^*_{AB} = 0.112$ $\pi^*_{A} = 0.070$
1200			$\pi^*_{AB} = 0.363$ $\pi^*_{A} = 0.070$	$\pi^*_{AB} = 0.149$ $\pi^*_{A} = 0.070$
1500				$\pi^*_{AB} = 0.233$ $\pi^*_{A} = 0.073$

Table 8: Optimal trigger assuming $\delta = 4\%$ and $\sigma = 40\%$.

4 Final remarks

In this paper we propose an option approach to evaluate the strategic value of flexibility to defer investment decisions in the Italian water service sector. We show how some technical flexibility might turn into managerial flexibility which has a substantial economic value.

The value of flexibility might be beneficial for the consumers. In fact if the provider can choose whether and when it is optimal to invest, he might bid more aggressively offering a lower tariff.

A Appendix

Within the range of π where it is non-optimal to invest in the larger scale project, the value of alternative A can be obtained as the solution of the following second order differential equation (Dixit and Pindyck, 1994):

$$\frac{1}{2}\sigma^2 \pi^2 V^A_{\pi\pi} + (r-\delta)\pi V^A_\pi - rV^A + \Pi^A = 0 \tag{19}$$

subject to the following boundary conditions (*value matching condition* and *smooth pasting condition*):

$$V^A(\pi^*_{AB}) = V^B(\pi^*_{AB}) - I^B \quad \text{and} \quad V^A_\pi(\pi^*_{AB}) = V^B_\pi(\pi^*_{AB}), \tag{20}$$

The optimal timing to switch from A to B turns out to be:

$$\tau^*_{AB} = \min(t \geq 0 \mid V^A(\pi^*_{AB}) = V^B(\pi^*_{AB}) - I^B). \tag{21}$$

The general solution of equation (19) can be written as:

$$V^A(\pi) = K_1\pi^\alpha + K_2\pi^\beta + v^A(\pi) \tag{22a}$$

where $1 < \alpha < r/(r-\delta)$, $\beta < 0$ are respectively the positive and negative root of the characteristic equation $\Psi(x) = \frac{1}{2}\sigma^2 x(x-1) + (r-\delta)x - r = 0$, and K_1, K_2 are two constants to be determined. The first two terms in (22a) represent the solution of the homogeneous equation, while the third term represents a particular solution. As particular solution we take the expected discounted value $v^A(\pi)$ of the benefits that project A generates in the absence of the option to switch to project B (Harrison 1985, page 44):

$$v^A(\pi) = E\left\{\int_0^T e^{-rt}\Pi^A_t dt\right\} = \frac{\Pi^A}{\delta}(1 - e^{-\delta T}) \tag{23}$$

To make sure $v^A(\pi)$ is positive we assume $\delta > 0$. Finally, in order to have a finite value for $V^A(\pi)$ when π gets very small, we set $K_2 = 0$ (i.e. $\lim_{\pi\to 0} V^A(\pi) = 0$). Therefore the general solution can be re-written in the following form:

$$V^A(\pi) = K_1\pi^\alpha + \frac{\Pi^A}{\delta}(1 - e^{-\delta T}) \tag{24}$$

Finally, since $K_1\pi^\alpha$ represents the correction we have to impose on the value of project A by the option to switch to B in the future, the constant K_1 must necessarily be positive. We obtain K_1 and π^*_{AB} by imposing the boundary conditions (20).

B Appendix

Unlike what happens when dealing with the European Call Option, to evaluate a perpetual option we use a differential equation which is not time-dependent.

Considering project A, the solution of (15) can be obtained by solving the following second order differential equation (McDonald and Siegel 1986; Dixit and Pindyck, 1994):

$$\frac{1}{2}\sigma^2\ \pi^2 F^A_{\pi\pi} + (r-\delta)\pi F^A_\pi - rF^A = 0 \tag{25}$$

imposing the usual boundary conditions:

$$F^A(\pi^*_A) = V^A(\pi^*_A) - I^A \quad \text{and} \quad F^A_\pi(\pi^*_A) = V^A_\pi(\pi^*_A), \tag{26}$$

Nevertheless, when analyzing (14) (or 24) we notice that the expression referring to the value of project A reveals two different forms depending on $\pi < \pi^*_{AB}$ or vice versa $\pi > \pi^*_{AB}$. Therefore we have two different boundary conditions (26) depending on $\pi^*_A > \pi^*_{AB}$ or $\pi^*_A < \pi^*_{AB}$. In particular we get:

$$\pi^*_A = \begin{cases} \frac{\alpha}{\alpha-1}\delta\frac{I^A}{X^A(1-e^{-\delta T})} & \text{if} \quad \frac{X^B}{X^A} - 1 < \frac{I^B}{I^A} \\ \\ \frac{\alpha}{\alpha-1}\delta\frac{I^B+I^A}{X^B(1-e^{-\delta T})} & \text{if} \quad \frac{X^B}{X^A} - 1 \geq \frac{I^B}{I^A} \end{cases} \tag{27}$$

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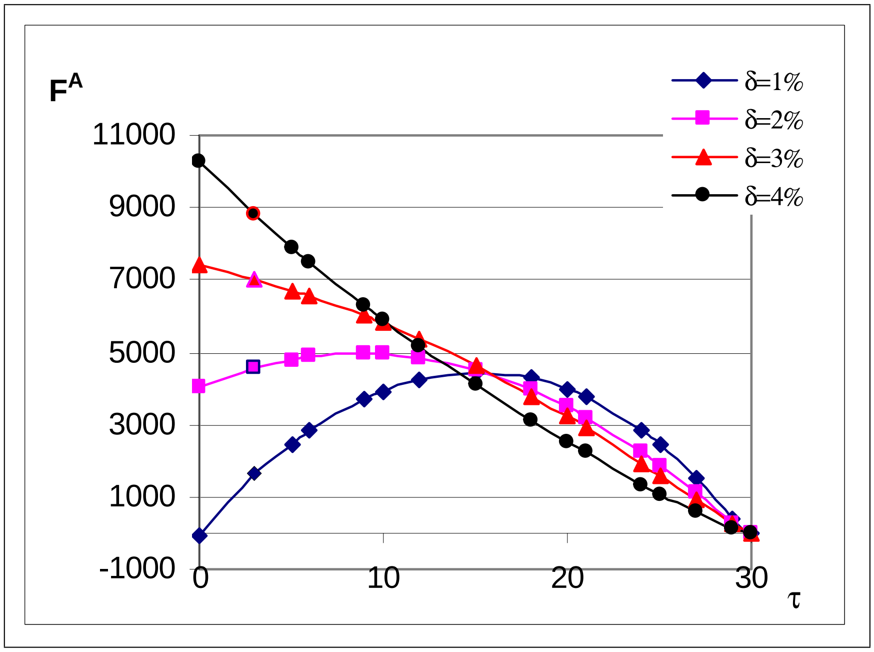

Figure 1

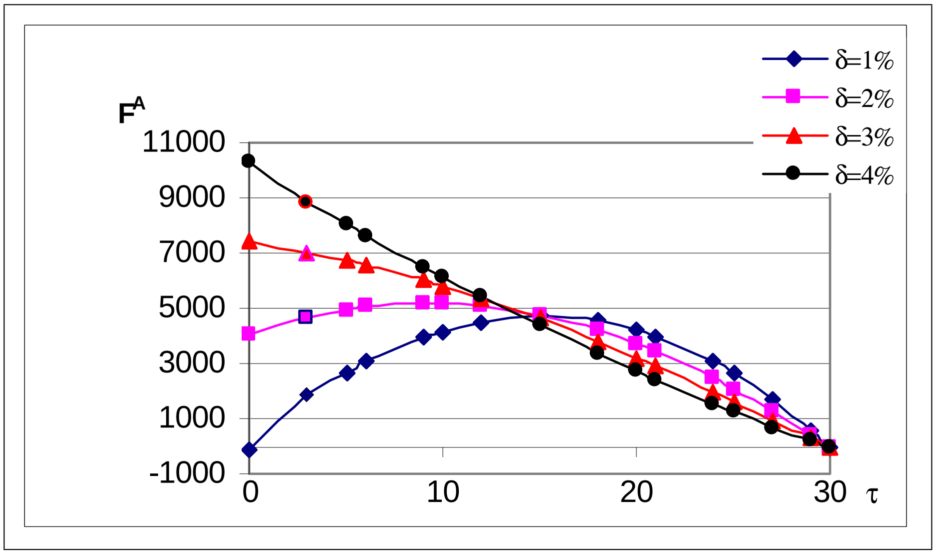

Figure 2

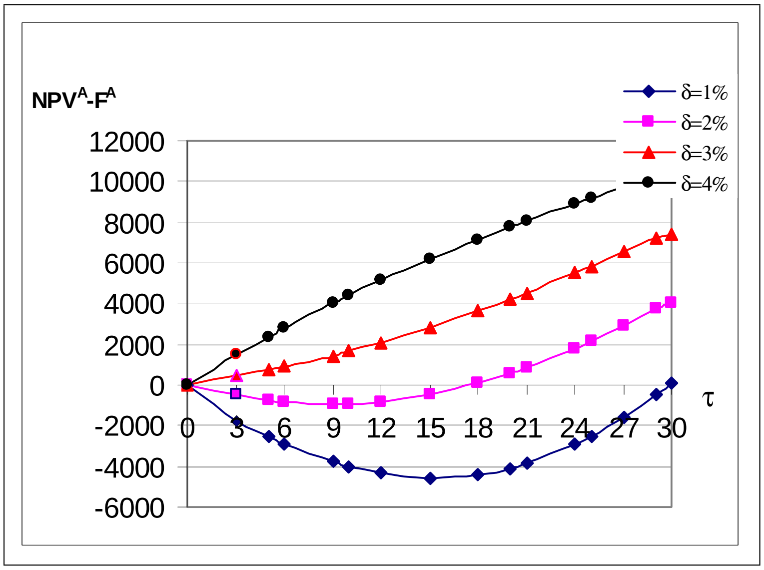

Figure 3

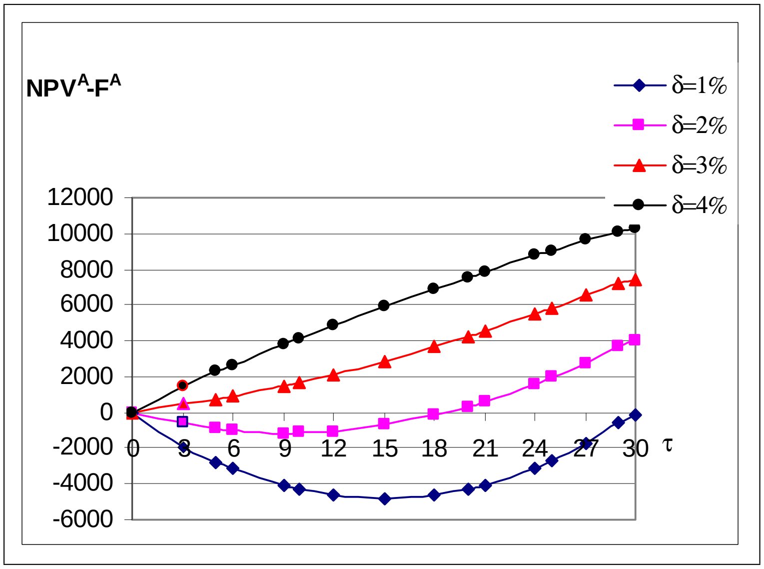

Figure 4

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(lix) This paper was presented at the ENGIME Workshop on "Mapping Diversity", Leuven, May 16-17, 2002
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